



Intraosseous Vascular Access Bibliography

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Intraosseous Vascular Access Bibliography

Anatomy, Physiology and Pathology

YEAR: 2018

Beverly M, Mellon S, Kennedy JA, Murray DW. Intraosseous pressure during loading and with vascular occlusion in an animal model. Bone Joint Res 2018;7(8):511-6

959

This article studied subchondral intraosseous pressure (IOP) in an animal model during loading and with vascular occlusion. IOP recordings from 5 femoral condyles and 7 proximal tibias in 5 rabbit subjects were obtained. The effect on IOP of loading by 1 body weight, arterial occlusion then loading, and venous occlusion then loading were assessed. A load of 1 body weight caused the basal IOP to rise as well as IOP at various sites. A clip applied to the proximal femoral artery caused the IOP to fall while a clamp on the femoral vein caused the IOP to rise. Saline injected into the femoral head caused pressure at the femoral condyle to increase and vice versa when saline was injected at the femoral condyle. IO injection of saline in the femur had no effect on IOP at the tibia. The authors conclude that IOP is not constant.

Beverly M, Murray D. Factors affecting intraosseous pressure measurement. J Orthop Surg Res 2018;13(1):187. doi:10.1186/s13018-018-0877-z

960

This study explored the physiology of normal subchondral perfusion and IOP. Using 21 anesthetized rabbits intraosseous pressure (IOP) was measured using IO needles in the subchondral cancellous bone of the femoral head, femoral condyle, and proximal tibia. A series of experiments investigated the following: normal baseline IOP; method of measuring; IOP wave forms; drug administration; relationship between systemic blood pressure, IOP and pulse pressure; relationship between IOP and pulse pressure; and vascular occlusion. The authors concluded that subchondral cancellous bone behaves as a perfused tissue and that IOP is mainly a reflection of arterial supply. A single measure of IOP can vary and reflects only perfusion at the needle tip.

YEAR: 2017

Bewick VJ. Intraosseous cannulation in children. Anaesth Intens Care Med 2017;18(11):551-4. UK

961

This article describes the anatomy and physiology of IO cannula insertion as well as indications and contraindications of IO use. Devices and techniques as applied to the pediatric population are discussed, including EZ-IO.

Jansen G, Leimkuhler K, Mertzlufft F. Intramedullary placement of intraosseous cannulas inserted in the preclinical treatment of polytrauma patients: A retrospective, computed tomography-assisted evaluation. Anaesthesist 2017;66(3):168-76. doi:10.1031007/s00101-016-0257-1

985

This article describes a retrospective, CT-assisted evaluation of IO cannula placement. Over a 5 year period all multislice-CT trauma scans performed in a trauma center were monitored for intraosseous devices in situ. 982 patients were evaluated and 13 IO cannulas were found in 11 patients. In all cases, the EZ-IO device was used. Evaluation of placement found that all applications were placed correctly, but none were according to current guidelines. The site of puncture deviated in all cases with the most common error of overshooting during needle introduction. (Article in German)

Jousi M, Saikko S, Nurmi, J. Intraosseous blood samples for point-of-care analysis: Agreement between intraosseous and arterial analyses. Scand J Trauma Resusc Emerg Med 2017;25(1):92. doi:10.1186/s13049-017-0435-4

945

Study using 31 healthy volunteers to evaluate IO blood samples drawn from the proximal tibia compared to arterial and venous samples using a POC lab device. Two samples were drawn from each site with no significant difference observed in the results with or without waste blood. Results varied particularly between the arterial and IO samples; and for several parameters. Authors concluded that IO blood samples may be evaluated using the i-STAT® point-of-care analyser; and results should be interpreted with care in the clinical situation context.

Nassar BS, Kerber R. Improving CPR performance. CHEST 2017;152(5):1061-9. doi:10.1016/j.chest.2017.04.178

1001

This manuscript provides an overview of CPR physiology, especially as it relates to compression and ventilation. The placement of peripheral and central venous catheters can interfere with compressions. As such, IO access is an alternative that allows drug administration with similar pharmacokinetics and absorption as peripherally administered medications and a higher insertion success rate (>80%).

Osbn N, Rogers MJ, Walsh TJ, Yang C. Peripheral rapid infusion via the corpus cavernosum: An investigation of penile vascular access flow rates. J Trauma Acute Care Surg 2017;83(5):975-7. doi:10.1097/TA.0000000000001668

1005

This study investigates infusion flow rates through a standard 16-gauge peripheral angiocatheter inserted into a single corpus cavernosum of the penis to support the hypothesis that the penis can be an efficient means of providing rapid fluid resuscitation. This study suggests that the penis may be an alternative to traditional vascular access routes (peripheral IVs, IO insertion, central venous catheters, and vein cutdown procedures) when vascular access is difficult. Flow rates in the study were comparable and in some cases superior to other alternative means of vascular access.

YEAR: 2016

Burgert JM, Johnson AD, Garcia-Blanco J, et al. The effects of proximal and distal routes of intraosseous epinephrine administration on short-term resuscitative outcome measures in an adult swine model of ventricular fibrillation: A randomized controlled study. Am J Emerg Med 2016;34:49-53. doi:10.1016/j.ajem.2015.09.007

778

Preclinical RCT evaluating the relationships between the anatomical distance of IO epinephrine and measures of resuscitative outcome in an adult swine model of ventricular fibrillation (VF). There were no significant differences between the HIO, TIO, and IV groups relative to the occurrence of ROSC, 30-minute post-ROSC survival, and time to ROSC. The anatomical distance of IO epinephrine injection from the heart did not affect short-term measures of resuscitative outcome in an adult swine model of VF including the occurrence of ROSC, 30 minute post-ROSC survival, and time to ROSC. Rapidly administered epinephrine, irrespective of route of administration, increased the chance of ROSC and survival to 30 minutes post-ROSC in this study.

Intraosseous Vascular Access Bibliography

Anatomy, Physiology and Pathology

- Kehrl T, Becker BA, Simmons DE, Broderick EK, Jones RA. Intraosseous access in the obese patient: Assessing the need for extended needle length. *Am J Emerg Medicine* 2016;34(9):1831-4. doi:10.1016/j.ajem.2016.06.055** 780
- This study examined the relationship between body mass index (BMI), the ability to palpate the tibial tuberosity (TT), and soft tissue depth at recommended IO insertion sites in obese patients using ultrasound. Authors concluded in obese adults with a palpable TT or BMI \leq 43, a 25 mm IO needle is likely adequate at the proximal and distal tibial insertion sites; and at the proximal humerus site a 45 mm is recommended.
- Petitpas F, Guenezan J, Vendevre T, Scepti M, Oriot D, Mimoz O. Use of intra-osseous access in adults: A systematic review. *Crit Care* 2016;20:102. doi:10.1186/s13054-016-1277-6.** 810
- This article reports the results of a systematic review using PubMed for current evidence through 2015 for intraosseous (IO) vascular access use in adults requiring resuscitative procedures. General anatomy, indications and contraindications and available devices are discussed. Authors determined IO infusion is indicated in all critical situations with difficult vascular access; contraindications are few; and serious complications uncommon.
- France
- Puga TA, Montez DF, Davlantes C, Miller LJ, Philbeck TE. Swine study shows no intramedullary effects of power-injected contrast media using intraosseous access. *J Vasc Access* 2016;17(4):e16** 785
- A preclinical study evaluating the immediate effects of power injected contrast media on the medullary space of anesthetized swine. Contrast media (150 mL) was administered at a rate of 5 mL/second. For each limb receiving power injection a control limb was submitted for evaluation. The pathologist was blinded to which limb received power injection. Results showed no histological difference in limbs receiving and not receiving power injection. This study was sponsored by Teleflex Incorporated.
- Wilson J, Passmore A, Leger S, Lannan J, Bentley M, Johnson D. Effects of tibial intraosseous and intravenous administration of Hextend on time of administration and hemodynamics in a hypovolemic swine model. *Am J Disaster Med* 2016;11(3):193:201. doi:10.5055/adjm.2016.0239** 836
- A preclinical study comparing administration of Hextend via IV and tibial intraosseous (IO) access routes for time for administration and hemodynamic measures in a hypovolemic swine model. Following exsanguination, 500 mL of Hextend was administered via both routes; a control group received no Hextend. Hemodynamic measures data were collected every 2 minutes for 8 minutes. The mean time for administration in the IV group was 10 minutes 16 seconds (\pm 2 minutes 47 seconds), and for the IO group it was 10 minutes 12 seconds (\pm 1 minutes 36 seconds). There was no significant difference in systolic blood pressure, diastolic blood pressure, mean arterial pressure, cardiac output, and stroke volume.
- YEAR: 2015**
- Bradburn S, Gill S. Understanding and establishing intraosseous access (317). *World Federation of Societies of Anaesthesiologists*. June 26, 2015** 955
- This document is a tutorial provided by the World Federation of Anaesthesiologists geared at understanding and establishing intraosseous access. It provides an overview of venous blood drainage from bones as well as indications, contraindications, common access sites, advice for establishing access, an overview of device types, insertion techniques, and complications.
- Foley LS, Kulungowski AM. Vascular anomalies in pediatrics. *Adv Pediatr* 2015;62(1):227-55. doi:10.1016/j.yapd.2015.04.009. http://dx.doi.org/10/1016/i.yapd.2015.04.009** 921
- This article describes various pediatric vascular anomalies, including intraosseous vascular malformations which can lead to weakness in the bone diaphysis, predisposing to pathological fracture.
- Frascone RJ, Salzman JG, Adams AB, Bliss P, Wewerka SS, Dries DJ. Evaluation of intraosseous pressure in a hypovolemic animal model. *J Surg Res* 2015;193(1):383-90. http://dx.doi.org/10.1016/j.jss.2014.07.007** 736
- Preclinical study to determine whether intraosseous pressure (IOP) could be consistently recorded and similarity of IOP to central venous and arterial pressure in a porcine hemorrhagic shock model. IOP tracings were tracked reliably from the proximal humerus, distal femur, and proximal tibia. Baseline IOP ranged from 16-18 mm Hg among the three sites, which was approximately 23% of arterial pressure. This study was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.
- Johnson D, Garcia-Blanco J, Burgert J, et al. Effects of humeral intraosseous versus intravenous epinephrine on pharmacokinetics and return of spontaneous circulation in a porcine cardiac arrest model: A randomized control trial. *Ann Med Surg* 2015;4(3):306-10. doi:10.1016/j.amsu.2015.08.005** 802
- Prospective preclinical study by to determine the effects of humeral IO (HIO) and IV epinephrine administration during cardiac arrest on pharmacokinetics, ROSC, and odds of survival. There were no significant differences in ROSC, maximum concentration; except at 30 s, and time-to-concentration-maximum between the HIO and IV groups. Significant differences existed between the experimental groups and the control. The HIO delivered a higher concentration of epinephrine than the IV route at 30 s, which they noted may be a survival advantage. Authors suggested clinicians consider using the IO route to administer epinephrine when IV access is unobtainable.
- Montez DF, Puga T, Miller L, et al. Intraosseous infusions from the proximal humerus reach the heart in less than 3 seconds in human volunteers. *Ann Emerg Med* 2015;66(4s):S47. http://dx.doi.org/10.1016/j.annemergmed.2015.07.165** 771
- In a healthy adult volunteer study contrast media was injected through the proximal humerus site and captured under fluoroscopy as it entered the heart. The mean time it took from injection at the insertion site to visualize contrast entry into the superior vena cava and the right atrium was 2.42 seconds. Abstract presented at ACEP 2015. This study was sponsored by Teleflex Incorporated.

Intraosseous Vascular Access Bibliography

Anatomy, Physiology and Pathology

Overbaugh R, Davlantes C, Miller L, Montez D, Puga T, Philbeck TE. Intraosseous vascular access catheter appears safe during extended dwell: a preliminary report. *Ann Emerg Med* 2015;66(4):S5 772

Abstract describing preliminary results for the first 24 subjects of an EZ-IO study evaluating catheter dwell times for 48 hours. Initial data indicate that IO vascular access can be safely maintained for a period up to 48 hours without risk of osteomyelitis or other serious adverse events. Authors also noted that additional analgesics for IO infusion pain management may be more effective than the current solely administering lidocaine into the IO space. This study was sponsored by Teleflex Incorporated.

Pasley J, Miller CHT, DuBose J, et al. Intraosseous infusion rates under high pressure: a cadaveric comparison of anatomic sites. *J Trauma Acute Care Surg* 2015;78(2):295-9. DOI: 10.1097/TA.0000000000000516 750

A cadaveric study evaluating intraosseous (IO) vascular access insertion sites for attainable flow rates under 300 mmHg. The EZ-IO was used to establish IO access at the proximal humerus and proximal tibia sites; the FAST1 was used to establish sternal IO access. The total volume of fluid infused at the three IO access sites was 469 ± 190 mL for the sternum; 286 ± 218 mL for the humerus; and 154 ± 94 mL for the tibia. The mean flow rate infused at each site was as follows: 93.7 ± 37.9 mL/min for the sternum; 57.1 ± 43.5 mL/min for the humerus; and 30.7 ± 18.7 mL/min for the tibia. First attempt placement success was 100% for the sternum and proximal humerus and 81% for the tibia.

Puga T, Hanes MA, Miller LJ, et al. Intramedullary effects of power-infused contrast by intraosseous access. *Ann Emerg Med* 2015;66(4s):s95 786

A preclinical study evaluating the immediate effects of power injected contrast media on the medullary space of anesthetized swine. Contrast media (150 mL) was administered at a rate of 5 mL/second. For each limb receiving power injection a control limb was submitted for evaluation. The pathologist was blinded to which limb received power injection. Results showed no histological difference in limbs receiving and not receiving power injection. This study was sponsored by Teleflex Incorporated.

Salzman J, Burnett A, Frascione R, et al. Intraosseous pressure monitoring in critically ill and injured patient. *Crit Care Med* 2015;43(12 Suppl):abstract 183:47. doi: 10.1097/01.ccm.0000474011.25695.a8 848

A pilot study evaluating the relationship between intraosseous (IO) pressure measurements and blood pressure obtained via external blood pressure cuff in ICU patients. Patients with IO access established by EMS or in the emergency department with planned admission to the ICU or surgical ICU were included in the study. External pressures were recorded every 15 minutes and IO pressure was monitored via a transducer for 12 continuous hours. Results showed IO pressures were approximately 30% of external blood pressure cuff readings.

Saul T, Siadecki SD, Berkowitz R, Rose G, Matilsky D. The accuracy of sonographic confirmation of intraosseous line placement vs physical examination and syringe aspiration. *Am J Emerg Med* 2015;33(4):586-8. doi: 10.1016/j.ajem.2014.12.034 746

A preclinical study comparing three methods used to confirm intraosseous (IO) catheter tip placement within the IO space. Using an immature anesthetized swine, 8 IO needles were inserted, 4 properly placed within the IO space and 4 placed in the subcutaneous tissue. Physician sonographers (n=32) participated in the study and determine IO proper and improper IO line placement using physical examination, syringe aspiration, and ultrasonography after administering 5 cm3 of normal saline through each IO line. Confirmation via physical examination resulted in 32/32 successful evaluations; syringe aspiration resulted in 22/32 successful evaluations; and ultrasonography resulted in 30/32 successful evaluations.

YEAR: 2014

Cervinski MA. Laboratory analysis of intraosseous blood: bad to the bone? *Clin Chem Lab Med* 2014;doi:10.1515/cclm-2014-0104 704

A letter to the editor questioning the practice of using IO blood for laboratory analysis. The author identifies there is a lack of clinical evidence supporting IO blood laboratory analysis and concludes that IO access should be limited to infusion of fluid and medications until the relationship of IO blood to peripheral blood is defined.

Cervinski MA. Laboratory analysis of intraosseous blood: bad to the bone? *Clin Chem Lab Med* 2014;52(8):e187-9. doi: https://doi.org/10.1515/cclm-2014-0104 941

This letter to the editor includes a brief review of the literature, discusses the limitations associated with studies on IO derived blood samples, and recommends IO blood may only be useful in cases of suspected overdose for toxicology.

Lee BK, Jeung KW, Lee HY, et al. Confirmation of intraosseous cannula placement based on pressure measured at the cannula during squeezing the extremity in a piglet model. *Resuscitation* 2014;85(1):143-7. doi: 10.1016/j.resuscitation.2013.09.001 678

In this pre-clinical study, investigators sought to determine if the pressure readings at the proximal tibia IO site served as a good indicator of proper IO placement when the foot of the limb was squeezed. Traditional methods used to determine correct IO placement, including needle stability, aspiration of blood, and easy infusion, were used as comparators. Results showed the increased pressure reading at the IO site successfully predicted correct IO placement in all cases; traditional methods did not consistently correctly identify proper IO needle placement.

Pasley J, Miller C, Dubose J, et al. Intraosseous infusion rates under high pressure: a cadaveric comparison of anatomic sites. 2014 Annual Scientific Assembly for the Eastern Assoc for the Surgery of Trauma meeting. <http://www.dtic.mil/cgi-bin/GetTRDoc?AD=ADA597324>. Published January 2014. Accessed May 12, 2014 728

This report describes a study conducted by the Air Force Research Laboratory comparing intraosseous infusion rates between IO sites in a cadaveric model to determine if there is a site that is most effective for volume resuscitation. Using 16 cadavers procured within 72 hours of death, IO access was established in the proximal tibia and proximal humerus using the EZ-IO and in the sternum using the FAST1. Results showed the mean flow rate in the sternum was 1.6 times greater than the humerus and 3.1 times greater than the tibia. An abstract describing this report was presented by oral presentation at the 2014 annual scientific assembly for the Eastern Association for the Surgery of Trauma meeting.

Intraosseous Vascular Access Bibliography

Anatomy, Physiology and Pathology

Sontgerath JS, Rubal BJ, DeLorenzo RA, Morgan TL, Ward JA. Variability in intraosseous flush practices of emergency physicians. Am J Emerg Med 2014;http://dx.doi.org/10.1016/j.ajem.2014.03.001 719

This prospective study sought to evaluate intraosseous flush practices of emergency physicians. Using cadavers, 15 emergency physicians were asked to flush an IO catheter placed in the proximal tibia and proximal humerus IO insertion sites with 10 mL normal saline as they would in clinical practice; IO pressure measurements were recorded using an IO catheter inserted in the diaphysis of the target bones. Results showed the median IO pressure generated was 903 mmHg and the median flush duration was 5.2 seconds. Result showed significant interoperator variability with greater than 35-fold difference in flush forces. The authors concluded that it may be prudent practice for providers to extend the flush over several seconds to limit the maximal pressures.

Young SW, Zhang M, Freeman JT, Mutu-Grigg J, Pavlou P, Morre GA. The Mark Coventry Award: Higher tissue concentrations of vancomycin with low-dose intraosseous regional versus systemic prophylaxis in TKA. Clin Orthop Relat Res 2014;472(1):57-65. doi:10.1007/s11999-013-3038-z 620

This randomized, controlled study compared tissue concentrations at the surgical site of regionally and systemically administered prophylactic vancomycin, in 30 patients undergoing total knee arthroscopy. The antibiotic was administered using three methods: 250mg through IO regional administration in the proximal tibia (IORA); 500mg through IORA; and 1g administered systemically through IV. Results showed the tissue concentration of vancomycin was greater in the 250mg IORA group than the systemic IV group, and the 500mg IORA group had higher concentrations than both groups.

YEAR: 2013

Frascone RJ, Salzman JG, Bliss P, Adams A, Wewerka SS, Dries DJ. Decreasing intraosseous pressure and increasing respiratory variability track fluid volume reduction in a porcine hypovolemia model. Ann Emerg Med 2013;62(4S):S14 666

A pre-clinical study that evaluated use of intraosseous (IO) pressure as an indicator of changes in fluid volume status during a hemorrhagic shock protocol. Central venous and arterial pressures were used as comparators. Results showed IO pressure decreased consistently during the controlled shock protocol. Authors concluded IO pressure appears to be equivalent to CVP as an indicator of fluid volume status. This study was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.

Frascone RJ, Salzman JG, Bliss P, Adams A, Wewerka SS, Dries DJ. Intraosseous pressure tracings mimics arterial pressure tracings in timing and contour. Ann Emerg Med 2013;62(4S):S13 - 4 665

A pre-clinical study that compared intraosseous (IO), central venous and arterial pressure tracings in a porcine model. Results showed that IO pressure was approximately 25% of arterial pressure. A sampling of IO blood gases revealed oxygenation levels of venous blood. This study was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.

Frascone RJ, Salzman JG, Ernest EV, Burnett AM. Use of an intraosseous device for invasive pressure monitoring in the ED. Am J of Emerg Med 2014;32(6):692.e3-692.e4.doi:10.1016/j.ajem.2013.12.029 667

A case study describing intraosseous pressure monitoring, through tibial IO access, using a standard arterial pressure monitoring transducer during resuscitation of a 31-year-old male in cardiac arrest. Pressure readings were recorded for approximately 53 minutes and were compared to non-invasive blood pressure cuff monitoring at the same time points. IO systolic, diastolic and mean IO pressures were approximately 40% of arterial pressures. This is the first case report demonstrating IO space has a measureable blood pressure and it correlates with pressure obtained through conventional techniques.

Lairet J, Beberta V, Lairet K, et al. A comparison of proximal tibia, distal femur, and proximal humerus infusion rates using the EZ-IO intraosseous device on the adult swine (Sus scrofa) Model. Prehosp Emerg Care 2013;17:280-4. Doi:10.3109/10903127.2012.755582 642

Pre-clinical study comparing flow rates achieved after insertion with the EZ-IO in the proximal tibia, distal femur, and proximal humerus in a swine model. IO catheters were placed in each site and normal saline was infused for 10 minutes using a pressure bag at the highest achievable pressures greater than 300mmHg. The flow rates through the proximal humerus were statistically greater than that of the femur or proximal tibia. The femur flow rates were higher than the proximal tibia but similar. Post-mortem histopathologic evaluations done to assess for damage due to the high infusion pressures were consistent with IO catheter placement.

Lewis GC, Crapo SA, William JG. Critical skills and procedures in emergency medicine- vascular access skills and procedures. Emerg Med Clin N Am 2013;31(1):59-86. doi: 10.1016/j.emc.2012.09.006 631

This article provides an overview of various vascular access modalities in emergency medicine including peripheral IV, venous cut-down, central venous catheter, intraosseous access, umbilical vessel access, and arterial access. The anatomy and physiology, indications and contraindications, procedure steps and special considerations are outlined for each access methods discussed.

Mills A, Pappin D, Field V, Thorp-Jones D. Intraosseous access in the peripartum patient: is your needle long enough? Int J Obstet Anesth 2013;22(1):S30 675

This abstract describes a study in which the investigators sought to determine the approximate patient population in which the 25mm EZ-IO needle set was sufficient length to establish IO access in peripartum patients. Ultrasound was used to determine the tissue depth at four insertion sites. Twenty-six women were recruited with a median gestation of 34 weeks. In 88% of patients with a BMI<40 kg/m² the 25mm needle is sufficient to reach the bone marrow at both tibial sites. For the humeral site, IO placement may be more difficult for patients with a BMI>25 kg/m².

UK

Intraosseous Vascular Access Bibliography

Anatomy, Physiology and Pathology

- Montez DF, Puga TA, Garcia MR, et al. Intraosseous blood correlates with venous blood in healthy subjects using point-of-care analyzers. *Ann Emerg Med* 2013;62(4S):S40** 676
- A clinical study evaluating the relationship between IO blood and peripheral venous blood lactate levels analyzed using the i-STAT point-of-care analyzer in healthy volunteers. Results showed IO blood lactate levels were comparable to venous blood lactate levels with a positive statistical correlation. This study was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.
- Plancade D, Ruttimann M, Wagnon G, et al.. La perfusion intraosseuse chez l'adulte. *Annales Francaises d'Anesthesie et de Reanimation* 2013;<http://dx.doi.org/10.1016/j.annfar.2013.02.024>. French** 617
- This article in French gives an overview of intraosseous vascular access including the physiology of IO infusion, insertion sites, indications, and complications. Available IO devices on the market are described including, time to insertion, success rate and cost.
- Veldhoen ES, de Vooght KMK, Sliker MG, Versluys AB, Turner NMB. Analysis of bloodgas, electrolytes and glucose from intraosseous samples using an i-STAT point-of-care analyser. *Resuscitation* 2013;<http://dx.doi.org/10.1016/j.resuscitation.2013.12.002>** 692
- A prospective study comparing IO and venous laboratory values obtained from a point-of-care analyzer (i-STAT) in 20 children. IO blood specimens were collected from the iliac crest; 2 ml were discarded before the sample was collected analysis. Results showed differences between venous and IO sample were clinically acceptable for pH, base excess, sodium, ionized calcium and glucose in hemodynamically stable patients. Authors concluded that analysis of IO samples with a bedside point-of-care analyzer is feasible and in emergency situations may be useful to guide treatment.
- Wolfe HA, Donoghue A, Berg RA. Are we ready to put the squeeze into all IO placements? *Resuscitation* 2013;<http://dx.doi.org/doi.10.1016/j.resuscitation.2013.10.018>** 686
- This article discusses the preclinical study by Lee 2013 in which successful IO placement in the proximal tibia was confirmed by squeezing the foot and obtaining a measured pressure at the IO cannula site greater than 80mmHg. The author challenges this method indicating that it should not be implemented clinically until additional research has been performed confirming its validity in humans.
- YEAR: 2012**
- Pallin DJ. Intraosseous vs intravenous access for adults with out-of-hospital cardiac arrest. *Journal Watch Emergency Medicine* 2012; http://emergency-medicine.jwatch.org/cgi/content/full/2012/106/1?q=etoc_jwca** 526
- This editorial discussed a prior publication by Reades, et al that evaluated first attempt placement success rates for tibial IO, humeral IO, and peripheral IV in the prehospital setting. The author concluded that the research shows tibial IO access is the best route for adults with out-of-hospital cardiac arrest.
- Papakonstantinou MK, Pan WR, Le Roux CM, Richardson MD. New approach to the study of intraosseous vasculature. *ANZ J Surg* 2012;82(10):704-7. doi:10.1111/j.1445-2197.2012.06142.x** 584
- This article describes a post mortem study evaluating a newly developed technique to study the intraosseous vasculature of the humerus involving injection of ink directly into the anterior circumflex humeral artery. This technique allowed visualization of the main nutrient artery to the proximal humerus vasculature until they reached articular cartilage or crossed cortical bone again to enter the rotator cuff tendons.
- Paxton JH. Intraosseous vascular access: A review. *Trauma* 2012;14(3):195-232. DOI:10.1177/1460408611430175** 690
- An overview of IO vascular access including a review of currently available literature. The author discusses various IO devices available and their performance metrics, IO access sites, flow rates, advantages and disadvantages of IO access compared to conventional access methods, complications and recommendations on use of the approach. The author concludes that while IO access may not be appropriate for all patients, it deserves a place in the modern provider's armamentarium.
- Rubal BJ, McKay K, Armstrong KR, Rubal MP, Marbach MJ. Variability in intraosseous pressure induced by saline flush of an intraosseous cannula by multiple practitioners. *Lab Animal* 2012;41(8):224-9** 578
- This pre-clinical study sought to evaluate the various pressure levels obtained by 22 veterinary clinicians when administering a 10ml normal saline flush of an IO catheter. The EZ-IO was used to establish access in an isolated, cadaveric swine femur. The authors found the median peak intraosseous pressure was 615 mmHg with a range of 57 to 1,100 mmHg. Authors concluded that there is a great deal of variability between clinicians and their flush pressure and that a standardized flush protocol may be beneficial.
- Rush S, Bremer J, Foresto C, Rubin AM, Anderson PI. A magnetic resonance imaging study to define optimal needle length for humeral head IO devices. *J Spec Oper Med* 2012;12(2):77-82** 577
- This article describes a retrospective study in which 50 consecutive MRI images were evaluated of the humerus for the purpose of determining the optimal needle length necessary for successful proximal humerus IO insertion. Results showed the cortical thickness was 4mm in all cases and that an IO needle length ranging between 40-50mm should be used via the anterior approach. The EZ-IO is specifically discussed in relation to the proximal humerus IO insertion site; and a 24 patient post mortem review of the EZ-IO placed in the proximal humerus is discussed.
- Strandberg G, Eriksson M, Gustafsson MG, Lipcsey M, Larsson A. Analysis of intraosseous samples using point of care technology: An experimental study in the anesthetized pig. *Resuscitation* 2012; 83(11):1381-5. doi: 10.1016/j.resuscitation.2012.04.007** 558
- This preclinical study sought to determine the accuracy of IO blood lab values by comparing lab results obtained using an I-Stat for IO blood and arterial blood. The authors concluded that the agreement between intraosseous and arterial analysis seemed to be good enough to be clinically useful, and that there were no clinically significant differences between samples collected from the right and left tibia.

Intraosseous Vascular Access Bibliography

Anatomy, Physiology and Pathology

- Studnek JR, Fernandez AR, Vandeventer S, Reades R. Assessing paramedic comfort with three methods for gaining vascular access during out-of-hospital cardiac arrest resuscitation. *Prehosp Emerg Care* 2012;16(1):162. doi:10.3109.10903127.2011.624676** 518
- This abstract presented at the 2012 NAEMSP scientific assembly described a study in which the comfort level of paramedics was evaluated as it related to establishing vascular access in out of hospital cardiac arrest resuscitation, using a predetermined method (PIV, humeral IO, tibial IO). Results showed that paramedics were typically comfortable with the method assigned.
- Tan BKK, Chong S, Koh ZX, Ong MEH. EZ-IO in the ED: an observational, prospective study comparing flow rates with proximal and distal tibia intraosseous access in adults. *Am J Emerg Med* 2012;30(8):1602-6.doi.10.1016/j.ajem.2011.10.025** 519
- This prospective observational study compared flow rates between distal and proximal tibia IO access in adults, with each adult serving as their own control. The EZ-IO was used to facilitate IO access. IO infusion was performed with and without pressure. The authors concluded that infusion flow rates were significantly higher in the proximal tibia as compared to the distal tibia, and that flow rates are significantly higher with pressured infusion vs. non-pressured infusion. This study was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.
- Wampler D, Manifold C. Changes in end-tidal carbon dioxide during hypothermia in a swine model. *Prehosp Emerg Care* 2012;16(1):155-6. doi:10.3109/10903127.2011.624676** 521
- This abstract presented at the 2012 NAEMSP scientific assembly evaluated end-tidal carbon dioxide (ETCO2) levels under initial induction of hypothermia, rewarming, and a second induction of hypothermia, via IO and IV infusion in the swine model. The authors concluded that there was no demonstrated association of ETCO2 with brain temperature during the initial induction. However, during rewarming and second induction of hypothermia the association of ETCO2 and brain temperature had a direct and proportional association. This research was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.
- Wampler D, Schwartz D, Shumaker J, Bolleter S, Beckett R, Manifold C. Paramedics successfully perform humeral EZ-IO intraosseous access in adult out-of-hospital cardiac arrest patients. *Am J of Emerg Med* 2012;30:1095-9. doi:10.1016/j.ajem.2011.07.010** 520
- This study conducted by the San Antonio Fire Department evaluated the first-attempt success rate for humeral EZ-IO placement by paramedics in prehospital adult cardiac arrest patients. Humeral placement was attempted in 247 cardiac arrest patients; first attempt placement success rate was 91%. Authors concluded that humeral IO placement is a reliable method for vascular access in this patient population. This research was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.
- YEAR: 2011**
- Auerhammer J. [Lebensbedrohliche arterielle blutung aus der a. carotis communis: Fallstricke bei der intraossaren punktion]. *Notfall Rettungsmedizin* 2011;14(2)147-150;doi 10.1007/s10049-010-1380-1. German** 490
- This article in German presents a case of a 67-year-old female patient with an arterial bleed and venous access difficulties in whom IO access was attempted unsuccessfully two times using two different IO systems. The author concluded that IO success is dependent upon IO anatomy and physiology knowledge as well as knowledge of the device being used.
- Borron SW, Arias JC, Bauer CR, et al. Intraosseous line placement for antidote injection by first responders and receivers wearing personal protective equipment. *Am J Emerg Med* 2011;29(4):373-81.doi:10.1016/j.ajem.2009.10.009** 424
- This article describes a preclinical trial with a caprine model that assessed the ability of protected, experienced first responders and limited-experience first receivers to place IO lines for antidote administration using the EZ-IO device. First responders placed IO lines successfully in 100% of cases, and first receivers placed IO lines successfully in 91% of the cases. Investigators concluded that IO lines may facilitate earlier administration of antidotes to hazardous material victims.
- Cullen PM. Intraosseous cannulation in children. *Paediatric Critical Care* 2011;13(1):28-30** 523
- This article presented a general overview of IO use in pediatrics. The history, techniques, anatomy and physiology, complications and a short discussion of most devices on the market, including the EZ-IO, were discussed.
- UK
- Kehrl T, Broderick E. Relationship of body mass index and increased difficulty with intraosseous needle placement: assessment of tissue depth using ultrasound. *Ann Emerg Med* 2011;54(4s):S263** 531
- In this abstract the authors attempted to establish a relationship in obese patients (BMI >30) between BMI, ability to palpate the tibial tubercle, and tissue depth at the IO insertion sites. Results showed that in obese patients, IO placement with a 25mm catheter is feasible at the proximal and distal tibial sites if the tibial tubercle is palpable and that insertion into the proximal humerus in this population is not recommended.
- Abstract only
- Miller LJ, Philbeck TE, Puga TA, Montez DF, Escobar GP. A pre-clinical study to determine the time to bone sealing and healing following intraosseous vascular access. *Ann Emerg Med* 2011;58(4S):S240** 475
- The objectives of this study were to evaluate the amount of time necessary following IO insertion and infusion for the bone to heal such that a second IO catheter can be placed in the same bone without the risk of extravasation from the first hole; and to determine the length of time required to show radiological evidence of closure. Four anesthetized goats were used for the study. Twenty-four hours post insertion, extravasation was observed in 2 of 4 tibial sites with no extravasation in 4 humeral sites. Forty-eight hours post insertion, no extravasation was observed in tibial or humeral sites. Authors concluded that IO infusion should not be attempted in the same bone as a previous IO insertion within 48 hours of removal of the first IO catheter. Radiological examination showed evidence of bone healing as early as 6 days post IO placement. This research was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.

Intraosseous Vascular Access Bibliography

Anatomy, Physiology and Pathology

- Nagler J, Krauss B. Intraosseous catheter placement in children. NEJM 2011;364(8):e14-8** 491
This article provides an overview of intraosseous vascular access for pediatrics and discusses general indications, contraindications, complications, and intraosseous devices.
- Smart RJ, Marsh S, Rosenberg M. Intraosseous access in oral and maxillofacial surgical practice. J Oral Maxillofac Surg 2011;69(11):2708-13. doi:10.1016/j.joms.2011.02.101** 441
This article describes IO access in terms of efficacy, indications/contraindications for use, and the IO procedure and comparison of devices to make a case for IO use in oral and maxillofacial surgical practice. In discussing IO devices citing published data, the author identified the EZ-IO device as the most accurate, efficacious, and precise system when trying to achieve IO access.
- YEAR: 2010**
- Fenwick R. Intraosseous approach to vascular access in adult resuscitation. Emerg Nurse 2010;18(4):22-5** 456
This article reviews intraosseous vascular access and its increased use in adult resuscitation. The IO route is described, including indications, contraindications, insertion sites and devices.
- Kovar J, Gillum L. Alternate route: the humerus bone - a viable option for IO access. JEMS 2010;35(8):52-59** 505
Authors describe an early observational study (N=120) comparing intraosseous access in the humerus and the tibia, using the EZ-IO. Investigators concluded that the humerus is an acceptable IO site, which may be preferable under certain clinical conditions. This research was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.
- Larson SD, Hebra A, Raju R, Lee S. Vascular access, surgical treatment. <http://emedicine.medscape.com/article/1018395>. Updated January 25, 2010** 446
This article describes the vascular access options available to physicians caring for children, including details about each method, placement technique, indication, and complications.
- Luck RP, Haines C, Mull CC. Intraosseous access. J Emerg Med 2010;39(4):468-75. doi:10.1016/j.jemermed.2009.04.054** 492
This article provides an overview of intraosseous vascular access and discusses general indications, contraindications, complications, and intraosseous devices.
- Mader TJ, Walterscheid JK, Kellog AR, Lodding CC. The feasibility of inducing mild therapeutic hypothermia after cardiac resuscitation using iced saline infusion via an intraosseous needle. Resuscitation 2010;81(1):82-6** 440
In this study, using a swine model, investigators concluded that mild therapeutic hypothermia can be effectively induced after successful resuscitation of prolonged ventricular fibrillation through infusion of chilled saline via the IO catheter.
- Miller L, Philbeck T, Montez D, Puga T. A two-phase study of fluid administration measurement during intraosseous infusion. Ann Emerg Med 2010;56(3):S151** 498
This abstract, presented at the 2010 ACEP Research Forum, describes a study designed to determine infusion flow rates through the proximal humerus and proximal tibia. Investigators found that, at all infusion pressure levels, the humerus provided substantially greater flow rates than the tibia. They concluded that, for most situations, adequate IO infusion rates can be achieved using the tibial site, but the proximal humerus site should be strongly considered when greater infusion flow rates are required. This research was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.
- Miller L, Philbeck T, Montez D, Puga T. Volunteer studies of pain management during intraosseous infusion. Ann Emerg Med 2010;56(3):S141** 499
This abstract presented at the 2010 ACEP Research Forum describes a study designed to compare Lidocaine's effect on pain during fluid infusion through the tibial and humeral IO routes. Authors concluded that, for adequate IO infusion rates with minimal and tolerable pain, 40mg of preservative-free Lidocaine may be needed; followed by a rapid normal saline syringe flush of at least 10mL and another 20mg of Lidocaine. Additional dosing and flushing may be required. For less overall pain due to IO infusion, and greater infusion flow rates, the proximal humerus should be strongly considered, using a longer IO needleset. This research was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.
- Navarro K. Intraosseous infusion. Texas EMS Magazine 2010;Nov/Dec:34-9** 447
This article provides a brief history of IO infusion and further discusses this vascular access technique in terms of anatomy and physiology, indications and contraindications, performing the manual procedure, and possible complications. A case study is discussed in which a 7-month-old male was treated under emergency circumstances with IO infusion in the lower limb and developed compartment syndrome, resulting in a below the knee amputation.
- Rahman O, Willis L. Vascular procedures in the critically ill obese patient. Crit Care Clin 2010;26(4):647-60. doi:10.1016/j.ccc.2010.08.003** 451
This article discusses vascular access procedures in critically ill obese patients. Anatomic considerations, general procedural considerations such as location of the procedure and patient positioning, catheter insertion technique, ultrasound guided insertion, intraosseous insertion, and other various considerations are evaluated.

Intraosseous Vascular Access Bibliography

Anatomy, Physiology and Pathology

- Rubal BJ, Gerhardt RT, Sartin CW, et al. Medullary shear and pressure changes associated with high intraosseous infusion rates in an isolated hind limb preparation. *Ann Emerg Med* 2010;56(3):S113** 501
This abstract describes an animal study, presented at the 2010 ACEP Research Forum, that examined shear and pressure changes within the medullary space during intraosseous infusion. Results suggest that resistance to flow depends of cannula placement site, IO pressure rises rapidly with infusion rates, and medullary compression and axial shear are present at high infusion rates.
- Vizcarra C, Clum S. Intraosseous route as alternative access for infusion therapy. *J Infus Nurs* 2010;33(3):162-74** 482
This article provides an overview of IO anatomy and physiology, IO access indications, care, and management; describes therapies administered via IO access; and discusses the expanding use of IO access into areas within hospitals during nonemergency clinical situations. It also includes a table addressing indications for IO access in the hospital, as well as a table addressing the general insertion procedure for IO access.
- Xie F, Hou KD, Song Q, Jiang CG. The change in bone marrow after intraosseous hypertonic saline-hydroxyethyl starch infusion for resuscitation of hemorrhagic shock in dog. *Chin Crit Care Med* 2010;22(5):309-12.doi.10.3760/cma.j.issn.1003-0603.2010.05.017** 459
This article in Chinese, describes a study that evaluated the effects to the bone marrow following IO infusion of hypertonic saline-hydroxyethyl (HSH) in the dog model; using a normal saline group (NS) and a non-infusion group. The test subjects were put into shock and resuscitated. Results showed that at 48 hours post infusion and 1 week post infusion changes were seen in the bone marrow and peripheral blood in the HSH and NS groups as compared to the non-infusion group. At 4 weeks post infusion, the NS group and HSH group recovered to normal level. Bone marrow morphology changed slightly but no bone necrosis occurred. The author concluded that HSH in small amounts via IO is safe and effective as a fluid resuscitation measure for shock, and little change in bone marrow has been found after infusion.
- YEAR: 2009**
- Barrett J. Adult Intraosseous infusion: "Good to the bone!" *Response* 2009;36(3):19-21** 461
This article addresses adult IO infusion, primarily in the pre-hospital setting, with regard to the history of IO, anatomy and physiology, training considerations, clinical guidelines and contraindications, and financial considerations.
- Bell MK, Lowe C .. Push hard and push fast: The who, how, and why of pediatric advanced life support (PALS). *Pediatr Emerg Med Pract* 2009;6(11):1-30** 958
This is a continuing medical education (CME) document discussing pediatric advanced life support guidelines. It is geared toward pediatric emergency medicine physicians. IO is a preferred route of drug administration.
- Borron SW, Arias JC, Bauer CR, Sanchez M, Fernandez M, Jung I. Hemodynamics after intraosseous administration of hydroxocobalamin or normal saline in a goat model. *Am J Emerg Med* 2009;27:1065-71** 439
In a preclinical study using a caprine model, researchers assessed the hemodynamics of hydroxocobalamin (OHCo) compared to normal saline (NS) by the intraosseous (IO) route and concluded that the effects of OHCo given by the IO route in non-CN-poisoned goats are mild and well tolerated. Investigators concluded that IO administration of OHCo may "find a role in the settings of individual patients with cyanide-induced cardiovascular collapse or mass cyanide casualties".
- Miller J, Lairet J, DeLorenzo R, Pitotti R. Intraosseous infusion of crystalloid fluid immediately after intraosseous infusion of nitroglycerin in the proximal tibia of a swine (sus scrofa) model. *Ann Emerg Med* 2009;54(3):S140** 414
This abstract for a presentation at the 2009 ACEP Research Forum describes a swine study that evaluated crystalloid fluid flow through an IO needle following nitroglycerin infusion in a swine model. Investigators concluded there was not a significant increase in flow rate after administration of IO nitroglycerin.
- Miller L, Philbeck T, Montez D, Spadaccini C. A new study of intraosseous blood for CBC and chemistry profile. *Ann Emerg Med* 2009;54(3):S59** 412
This abstract for a presentation at the 2009 ACEP Research Forum describes a volunteer study that examined the relationships between IO and venous blood samples when analyzed for complete blood count and chemistry profile. Researchers concluded that the IO space is a reliable source for blood used for CBC and chemistry profile. Results may be moderately reliable for carbon dioxide, but unreliable for WBC counts that appear to be elevated and platelet counts that appear lower. This study was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.
- Miller LJ, Philbeck TE, Montez DF, Spadaccini CJ. A new study of intraosseous blood for laboratory analysis. *Arch Pathol Lab Med* 2009;133:1628** 409
This abstract for a presentation at the College of American Pathology 2009 meeting describes a volunteer study that examined the relationships between IO and venous blood samples when analyzed for complete blood count and chemistry profile. Researchers concluded that the IO space is a reliable source for blood used for CBC and chemistry profile. Results may be moderately reliable for carbon dioxide, but unreliable for WBC counts that appear to be elevated and platelet counts that appear lower.
- Ong ME, Chan YH, Oh HH, Ngo AS. An observational prospective study comparing tibial and humeral intraosseous access using the EZ-IO. *Am J Emerg Med* 2009;27:8-15** 417
Comparison of tibial and humeral IO use in 24 adults. Both sites suitable for IO infusion. This study was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.

Intraosseous Vascular Access Bibliography

Anatomy, Physiology and Pathology

- Paxton JH, Knuth TE, Klausner HA. Proximal humerus intraosseous infusion: a preferred emergency venous access. *J Trauma* 2009;67:606-11** 430
- This article describes the first clinical study that focuses on the proximal humerus as an IO site. It is also the first article describing a comparison between IO access and peripheral IV (PIV) and central venous catheters (CVC). They found that IO catheter placement was significantly faster than PIV or CVC placement, and concluded that IO access is life-saving when PIV or CVC is difficult or impossible. This study was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.
- Tsung HW, Blaivas M, Stone MB. Feasibility of point-of-care colour Doppler ultrasound confirmation of intraosseous needle placement during resuscitation. *Resuscitation* 2009;80:665-8** 425
- Color Doppler ultrasound revealed extraosseous flow in incorrectly placed IO insertions. Recommends point-of-care Doppler machine to verify placement.
- Wright JK, Christy RJ, Tharp RV, Kalns JE. Evaluation of intraosseous delivery of factor VIIa during hemorrhagic shock in the pig. *Mil Med* 2009;174:119-23** 419
- This swine study was designed to determine if intraosseous infusion is suitable to delivery recombinant human factor VIIa (rFVIIa) during hemorrhagic shock. Investigators concluded that administration of rFVIIa via IO infusion is a safe route for delivery and is likely to produce blood levels required to improve hemostasis during shock.
- YEAR: 2008**
- Borron S, Arias J, Sanchez M, et al. Intraosseous line placement by hazardous materials responders and receivers for hydroxocobalamin administration. *Ann Emerg Med* 2008;52(4):S97** 420
- Animal (goat) study to determine the capacity and time required for protected hazardous materials responders and receivers to accomplish vascular access and hydroxocobalamin administration for antidotal treatment for exposure to cyanide and other poison agents. Using the EZ-IO device, researchers concluded that the time required for IO administration of the drug was shorter than intravenous administration; and that IO placement is readily accomplished wearing all levels of chemical protective garments and equipment.
- Nicoll SJB, Rochester SJ. Blood sampling through intraosseous needles: Time to stop? *Resuscitation* 2008;79:168-176.doi: 10.1016/j.resuscitation.2008.04.018** 549
- Two letters to the editor regarding use of IO blood for sampling in the emergency setting. One letter states it should no longer be done and only arterial or femoral venous samples should be used during resuscitation; the second notes the importance of IO blood sampling in emergency situations when time cannot be delayed for central line access, stating it is key that the sample be properly labeled as IO blood.
- Salter R. Reply to letter: Blood sampling through intraosseous needles: time to stop? *Resuscitation* 2008;79:168-9. doi:10.1016/j.resuscitation.2008.04.017** 727
- Two letters to the editor regarding use of IO blood for sampling in the emergency setting. One letter by S. Nicoll and S. Rochester states it should no longer be done and only arterial or femoral venous samples should be used during resuscitation. The second by R. Salter notes the importance of IO blood sampling in emergency situations when time cannot be delayed for central line access, stating it is key that the sample be properly labeled as IO blood.
- UK
- Susi L, Reader A, Nusstein J, Beck M, Weaver J, Drum M. Heart rate effects of intraosseous injections using slow and fast rates of anesthetic solution deposition. *Anesth Prog* 2008;55(1):9-15** 720
- This article describes a prospective cross-over study that evaluated the effects on heart rate of intraosseous administration of 2% lidocaine at various deposition rates in dental practice. Results showed the mean maximum heart rate was statistically higher with the fast intraosseous injection over the two slow injections.
- YEAR: 2007**
- Favier JC, Landy C, Pernod G, Walkowiak P, Rottiman M. [Continuous intraosseous epinephrine infusions in adults: its interest when haemodynamics is poor]. *Ann Fr Anesth Reanim* 2007; 26: 884-5. French** 406
- Article describes the IO route to deliver epinephrine.
- Hoskins SL, Zachariah BS, Copper N, Kramer GC. Comparison of intraosseous proximal humerus and sternal routes for drug delivery during CPR. *Circulation* 2007;116:II_993** 386
- Results from this, study which sought to compare drug delivery time using the proximal humerus IO route to delivery time using the sternal IO route, suggest that IO proximal humerus is comparable to IO sternal for prompt drug delivery during CPR.
- Stone MN, Teismann NA, Wang R. Ultrasonographic confirmation of intraosseous needle placement in an adult unembalmed cadaver model. *Ann Emerg Med* 2007;49(4):515-9. doi:10.1016/j.annemergmed.2006.11.009** 832
- A cadaveric study evaluating the use of ultrasonography visualization of flow within the intraosseous space to confirm proper needle placement. In a sample of 4 freshly frozen, unembalmed cadavers with bilateral distal tibia IO access, ultrasonography accurately detected the flow of crystalloids through the IO space 100%.

Intraosseous Vascular Access Bibliography

Anatomy, Physiology and Pathology

YEAR: 2006

Engle WA. Intraosseous access for administration of medications in neonates. Clin Perinatol 2006;33(1):161-8 662
An overview of IO vascular access use in neonates, including focus on available evidence, history, technique, physiology, clinical indications, complications, and contraindications. The author closes acknowledging IO administration of resuscitation medications and fluids in neonates is an alternative when IV access is not possible.

Hoskins SL, Kramer GC, Stephens CT, Zachariah BS. Abstract 79: Efficacy of epinephrine delivery via the intraosseous humeral head route during CPR. Circulation 2006;114:II_1204 422
Results from this study which sought to determine the efficacy of intraosseous drug delivery using the proximal humerus during CPR in swine showed that the humeral route generated higher mean arterial pressures than central venous or endotracheal delivery.

Peutrell JM. Intraosseous cannulation. Anesthesia and Intensive Care Medicine 2006;7(1):28-30. Doi:10.1383/anes.2006.7.1.28 637
An overview of intraosseous cannulation in the pediatric population. Anatomy, technique, contraindications, complications and laboratory investigations are all discussed.

YEAR: 2005

Hoskins S, Nascimento P, Espana J, Kramer G. Pharmacokinetics of intraosseous drug delivery during CPR. Shock 2005;23:35 423
This animal study compared IO drug delivery in the tibia versus the sternum during CPR. Researchers concluded that during CPR IO infusions delivered via both sites were effective—although sternal delivery was faster; and that IO sternum access is comparable to IV access for drug delivery during CPR.

Hoskins S, Stephens C, Kramer G. Efficacy of intraosseous drug delivery during cardiopulmonary resuscitation in swine. Paper presented at the annual meeting of the National Association of EMS Physicians, Registry Resort, Naples, FL. 2009-05-25 from http://www.allacademic.com/meta/p64887_index.html 506
This study abstract discusses use of the EZ-IO to determine the pharmacokinetics (PK) and efficacy of tibial IO drug delivery during treatment of cardiac arrest in the swine model, as compared to IV access. Results showed that PK analysis of IO drug delivery via the tibial route showed a delay of 20-50 seconds compared to IV; however, physiologically significant levels of epinephrine were reached as MAP. This research was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.

Kramer GC, Hoskins SL, Espana J, do Nascimento P. Intraosseous drug delivery during cardiopulmonary resuscitation: relative dose delivery via the sternal and tibial routes. Acad Emerg Med 2005;12:s6. 332
Animal study compared the sternal and tibial routes for IO drug delivery during CPR. Investigators concluded that both the sternal and tibial routes can effectively deliver near equivalent doses during CPR in swine.
http://www.aemj.org/cgi/content/abstract/12/5_suppl_1/67

Mackinnon MA. Permissive hypotension: a change in thinking. Air Med J 2005; 24: 70-2 347
Case report. Finds more positive outcomes with fluid restriction (permissive hypotension) in patients with uncontrolled hemorrhagic shock.

Meyer C, Alt V, Hassanin H, Heiss C, Stahl JP, Giebel G, Koebke J, Schnettler R. The arteries of the humeral head and their relevance in fracture treatment. Surg Radiol Anat 2005;27:232-7 340
Arterial supply of the humeral head and the clinical relevance of the vessels in the proximal humeral fracture and in different techniques of fracture treatment.

Silverman AS, Wang VW. Shock: A common pathway for life-threatening pediatric illnesses and injuries [CME]. Pediatr Emerg Med Pract 2005;2(10):1-22 1020
This is a continuing medical education (CME) document that provides an overview of shock and discusses management of shock in the pediatric patient. It is geared toward pediatric emergency medicine physicians. IO is a supported route for obtaining vascular access.

YEAR: 2004

Clem M, Tierney P. Intraosseous infusions via the calcaneus. Resuscitation 2004;62(1):107-12 322
Cadaver study demonstrating immediate entry of methyl green dye into the venous system after IO infusion via the calcaneus in 14 of 20 cadaver legs (70%).

Eslami. Intraosseous access. <http://www.emedicine.com/ped/topic3053.htm> Last updated October 22, 2004 320
Web publication discussing the indications, contraindications, insertion sites and complications of IO access.

Haas NA. Clinical review: vascular access for fluid infusion in children. Crit Care 2004;8(6):478-84.doi:10.1186/cc2880 323
Review article describing how IO has replaced saphenous venous cutdowns in pediatric emergencies and decreased need for immediate central venous access.

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- Saglam M, Ugurel S, Kilciler M, et al. [Intraosseous urography compared with intravenous urography: An experimental study in the rabbit model]. Turk J Vet Anim Sci 2004; 28: 933-42. Turkish** 384
Evaluation of the Bone Injection Gun (BIG) for the administration of contrast media for urography. Concludes that BIG-assisted intraosseous urography may be an effective and reliable alternative to intravenous urography in pediatric and adult human patients.
- YEAR: 2003**
- Boon JM, Gorry DL, Meiring JH. Finding an ideal site for intraosseous infusion of the tibia: an anatomical study. Clin Anat 2003;16(1):15-8** 300
Investigation of the relationship between insertion site for the IO needle, epiphyseal growth plate and ease of needle insertion into the various locations of the tibia in newborn infants. Recommends that needle be placed 10 mm distal to the tibial tuberosity to avoid the epiphyseal growth plate and ensure ease of insertion.
- Claudet I, Baunin C, Laporte-Turpin E, Marcoux MO, Grouteau E, Cahuzac JP. Long-term effects on tibial growth after intraosseous infusion: a prospective, radiographic analysis. Pediatr Emerg Care 2003;19(6):397-401** 313
Prospective radiographic study of 23 children who had received intraosseous infusion via trocar. Found no long-term effect on tibial growth with properly placed trocar.
- Gluckman, W, Forti RJ. Intraosseous cannulation. www.emedicine.com/ped/topic2557.htm Last Updated: Jan 14, 2003** 301
Web article discusses IO cannulation procedure insertion sites, pathophysiology, risks, contraindications and complications.
- LaRocco BG, Wang HE. Intraosseous infusion. Prehosp Emerg Care 2003;7:280-5** 309
A comprehensive and accessible review of the history, anatomy, technique, and clinical application of intraosseous infusion.
- McCarthy G, O'Donnell C, O'Brien M. Successful intraosseous infusion in the critically ill patient does not require a medullary cavity. Resuscitation 2003;56:183-6** 297
Study in human demonstrating transport of methyl green dye to the peripheral veins in 5 of 8 IO infusions (62%) in bones without medullary cavity (calcaneus and radial styloid).
- YEAR: 2002**
- Bilibin DP, Shevelev OA, Khodorovich NA. Osteovisceral afferent interrelations. Bull Exp Biol Med 2002; 139: 658-61** 286
Preclinical study in anaesthetized cats demonstrating that stimulation of intraosseous receptors decreased the threshold of evoked potential in the cerebral cortex in response to stimulation of the heart, stomach and duodenum. Concludes that stimulation of intraosseous receptors increases sensitivity of visceral sensory receptors and may provoke the development of pain syndromes.
- Ichioka N, Inaba M, Kushida T, Esumi T, Takahara K, Inaba K, Ogawa R, Iida H, Ikehara S. Prevention of senile osteoporosis in SAMP6 mice by intrabone marrow injection of allogeneic bone marrow cells. Stem Cells 2002; 20: 542-51** 292
Preclinical study in mice demonstrating that transplantation of bone marrow from normal allogenic mice injected directly into the bone marrow cavity of irradiated recipient mice can prevent and treat osteoporosis.
- Laroche M. Intraosseous circulation from physiology to disease. Joint Bone Spine 2002;69:262-9** 989
This article provides an indepth overview of intraosseous circulation including blood vessel anatomy, vascularization, intraosseous blood flow, angiogenesis, bone remodeling, osteonecrosis, bone infarction, and osteoporosis.
- Manggold J, Sergi C, Becker K, Lukoschek M, Simank HG. A new animal model of femoral head necrosis induced by intraosseous injection of ethanol. Lab Anim 2002; 36: 173-80** 295
Basic research study in sheep demonstrating that intraosseous injection of ethanol directly into the center of the femoral head produced necrotic changes similar to the early stages of osteonecrosis. The model holds potential for evaluating new therapeutics for the disease.
- Meechan JG. Supplementary routes to local anaesthesia. Int Endod J 2002;35(11):885-96** 954
This paper describes supplementary techniques available to provide pulpal anaesthesia, of which IO administration is included.
- Scheuch BC, Van Hoogmoed LM, Wilson WD, Snyder JR, MacDonald MH, Watson ZE, Steffey EP. Comparison of intraosseous or intravenous infusion for delivery of amikacin sulfate to the tibiotarsal joint of horses. Am J Vet Res 2002; 63: 374-80.** 289
Preclinical study in 21 horses comparing IV to IO infusion for delivery of amikacin sulfate to the tibiotarsal joint. Concludes that IV infusion results in higher drug concentrations in the joint.

Intraosseous Vascular Access Bibliography

Anatomy, Physiology and Pathology

YEAR: 2001

Caldwell J, Ziglar M. Hemorrhagic shock in children: Understanding the underlying mechanisms of shock syndrome. Am J Nurs 2001;101(Supplement):25-7 964

This article gives an overview for nurses of the treatment of shock in children. Intraosseous administration of fluids is a means of resuscitation.

YEAR: 2000

Fisher R, Prosser D. Intraosseous access in infant resuscitation. Arch Dis Child 2000;83:87 252

Laboratory study comparing flow rates through different IV cannulas with an 18 G IO cannula. Found that fluids could be infused more quickly with the IO cannula. Speculates that the bone marrow cavity of an infant has more capacitance than a peripheral vein.

Gallatin E, Stabile P, Reader A, Nist R, Beck M. Anesthetic efficacy and heart rate effects of the intraosseous injection of 3% mepivacaine after an inferior alveolar nerve block. Oral Surg Oral Med Oral Pathol Endod 2000; 89: 83-7 268

Dental study demonstrating that intraosseous injection of 1.8 ml of 3% mepivacaine to augment nerve block in the first molar significantly increased the anesthetic success over 30 minutes and had a minimal effect on heart rate.

Hurren JS. Can blood taken from intraosseous cannulations be used for blood analysis? Burns 2000; 26: 727-30 262

Study comparing IO blood samples to IV samples for blood chemistry values. For many parameters, IO and IV levels were similar. Authors caution that potassium and glucose levels should be interpreted with care. Also found that white cell and platelet counts in the IO samples were very different from those measured in IV blood samples.

Mattera CJ. Take aim--hit your IO target. A comprehensive approach to pediatric intraosseous infusion, including site selection, needle insertion & ongoing assessment. Part 2. JEMS 2000;25(4):38-48 264

Overview of pediatric IO infusion targeted for an EMS/paramedic audience. Discusses anatomy of long bones, indications, advantages, contraindications, steps for insertion, fluid administration and ongoing assessment and documentation.

McCarthy G, Buss P. Does intraosseous have to mean intramedullary? J Accid Emerg Med 2000; 17: 432 267

Case report of a 3-year-old collapsed child successfully resuscitated with the use of an intraosseous needle placed in the calcaneum. Includes detailed description of needle insertion technique.

Pan'ko SV, Antipov IG, Semenidov IN, Sosnovskaya OL, Golovanova TA, Sanin AV. [Suppression of graft versus host reaction by depositing a magnet-controlled adriamycin dosage form in bone marrow allotransplantation in animal experiments]. Vestnik Rossijskoi Akademii Meditsinskikh Nauk 2000;(3): 10-5. Russian. Abstract 251

Intraosseous transplantation of bone marrow in combination with long-acting Adriamycin may inhibit acute and chronic graft versus host reactions.

Voelckel WG, Lindner KH, Wenzel V, Krismer AC, Hund W, Muller G, Oroszy S, Kornberger E, Lurie KG, Mair P. Intraosseous blood gases during hypothermia: correlation with arterial, mixed venous, and sagittal sinus blood Crit Care Med 2000; 28: 2915-20 259

Preclinical model of hypothermia. Found intraosseous pCO₂ levels correlated with arterial or mixed venous pCO₂ during hypothermia within 10 mmHg. Intraosseous pH values were comparable with mixed venous or sagittal sinus pH within of 0.05 units during hypothermia.

Vreede E, Bulatovic A, Rosseel P, Lassalle X. Intraosseous infusion. Update in Anesthesia 2000;12 (Article 10):1. <http://rcpals.com/downloads/2007files/may/pals/IntraosseousInfusion.html> 263

Brief overview of IO infusion for an anesthesiology audience. Discusses technique, indications, contraindications, equipment, anatomical target sites and potential complications.

Yankovskis G, Beldava I, Livina B. Osteoreflexory treatment of alcohol abstinence syndrome and craving for alcohol in patients with alcoholism. Acupunct Electrother Res 2000;25:9-16 255

Osteoreflexory therapy (intraosseous injection of 0.5 to 1.0 ml of 0.9% saline solution) reduced alcohol craving in patients treated for alcoholism.

Abstract only

YEAR: 1999

Abdelmoneim T, Kissoon N, Johnson L, Fiallos M, Murphy S. Acid-base status of blood from intraosseous and mixed venous sites during prolonged cardiopulmonary resuscitation and drug infusions. Crit Care Med 1999;27:1923-8 242

Preclinical study in anaesthetized piglets demonstrating that intraosseous blood samples reliable to assess acid-based balance in the early stages of cardiac arrest and first 15 minutes of cardiac pulmonary resuscitation.

Intraosseous Vascular Access Bibliography

Anatomy, Physiology and Pathology

- Efimov IuV, Zaitsev VG, Sychugov AV. [The treatment of patients with complicated mandibular fractures using a method for the intraosseous administration of biologically active drug agents]. Stomatologiya (Mosk) 1999; 78; 26-7. Russian** 248
Article in Russian; no English translation.
- Johnson L, Kissoon N, Fiallos M, Abdelmoneim T, Murphy S. Use of intraosseous blood to assess blood chemistries and hemoglobin during cardiopulmonary resuscitation with drug infusions. Crit Care Med 1999; 27: 1147-52** 235
Preclinical study in piglets comparing IO vs IV blood samples during CPR. Concludes that IO samples may not yield accurate results during resuscitation periods > 5 minutes or if drug or fluid boluses have been infused into the IO sample site.
- YEAR: 1998**
- McCarthy G, Buss P. The calcaneum as a site for intraosseous infusion. J Accid Emerg Med 1998;15:421.doi:10.1136/emj.15.6.421** 445
A 3-year old male presented at the emergency department with rapidly progressing circulatory collapse clinically aligned with meningococcal septicemia. Attempts at peripheral and central venous access were unsuccessful. Attempts at tibial IO insertion were unsuccessful with a number of needles bending when cortical penetration was attempted. IO insertion was successfully achieved at the medial aspect of the calcaneum. IO infusion was continued for 6 hours and removed when no longer needed. The patient fully recovered and the calcaneal site healed without complication.
- Nasimi A, Gorin P, Berthier M, Boussemart T, Follet-Bouhamed C, Oriot D. [Use of the intraosseous route in a premature infant]. Arch Pediatr 1998; 5: 414-7. French** 231
Case report of a 34-week-old pre-term neonate with septic shock requiring emergency treatment. Umbilical vein was unusable. Resuscitation with IO access was successful. Concludes that IO access be used before attempting access with superior longitudinal sinus.
Abstract
- Stovroff M, Teague WG. Intravenous access in infants and children. Pediatr Clin North Am 1998;45:1373-93** 227
Review article discussing techniques for venous access in the pediatric patient includes anatomical target sites, clinical indications, advantages and disadvantages.
Review
- YEAR: 1997**
- Dubick MA, Kramer GC. Hypertonic saline dextran (HSD) and intraosseous vascular access for the treatment of haemorrhagic hypotension in the far-forward combat arena. Ann Acad Med Singapore 1997;26(1):64-9** 218
Review article highlighting preclinical data and 1 clinical study. Demonstrates that IO administration can be used for safe and rapid infusion of hypertonic saline dextran with the hemodynamic effect as IV administration.
- Kissoon N, Idris A, Wenzel V, Murphy S, Rush W. Intraosseous and central venous blood acid-base relationship during cardiopulmonary resuscitation. Pediatr Emerg Care 1997;13:250-3** 225
Preclinical study of piglets in cardiac arrest demonstrating divergent values for acid-base parameters between IO and IV blood samples during cardiac arrest. Speculates that divergence in acid-base values as CPR progresses may reflect local acidosis since IO samples resulted in lower pCO₂ and higher pH values than IV blood samples.
- Manley L. Pediatric hypovolemia: back to the basics. Int J Trauma Nurs 1997; 3:93-8** 220
Review article for trauma nursing audience describing advances in trauma care.
- YEAR: 1996**
- Brickman KR, Rega P, Schoolfield L, Harkins K, Weisbrode SE, Reynolds G. Investigation of bone developmental and histopathologic changes from intraosseous infusion. Ann Emerg Med 1996;28(4):430-5** 216
Preclinical study in pigs examining developmental and histopathologic changes in bone following IO infusion and effect of osmolality and infusion speed. Found that infusion osmolality and speed was not related to physiologic or histologic changes in the bone marrow or in complication.
- Garcia CT, Cohen DM. Intraosseous needle: use of the miniature C-arm imaging device to confirm placement. Pediatr Emerg Care 1996;12:94-7** 210
Describes a miniature C-arm imaging device to accurately confirm proper needle placement in intraosseous infusions.
- Iwama H, Katsumi A. Emergency fields, obtaining intravascular access for cardiopulmonary arrest patients is occasionally difficult and time-consuming. J Trauma 1996;41(5):931-2** 207
Found that IO infusion into the clavicle during adult CPR had similar effects and flow rates as central venous infusion.

Intraosseous Vascular Access Bibliography

Anatomy, Physiology and Pathology

YEAR: 1995

Ronning G, Sager G, Revhaug A. Intraosseous infusion of a small volume of hyperosmotic fluid increases mean arterial pressure and lessens the catecholamine response in pigs with haemorrhagic shock. *Eur J Surg* 1995;161(10):715-20 195

Preclinical study in pigs demonstrating that IO hyperosmotic resuscitation increases circulatory performance and reduces the plasma and catecholamines concentrations during hemorrhagic shock .

YEAR: 1994

Evans RJ, McCabe M, Thomas R. Intraosseous infusion. *Br J Hosp Med* 1994;51(4):161-4 175

Review of IO infusion in children 6 years old and younger. Recommends IO for patients with life-threatening conditions requiring immediate vascular access. Reports less than 1% complication rate.

Iwama H, Katsumi A, Shinohara K, Kawamae K, Ohtomo Y, Akama Y, Tase C, Okuaki A. Clavicular approach to intraosseous infusion in adults. *Fukushima J Med Sci* 1994;40:1-8 167

Comparison of flow rates for IO infusion through the clavicle and subclavian venous infusion. Found no significant differences between the two infusion routes.

Abstract only

Kil'diushov AN. [Use of heparin in the early post-traumatic period in burns and hemorrhage]. *Anesteziol Reanimatol* 1994; Sept-Oct(5):26-8. Russian 163

Preclinical study in 86 injured dogs with hemostasis disorders. Plasma and platelet disorders normalized 3 hours after the onset of infusion therapy. The response was enhanced by IO infusion of isotonic saline.

Article in Russian-abstract only

Kissoon N, Peterson R, Murphy S, Gayle M, Ceithaml E, Harwood-Nuss A. Comparison of pH and carbon dioxide tension values of central venous and intraosseous blood during changes in cardiac output. *Crit Care Med* 1994; 22: 1010-5 180

Preclinical study in piglets comparing IO and central venous acid-base status during changes in cardiac output. Found IO samples can be easily obtained even during extreme hypervolemia. pH and pCO₂ were similar in both IO and IV samples under all study conditions.

Kruse JA, Vyskocil JJ, Haupt MT. Intraosseous infusions: a flexible option for the adult or child with delayed, difficult, or impossible conventional vascular access. *Crit Care Med* 1994;22(5):728-9 184

Discussion of IO infusion, including ease of use, low complication rates, and variety of fluids and drugs that can be administered through the IO route in children and adults.

Neal CJ, McKinley DF. Intraosseous infusion in pediatric patients. *J Am Osteopath Assoc* 1994;94(1):63-6. Review 187

Describes frustration associated with difficult venous access. Recommends intraosseous infusion technique as a non-collapsible vein for parenteral infusions.

Takada M, Yamamoto I, Morita R. Chronic intramedullary infusion of interleukin-1 alpha increases bone mineral content in rats. *Calcif Tissue Int* 1994; 55: 103-8 181

Preclinical study in rats examining bone mineral content following IO infusion of IL-1.

Ummenhofer W, Frei FJ, Urwyler A, Drewe J. Are laboratory values in bone marrow aspirate predictable for venous blood in paediatric patients. *Resuscitation* 1994;27(2):123-8 560

In this study bone marrow aspirate from the iliac crest and peripheral venous blood samples from 30 pediatric patients were compared to investigate the predictive value of bone marrow aspirate in performing laboratory studies. Laboratory tests with high predictability, moderate but clinically useful predictability are summarized. Tests that were systematically different from venous blood are also summarized.

YEAR: 1993

Bielski RJ, Bassett GS, Fideler B, Tolo VT. Intraosseous infusions: effects on the immature physis--an experimental model in rabbits. *J Pediatr Orthop* 1993;13:511-5 143

Preclinical study in 20 immature rabbits receiving IO infusion of saline, bicarbonate, or dopamine solutions into the tibia. Found no changes in bone growth or epiphyseal injury related to IO infusion.

YEAR: 1992

Brickman K, Krupp K, Rega P, Alexander J, Guinness M. Typing and screening of blood from intraosseous access. *Ann Emerg Med* 1992;21(4):414-7 509

This prospective, nonrandomized, crossover study evaluated bone marrow aspiration from the posterior iliac crest and peripheral venous blood for ABO and Rh typing as well as the presence of human leukocyte activity. No differences were seen in the ABO and Rh typing, and human leukocyte activity was detected in both the marrow and venous samples.

Intraosseous Vascular Access Bibliography

Anatomy, Physiology and Pathology

- Cilley RE. Intraosseous infusion in infants and children. Semin Pediatr Surg 1992;1(3):202-7** 139
Article promoting increased awareness of intraosseous infusion, familiarity with IO insertion techniques, and careful use of anatomical landmarks.
Abstract only
- Pollack CV Jr, Pender ES, Woodall BN, Tubbs RC, Iyer RV, Miller HW. Long-term local effects of intraosseous infusion on tibial bone marrow in the weanling pig model. Am J Emerg Med 1992; 10: 27-31** 138
Preclinical study in piglets finding that IO infusion of a normal saline bolus decreased overall cellularity in the tibial bone marrow. Speculates this may be due to a pressure effect from rapid injection.
- Welch RD, Waldron MJ, Hulse DA, Johnston CE 2nd, Hargis BM. Intraosseous infusion using the osteoport implant in the caprine tibia. J Orthop Res 1992;10(6):789-99** 129
Preclinical study of an implantable intraosseous infusion device (the osteoport) in a goat model. The device allowed for ready access to the vascular system through intraosseous infusion fluids and medications. IO infusion may result in fewer complications than conventional methods of vascular access.
- Woodall BN, Pender ES, Pollack CV Jr, Miller H, Tubbs RC, Andrew ME. Intraosseous infusion of resuscitative fluids and drugs: long-term effect on linear bone growth in pigs. South Med J 1992;85:820-4** 131
Preclinical study in pigs demonstrating that IO infusion of fluids and resuscitative drugs does not adversely affect subsequent bone growth and development.
- YEAR: 1991**
- Brattebo G, Wisborg T, Mellesmo S. [Intra-osseous infusion--a simple, rapid and lifesaving method]. Nord Med 1991;106(1):13-5. Norwegian** 118
Discussion of case reports of IO infusion, as well as physiology of IO and technique for IO access. Concludes that IO infusion is simple and safe. The technique can be successfully performed under field conditions by paramedical personnel, even by untrained personnel.
Abstract only
- Grisham J, Hastings C. Bone marrow aspirate as an accessible and reliable source for critical laboratory studies. Ann Emerg Med 1991;20(10):1121-4** 108
Clinical study demonstrating blood from the IO space to be a viable alternative source of blood for laboratory studies.
- Ros SP, McMannis SI, Kowal-Vern A, Zeller WP, Hurley RM. Effect of intraosseous saline infusion on hematologic parameters. Ann Emerg Med 1991;20(3):243-5** 119
Preclinical study in rabbits comparing hematologic parameters from IO blood samples before and after IO infusion of saline. Found significant differences in blood cell counts before and after IO infusion.
- Von Hoff DD. Intraosseous infusions: an important but forgotten method of vascular access. Cancer Invest 1991;9(5):521-8** 116
Review of intraosseous vascular access targeted for an oncology audience. Describes an implantable IO device with potential to make intraosseous access more convenient for the patient.
- YEAR: 1990**
- Fiser DH. Intraosseous infusion. N Engl J Med 1990;322(22):1579-81** 98
Review of the use of intraosseous infusion in children in the prehospital setting and in the emergency department. Outlines anatomy, indications and contraindications, technique, complications and role of intraosseous infusion in pediatrics.
- Joffe M. Blasts in peripheral blood with intraosseous infusions. Pediatr Emerg Care 1990;6:106-7** 89
Case reports of 2 children who died from Sudden Infant Death Syndrome (SIDS) with immature white cells in the peripheral blood. Blood was sampled near IO infusion site. Urges physician awareness of that patients receiving IO infusion may be at risk for immature white blood cells in the peripheral circulation in the absence of malignant, infectious, or infiltrative disease of the marrow.
- Miccolo MA. Intraosseous infusion. Crit Care Nurse 1990;10(10):35-47** 100
Nursing article that describes benefits of intraosseous infusion. Recommends IO for cardiopulmonary arrest and other medical
- Spivey WN. Intraosseous infusion: Current concepts : The medical college of Pennsylvania, Department of Emergency Medicine, Philadelphia, PA. J Emerg Med 1990;8(3):382** 743
This abstract describes a review of the literature on intraosseous pathways and reaches the conclusion that the rate of fluid administered is limited by the size of the marrow cavity and the complication is extravasation of fluids and/or drugs into the soft tissue.

Intraosseous Vascular Access Bibliography

Anatomy, Physiology and Pathology

Vinsel PJ, Moore GP, O'Hair KC. Comparison of intraosseous versus intravenous loading of phenytoin in pigs and effect on bone marrow. *Am J Emerg Med* 1990;8(3):181-3 429

A 15mg/kg dose of phenytoin was administered over 15 minutes to 6 pigs using the IV route and 6 pigs using the tibial IO route. Blood samples were taken every 5 minutes for 35 minutes to determine phenytoin levels. There was no statistical difference between the two groups. Bone cortex and marrow were microscopically examined and were normal after 5 weeks. Authors concluded the IO route is an effecting alternative to the IV route for administering phenytoin without permanent damage to the marrow.

YEAR: 1988

Oni OO, Stafford H, Gregg PJ. An investigation of the routes of venous drainage from the bone marrow of the human tibial diaphysis. *Clin Orthop* 1988;230:237-44 72

Basic science study examining vascular drainage from the human tibia using x-rays and barium perfusion. Found that blood from the IO space is diverted simultaneously into two independent extrasketal venous pathways. Found that IO blood drains directly into the systemic veins via large transcortical perforating vessels, which enables the blood to rapidly enter the general systemic circulation.

YEAR: 1987

Hodge D, Delgado-Paredes C, Fleisher G. Intraosseous infusion flow rates in hypovolemic "pediatric" dogs. *Ann Emerg Med* 1987;16(3):305-7 58

Preclinical study of IO flow rates during hypovolemia. Concludes that IO flow rates may be insufficient for definitive treatment of severe hypovolemic or hemorrhagic shock.

YEAR: 1979

Shoor PM, Berryhill RE, Benumof JL. Intraosseous infusion: pressure-flow relationship and pharmacokinetics. *J Trauma* 1979;19:772-4 32

Preclinical study of IO flow and pharmacokinetics in the bovine tibia. Mean time to initial effect of IO administration of epinephrine was 17 seconds with 90% maximal effect in 45 seconds. Concludes that experiment provides quantitative evidence of utility of IO infusion for resuscitation.

YEAR: 1978

Brickman KR, Rega P, Guinness M. A comparative study of intraosseous, intravenous and intraarterial pH changes during hypoventilation in dogs. *Ann Emerg Med* 1978;16:510 31

Preclinical study in dogs demonstrating active IO blood circulation even during acidosis and hypoxemia.

Lemperg RK, Arnoldi CC. The significance of intraosseous pressure in normal and diseased states with special reference to the intraosseous engorgement-pain syndrome. *Clin Orthop Relat Res* 1978;136:143-56 30

Intraosseous angiography and intraosseous pressure measurement can be useful for diagnosing bone pain and treatment site.

YEAR: 1958

Schoenherr WF. Intraosseous infusion of bone marrow. *JAMA* 1958;166(7):853 567

This letter to the editor is regarding the case of a 56 year-old man that ultimately developed aplastic anemia and required blood transfusions biweekly, and being considered for bone marrow transplants. The Editor's response briefly addressed the process of bone marrow transplantation.

YEAR: 1945

Henning N. Intrasternal and intraosseous injections and transfusions. *JAMA* 1945; 128: 240 17

Recommends intrasternal IO transfusions when the IV route is not available.

YEAR: 1944

Behr G. Bone-marrow infusions for infants. *Lancet* 1944; (Oct 7):472-3 14

Describes the tibia as a useful route for infusions in infants. Main advantages over IV infusions are ease, speed, and firm placement.

Intraosseous Vascular Access Bibliography

Case Studies

YEAR: 2019

Farrokh S, Cho SM, Lefebvre AT, Zink EK, Schiavi A, Puttgen HA. Use of intraosseous hypertonic saline in critically ill patients. J Vasc Access 2019;20(4):427-32. doi: 10.1177/1129729818805958. Epub 2018 Oct 17 1052

Retrospective case report of six patients describing the use of intraosseous (IO) administration for 23.4% saline administration to treat intracranial hypertension. In all six cases sodium levels were increased and there were no IO complications.

Mansfeld A, Radafshar M, Thorgeirsson H, Hoijer CJ, Segerlantz M. Palliative sedation via intraosseous vascular access: A safe and feasible way to obtain a vascular access end of life. J Palliat Med 2019;22(1):109-111. doi: 10.1089/jpm.2018.0398 1056

This is a case report of IO access for palliative sedation with propofol in a 56-year-old man with no venous access. IO access was gained using an EZ-IO driver and the patient was successfully treated with propofol for 4 days to manage intractable pain and agitation.

Sampson CS. Extravasation from a misplaced intraosseous catheter. Clin Pract Cases Emerg Med 2019;3(3):303-4 1068

A 75-year old female presented by EMS to the Emergency Department (ED) after a ventricular fibrillation cardiac arrest. EMS defibrillated the patient and placed a right proximal tibial EZIO intraosseous (IO) catheter which multiple medications (epinephrine, magnesium, amiodarone, and calcium chloride) were administered; and she had return of spontaneous circulation prior to ED arrival. The IO catheter wasn't patent upon arrival in the ED and was removed. The patient was discharged on day four with ecchymosis near the insertion site. Three weeks post discharge the patient presented with tissue necrosis in an area surrounding the initial proximal tibial IO insertion site. The patient's leg was debrided and grafting was performed; the author reported "good healing" three months post-event.

Schindler P, Helfen A, Wildgruber M, et al. Intraosseous contrast administration for emergency computed tomography: A case-control study. PLoS ONE 2019;14(5): e0217629. https://doi.org/10.1371/journal.pone.0217629 1067

Retrospective case-control feasibility study comparing proximal tibial intraosseous (PTIO) and peripheral intravenous (PIV) delivery of contrast media in 24 patients receiving emergent CT scans as part of trauma diagnostics (n=4 PTIO, n=20 PIV). Delivery of contrast media was by power injection with rates of 5cc/sec for CT images of the head and neck, chest, abdomen and leg vessels. There were no significant differences in ability to complete imaging protocols or image quality. There were no complications. The study was limited by low patient numbers.

YEAR: 2018

Abramson TM, Alreshaid L, Kang T, Mailhot T, Omer T. Fasciotomy: Ultrasound evaluation of an intraosseous needle causing compartment syndrome. Clin Pract Cases Emerg Med 2018;2(4):323-25 1041

This case review describes a complication of compartment syndrome post IO placement in a 64 year old male initially unresponsive and hypoglycemic. Approximately 15 minutes post-ED arrival compartment syndrome signs were noted and confirmed with compartment pressures. An ultrasound confirmed lack of flow from the IO needle and x-ray showed the needle set to be inserted 2 mm beyond the posterior tibial cortex. Patient was taken to surgery for fasciotomy and four compartment release with subsequent return of pulses.

*(Correspondence by the manufacturer 12-2018 with lead author confirmed the tibial placement was lateral and the patient had a full functional recovery).

Bowry R, Nour M, Kus T, et al. Intraosseous administration of tissue plasminogen activator on a mobile stroke unit. Prehosp Emerg Care 2018;25:1-6. doi:10.1080/10903127.2018.1526355 963

This study describes 3 cases in which tissue plasminogen activator (tPA) was administered via intraosseous (IO) access on a mobile stroke unit as part of the BEST-MSU study. IO access was obtained with the EZ-IO device as part of the study protocol.

Chalopin T, Lemaignan A, Guillon A, et al. Acute tibial osteomyelitis caused by intraosseous access during initial resuscitation: a case report and literature review. BMC Infectious Diseases 2018;18(1):665. doi: 10.1186/s12879-018-3577-8 1047

This report from France reports a case of tibial osteomyelitis in a 40 year old male that was diagnosed by MRI and biopsy three months post-intraosseous (IO) catheter removal. The patient was given parenteral as well as oral antibiotics and had a good outcome. The initial IO catheter placement was for treatment of overdose after failed IV attempts. The catheter was removed on the first day and the patient was treated with oral antibiotics due to local inflammation at the insertion site. He left against medical advice before a full treatment course was completed.

Crawford SB. Intraosseous vascular access device as a transarticular k-wire alternative in mallet finger laceration. Clin Pract Cases Emerg Med 2018;2(1):71-4. doi:10.5811/cpcem.2017.7.34811 969

This case study discusses the use of an IO vascular access device (EZ-IO) as a substitute for k-wire stabilization of mallet finger in a patient with distal fracture and tendon exposure of the third and fourth phalange. The needle driver of the EZ-IO was placed in a sterile glove and was then used to place the inner stylet of the device through the tip of the finger to achieve splint fixation in extension. The patient had a favorable outcome.

Intraosseous Vascular Access Bibliography

Case Studies

- Durnford S, Bulstrode H, Durnford A, Chakraborty A, Tarmey NT. Temporarily an extradural haematoma by intraosseous needle craniostomy in the District General Hospital by non-neurosurgical doctors-A case report. J Intensive Care Soc 2018;19(1):76-9. doi:10.1177/1751143717734997** 971

This is a case report of a 69 year-old male admitted to an ED in the UK with an extradural hematoma following closed head injury. He was treated with decompression of the hematoma using a 25 mm long EZ-IO intraosseous needle. This is believed to be the first reported use of an EZ-IO device in this manner in the UK. The patient succumbed to his injuries two days later. However, the authors recommend consideration of this technique when transfer to a hospital with a neurosurgery unit for craniostomy is not a feasible option.

- Han K, Kim J. Intraosseous anesthesia using a computer-controlled system during non-surgical periodontal therapy (root planning): Two case reports. J Dent Anesth Pain Med 2018;18(1):65-9. doi: 10.17245/jdpm.2018.18.1.65** 983

This paper presents two case reports of IO anesthesia using a computer-controlled intraosseous system (CIAS) for non-surgical periodontal therapy (root planing). CIAS-based induction of local anesthesia during non-surgical periodontal therapy was more comfortable for both patients relative to previous conventional local infiltration anesthesia (CLIA) treatment.

- Pac LJ, Rossi HA, Theyagarajan V, et al. Blood sample from an intraosseous device. Transfusion 2018;58:2472-3. doi:10.1111/trf.14762** 1008

This article describes a case report of a blood sample from a trauma patient that was drawn from a humeral head intraosseous device. The specimen gave correct blood typing results representative of the peripheral blood.

- Reic C, Fogg T, Healy G. Deformation of a humeral intraosseous catheter due to positioning for thoracostomy. Clin Exp Emerg Med 2018;5(3):208-9** 1013

This article describes a complication of a deformed EZ-IO catheter which was noted following removal of the catheter in an adult patient. The catheter had been placed by a helicopter emergency medical service team following a motor vehicle accident. The cause of the catheter bending was most likely the result of arm positioning for thoracostomy. No difficulties in removing the catheter were noted and it appeared to have been functioning effectively.

- Winkler M, Issa M, Lowry C, Chornenkyy Y, Sorrell V. Intraarticular extravasation, an unusual complication of computed tomographic angiography performed with intraosseous needle intravenous access. Cardiovasc Diagn Ther 2018;8(4):516-9. doi:10.21037/cdt.2018.06.04** 1033

This paper describes a case study of a 66 year-old female who presented to an emergency department with symptoms of an acute stroke. After failure of intravenous (IV) placement, humeral intraosseous (IO) access was obtained using the EZ-IO device. Contrast media (CM) for computed tomographic angiography (CTA) was later infused, off label, through the IO line. At the time of the CT scan 20 mL of CM was seen within the glenohumeral joint. The patient did not experience any ill effects from the extravasation following the procedure nor at her 1 week follow-up.

YEAR: 2017

- Bromberg R, Dave K, Mankodi D, Danckers M. Soft tissue laceration caused by lower extremity intraosseous access insertion in an obese patient. BMJ Case Rep 2017;doi:10.1136/bcr-2017-220069. (United Kingdom)** 938

This case report describes a complication of a laceration that occurred in an 85 year old morbidly obese female that presented in septic shock and received a proximal tibial IO placement. A 45 mm needle set was used for the initial insertion, which was completed without any initial problems; no stabilizer was placed. The patient had fluid resuscitation via the IO site with rapidly improved hemodynamics. During transport she developed a 7 cm laceration across the IO insertion site. The catheter was removed and laceration sutured. Authors opined that the lack of use of the EZ-Stabilizer dressing, the amount of soft tissue and thin skin and traction forces on the IO site applied during transport contributed to this complication.

- Budach NM, Niehues SM. CT angiography of the chest and abdomen in an emergency patient via humeral intraosseous access. Emerg Radiol 2017;24(1):105-8. doi:10.1007/s10140-016-1438-6. (Germany)** 823

This case report describes a CT angiography of the chest and abdomen done via an EZ-IO catheter placed in a critically ill patient's proximal humerus. The contrast media was infused at a rate of 4 mL/s and the infusion pressure never exceeded 300 mmHg. No immediate or short term complications were observed. The authors describe the overall image quality and vessel contrast observed as excellent.

- Bulstrode H, Kabwamab S, Durnford A, Hemptenstall J, Chakraborty A. Temporarily extradural haematoma by craniostomy using an intraosseous needle. Injury 2017;45(5):1098-1100. doi:10.1016/j.injury.2017.02.011** 939

This case report describes use of an intraosseous needle for initial management of increased intracranial pressure from an extradural bleed in a 43 year old female with a traumatic head injury. The patient was taken to surgery for a craniotomy and recovered without deficit.

Intraosseous Vascular Access Bibliography

Case Studies

Elliott A, Dubé P, Cossette-Côté A, et al. Intraosseous administration of antidotes-a systematic review. Clin Toxicol 2017; 55(10):1025-54. doi:10.1080/15563650.2017.1337122 917

This study reviews current IO administration of antidotes for patients that have presented to the emergency department with serious poisoning and IV access is not available. The study concluded that the evidence supporting the use of IO route for administering antidotes for poisoning patients is rare. Most evidence of IO access administration of antidotes has occurred in animal studies and case reports. Per author, despite lack of evidence, IO access is a potential option for antidotal treatments for resuscitation for patients where IV access is not available.

Helleman K, Kirpalani A, Lim R. A novel method of intraosseous infusion of adenosine for the treatment of supraventricular tachycardia in an infant. Pediatr Emerg Care 2017;33(1):47-8. doi: 10.1097/PEC.0000000000000966 871

This article describes a case in which adenosine was administered to a 2-week old patient with supraventricular tachycardia, which was successfully terminated following intraosseous administration of the drug.

Hodgetts JM, Johnston A, Kendrew J. Long-term follow-up of two patients with retained intraosseous sternal needles. J R Army Med Corps 2017;163(3):221-2. doi: 10.1136/jramc-2016-000699 872

This article describes two cases in which FAST1 intraosseous needle tips were retained in the sternal manubrium of patients following device removal. In each case, there were no long-term complications.

Mayer EF, Gianlanella P, Munjal I, Cunningham-Rundles C, Dara J. Fulminant sepsis due to granulibacter bethesdensis in a 4-year-old boy with x-linked chronic granulomatous disease. Pediatr Infect Dis J 2017;36(12):1165-6. doi:10.1097/INF.0000000000001659 992

This is a case report of a 4 year-old boy with chronic granulomatous disease (CGD), who had a fulminant and fatal infection with Granulibacter bethesdensis. Upon presentation to the hospital, intraosseous access was obtained for fluid resuscitation.

Santos AP, Conkin R, Dowd K. Needle break: Complication and management of intraosseous vascular access. Am Surg 2017;83(1):e18-20 1016

This report describes a case study of a 19 year-old male who had an IO catheter placement in the left proximal tibia with EZ-IO after sustaining injuries in a motorcycle accident. Upon removal of the IO access, the needle broke at the hub with the retained needle no longer exposed above the skin. Removal at the bedside using Hemostat forceps failed, as well as the use of a sternal needle holder and a wire twister. Under fluoroscopic guidance, a 4 mm Stryker Crown drill bit was used to remove the retained needle by coring it out of the bone. The site was irrigated, bone graft substitute was placed into the defect, and the surgical site was closed. The patient healed well and was discharged with no complications 3 days later.

Takei H, Nomura O, Yasuda M, Inoue N. Dermal abrasion due to semi-automatic intraosseous device. Pediatr Int 2017;59(5):641-2 1027

This paper describes a complication of dermal abrasion with the EZ-IO device in a 1 year old female in Japan who was treated in the emergency department for severe dehydration due to acute gastroenteritis.

Thadikonda KM, Egro FM, Ma I, Spiess AM. Deltoid compartment syndrome: A rare complication after humeral intraosseous access. Plast Reconstr Surg Glob Open 2017;5(1):e1208. doi: 10.1097/GOX.0000000000001208 807

Case report of a 64 year old female in critical condition that had bilateral humeral intraosseous (IO) access sites placed for resuscitation. Past medical history included a clotting disorder. IO access was removed within 24 hours after CVC placement. Eight days post-IO catheter removal the patient developed pain, swelling, decreased motion and firmness in the area near the IO site. Conservative management failed and clinicians confirmed elevated deltoid compartment pressures and diagnosed compartment syndrome. She was taken to the operating room for a fasciotomy. Post-operatively the patient had pain relief, improved range of motion and last check-up had no pain and full range of motion.

Yee D, Deolankar R, Marcantoni J, et al. Tibial osteomyelitis following prehospital intraosseous access. Clin Pract Cases Emerg Med 2017;1(4):391-4 936

Case report of a 29 year old that was diagnosed with osteomyelitis in his left tibia after a prehospital IO placement for resuscitation of cardiac arrest. Medications infused included naloxone, epinephrine, and amiodarone. The patient had ROSC and his IO catheter was removed within one hour of ED arrival due to infiltration. Diagnosis of tibial osteomyelitis occurred approximately 8 weeks post-initial placement.

YEAR: 2016

Azan B, Teran F, Nelson BP, Andrus P. Point-of-care ultrasound diagnosis of intravascular air after lower extremity intraosseous access. J Emerg Med 2016;51(6):680-3. http://dx.doi.org/10.1016/j.jemermed.2016.05.064 808

This case reports one patient in which they found a vascular air embolism via ultrasound when they were assessing the patient's femoral vessels prior to arterial line placement on the same side as a limb that had an IO device placed. The authors noted that it was possible air was introduced when the patient injected IV heroin to that same leg; but believe it was more likely the IO line or tubing was not flushed or left open for a period of time.

Intraosseous Vascular Access Bibliography

Case Studies

Davis J, Bates L. Rapid sequence induction via an intraosseous needle. J Intensive Care Society 2016;17(2):178-9

788

This article presents a case study of rapid sequence intubation via intraosseous (IO) access with a review of relevant literature. The authors describe a case of an adult male patient, peri-arrest with cardiogenic shock, cyanosed with un-recordable oxygen saturations and blood pressure. IO access was established in the proximal tibia and rapid sequence induction was performed using fentanyl, ketamine and suxamethonium. After 30 seconds direct laryngoscopy was attempted and intubation was secured on first attempt. The authors concluded that use of IO access for RSI can be useful in cases of difficult vascular access and rapid intubating conditions can be achieved which are comparable to using IV drug delivery.

Ginsberg-Peltz J. Time to bone healing after intraosseous placement in children is ill defined. Pediatr Emerg Care 2016;32(11):799-800. doi:10.1097/PEC.0000000000000652

944

This article discusses the difficulty in defining the time to bone healing after IO access insertion in children. A case study is presented of a 23 month old male with multiple comorbidities that had a tibial and proximal humerus IO placed then 3 weeks post IO placement had tibial swelling. Upon follow-up he was diagnosed with a tibial fracture and incomplete healing of the tibial bone accessed for IO use. Repeated IO access to a limb previously accessed is advised regardless of time after access. Authors emphasize that IO access is a "critically important tool" in pediatric emergency medicine and IO access should be used early and often.

Greenstein YY, Koenig SJ, Mayo PH, Narasimhan M. A serious adult intraosseous catheter complication and review of the literature. Crit Care Med 2016;44(9):e904-9. doi: 10.1097/CCM.0000000000001714

775

This article includes a case study of an adult patient who received an intraosseous (IO) catheter, that may have extravasated, resulting in vascular compromise. The patient was treated with pharmacologic intervention and the status was reversed. A review of the literature on adult IO complications is also described.

Hess T, Böhmer R, Arndt F, et al. Bilateral intraossärer zugang am humerus bei reanimation eines 3-Jährigen [Case Report- Bilateral humeral intraosseous access for CPR in a 3-years-old child]. Anästhesiol Intensivmed Notfallmed Schmerzther 2016;51(07-08):468-74. doi:10.1055/s-0042-110237.

819

This article in German describes a case study of a 3 year old child with a serious heart defect (after total cavopulmonary anastomosis) in which bilateral humeral IO access sites were obtained to manage her condition and the patient was discharged after 30 days without neurological deficits. Key messages include that IO access in children should be a primary access route in emergent and urgent situations, unless a suitable venous access is already available; the humeral head insertion site is an accepted method in emergency situations in adults and children; and IO access is intended for regular emergency administration of drugs. The purely preventive use of an IO is not indicated. Article in German.

Kjellemo H, Hansen AE, Øines DA, Nilsen TO, Wik L. Pediatric cardiac arrest due to trauma. Prehosp Emerg Care 2016;20(3):425-31. doi:10.3109/10903127.2015.1111479

879

This case study describes a "lifeless child" who had been trapped by an electrically operated garage door. An IO needles was placed in each tibia and adrenalin was administered. Despite being asystolic for up to 19 minutes, the child eventually recovered with neurologic reflexes and motor abilities intact.

Krishnan M, Lester K, Johnson A, Bardeloza K, Edemekong P, Berim I. Case report: Bent metal in a bone: A rare complication of an emergent procedure or a deficiency in skill set? Case Reports in Critical Care 2016;doi:10.1155/2016/4382481

806

This article describes a case in which an EZ-IO catheter inserted into the proximal humerus required surgical intervention for removal after traditional removal efforts failed. Authors noted the patient refused an attempt to stabilize the insertion site. Discussion and a brief review of the literature discusses available IO devices and complications. In conclusions authors opined that with education and training, EZ-IO may become the preferred method of achieving rapid vascular access for emergent resuscitation with a low risk for complications.

Strong D, Powell E, Tilney PVR. A 20-year-old-male with hemorrhagic shock. Air Med J 2016;35(1):8-11. http://dx.doi.org/10.1016/j.amj.2015.10.003

803

This case study describes the medical management of a 20 year old male post high-speed motor vehicle crash with multitrauma and in shock upon air medical team arrival. Care entailed aggressive airway support, bilateral chest decompressions, management of potential pelvic bleeding with a pelvic binder, one peripheral IV through which packed red blood cells and plasma were given and one proximal humerus IO through which 1 g tranexamic acid (TXA) was given.

Intraosseous Vascular Access Bibliography

Case Studies

YEAR: 2015

- Anson JA, Sinz EH, Swick JT. The versatility of intraosseous vascular access in perioperative medicine: a case series. J Clin Anesth 2015;27(1):63-7. <http://dx.doi.org/10.1016/j.jclinane.2014.10.002>** 729
- This article presents a 5-case series describing use of IO vascular access by anesthesiologists in the perioperative and critical care settings. All insertions were made in the proximal tibia and there were no adverse events reported. The devices cited as being used were the EZ-IO and the Cook Surfast manual needle. A proposed perioperative vascular access algorithm incorporating IO access is presented. The authors address key topics around IO access including use of same drug dosing as IV administered drugs, frequent palpation and monitoring of the insertion site for extravasation, low complication rate and actual risks associated with fat emboli and bone injury, pain and anxiety management in the awake patient and clinician-perceived pain. Administration of blood products, ACLS drugs, Lactated Ringer's solution and anesthetics are noted without complication. Use of IO aspirate for laboratory testing is noted, however use of the initial aspirate is indicated. Several patients in the case series were reported to find the discomfort of IO insertion preferable to multiple intravenous attempts. The authors concluded: IO lines can be placed quickly and safely in emergency situations or in elective surgical patients with difficult intravenous access; IO access can be useful in a wide variety of clinical settings; and is an important skill for anesthesiologist to learn.
- Ewy G, Bobrow B, Chikani V et al. The time dependent association of adrenaline administration and survival from out-of-hospital cardiac arrest. Resuscitation 2015;96:180-85. doi:10.1016/j.resuscitation.2015.08.011** 919
- This article discusses a retrospective analysis of data collected to investigate the possible time-dependent outcomes associated with adrenaline administration by personnel with Emergency Medical Services (EMS). Primary endpoint was survival to hospital discharge and positive neurological outcome. The study included 3,469 patients with out of hospital cardiac arrest (OHCA). Study concluded patients with OHCA that had been treated early with adrenaline and had a shockable rhythm had a survival rate to hospital discharge.
- Grabel Z, DePasse JM, Lareau CR, Born CT, Daniels AH. Intra-articular placement of an intraosseous catheter. Prehosp Disaster Med 2015;30(1):1-4. doi:10.1017/S1049023X14001290** 741
- Case report of a prehospital misplacement of an IO catheter into the intra-articular space of the knee joint when access was attempted in the field. Upon ED arrival IO placement was noted to be high and intra-articular placement was confirmed by xray. A sterile NS lavage was done and patient recovered without complication. Authors note this as a previously unidentified complication of IO placement and advise xray confirmation of affected sites with follow-up of intra-articular placements for the septic arthritis. (Picture of site appears to be an EZ-IO).
- Means L, Gimbar RP. Prothrombin complex concentrate administration through intraosseous access for reversal of rivaroxaban. Am J Emerg Med 2015;34(3):685.e1-2. doi:10.1016/j.ajem.2015.07.057. doi: 10.1016/j.ajem.2015.07.057** 765
- This paper describes a case study of a 64 year old man who presented to the ED with symptoms of bleeding related to rivaroxaban and clopidogrel. Due to concern for bleeding, low BP, and perceived difficulty in IV access, IO access was obtained. After access the patient experienced significant pain and was unable to tolerate large volume administration through the IO site. The patient was successfully treated with prothrombin complex concentrate (PCC), which has a smaller volume when compared to blood products. This was the first reported case of IO PCC administration.
- Northey LC, Shiraev T, Omari A. Salvage intraosseous thrombolysis and extracorporeal membrane oxygenation for massive pulmonary embolism. J Emerg Trauma Shock 2015;8(1):55-7** 929
- This is a case report of a 34 year old female with bilateral peripheral pulmonary emboli with bibasal consolidation and pleural effusions. Due to difficulty with establishing peripheral access, IO access was established in the proximal tibia and Alteplase was administered through the line. Central venous and arterial access were ultimately obtained, and extracorporeal membrane oxygenation (ECMO) was initiated. The patient ultimately recovered and was discharged from the hospital after 36 days. The authors noted that the combination of IO thrombolysis and ECMO for treatment of acute massive PE has not been previously reported and highlights the importance of appropriate access for administration of pharmacotherapy in the critically ill patient.
- Overbey JK, Kon AA. Dermal abrasion experienced as an adverse effect of the EZ-IO. J Emerg Med 2016;50(1):e7-10. doi: 10.1016/j.jemermed.2015.09.003.** 753
- This article presents a case report of a 7 month old female who received intraosseous vascular access via the EZ-IO in the distal femur that resulted in a dermal abrasion where the needle hub contacted the skin. The wound healed without significant complication however the scar at the IO site persisted at 11 months post the event. The authors recommend that providers use the minimal force necessary when operating the EZ-IO to avoid similar adverse events.
- Paterson ML, Callahan CW. The use of intraosseous fluid resuscitation in a pediatric patient with ebola virus disease. J Emerg Med 2015;49(6):962-4. <http://dx.doi.org/10.1016/j.jemermed.2015.06.010>** 796
- Case study of 9-month-old patient (approximate weight 7 kg) presented with Ebola Virus Disease (EVD) and severe dehydration. IO access was obtained using a 15 g Jamshidi device to the right proximal tibia. A total bolus of 280 mL of lactated ringers solution was infused; then the IO infusion continued for 12 hours until an IV could be established. Authors stated it is important for emergency disaster responders, as well as their responding organizations, to know and understand that IO access is an important and safe modality to use in patients with EVD, and in the austere settings often found in disaster settings.

Intraosseous Vascular Access Bibliography

Case Studies

Rottenstreich M, Malka I, Glassberg E, Schwartz O, Tarif B. Pre-hospital intra-osseous freeze dried plasma transfusion: a case report. Disaster and Military Medicine 2015;1(8):1-3

935

Case report of a 13 year old girl suffering from severe hemorrhagic shock due to blast injuries and gun shot wounds that received freeze-dried plasma via IO access as part of prehospital resuscitative efforts. Her vital signs improved upon arrival to the hospital; and she was released after 3 weeks of hospitalization.

Sampson CS, Bedy S-M. Lipid emulsion therapy given intraosseously in massive verapamil overdose. Am J Emerg Med 2015;33(12):1844.e1.doi: 10.1016/j.ajem.2015.04.061

767

A case study report of a 24-year old female who presented to the emergency department after consuming an over dose amount of verapamil. Central and peripheral venous access were obtained for delivery of vasopressors and intravenous fat emulsion 20% (IFE). IFE was initiated via peripheral IV (PIV) access but access was lost; administration through central access was not possible due to the potential drug interaction. Intraosseous (IO) access was established using the Arrow EZ-IO system in the proximal tibia without complication and IFE administration was resumed. The patient reported some pain with infusion. After half the bolus administration was delivered, the infusion pump alarmed due to inadequate flow. PIV access was obtained and IFE administration was resumed using the newly obtained access route. The authors suggested that the viscosity of the medication may have caused the delivery failure by infusion pump through the IO route and recommend slowing down the bolus rate of infusion for clinicians attempting this route for IFE administration in the future.

Suominen P, Nurmi E, Lauerma K. Intraosseous access in neonates and infants: Increased risk of compartment syndrome and leg amputation. Resuscitation 2015;96(Suppl 1):S131-2. http://dx.doi.org/10.1016/j.resuscitation.2015.09.313

1024

This is an abstract of a study that analyzed possible technical and anatomical factors leading to the complication of amputation as a result of IO placement. The study was prompted by a case report of amputation in a neonate after IO access using the EZ-IO device. The study measured medullary diameter of the proximal tibia at the recommended IO access site in three groups: 1-28 day old full term neonates, 1-12 month old infants, and 3-4 year old children. The mean diameter in each group was 7.7 mm, 9.9 mm, and 12.4 mm, respectively. The small size of the IO space, especially in neonates and infants, makes correct placement difficult. As such, complications should be taken into consideration in this patient population.

Suominen PK, Nurmi E, Lauerma K. Intraosseous access in neonates and infants: risk of severe complications- a case report. Acta Anaesthesiologica Scandinavica 2015;59(10):1389-93. doi: 10.1111/aas.12602

769

This case study describes a neonate who suffered a cardiac arrest, had return of spontaneous circulation (ROSC) and was treated with multiple medications and therapeutic hypothermia. The patient had received three IO needle insertions, one in the left tibia that was removed following swelling with bolus injection; one in the left distal femur that dislodged with movement of the patient's legs; and one in the right proximal tibia. Twenty-four hours after initial IO needle placement the child developed pallor and discoloration and was diagnosed with compartment syndrome to the right lower extremity. Five days post-IO insertion a below the knee amputation was performed. Medications infused via the IO access included epinephrine and norepinephrine infusions.

YEAR: 2014

Barlow B, Kuhn K. Orthopedic management of complications of using IO catheters. Am J Orthop 2014;43(4):186-90

694

Literature search for complications associated with IO access included 5759 patients with overall complication rate of 2.1 %. Two cases involving retained needle fragment discussed; one with a proximal tibial EZ-IO that required surgical removal. Authors concluded IO catheters are reliable tools for fluid and drug delivery to critically ill patients with low complication rates (which can be potentially serious but managed).

Chansa E, Kansen K, Gustafsson B. [An intraosseous blood transfusion in a critically ill child] Une transfusion sanguine par voie intraosseuse chez un enfant gravement malade. Afr J Emerg Med 2014;4(2):83-5. https://doi.org/10.1016/j.afjem.2013.05.003

658

This article describes a case study of a 31-month old infant that suffered hypovolemic shock due to severe epistaxis. After several failed peripheral and central line attempts an 18g needle was inserted intraosseously through the proximal tibia. The child received 300 mL of Ringer's Lactate in one hour then 200 mL of blood via the IO route by syringe boluses resulting in improvement. Cloxacillin was also administered IO as prophylaxis for infection. Authors conclude an IO blood transfusion should be the immediate intervention in similar life-threatening situations.

Zambia

Danz M, Schulz G, Hinkelbein J, Braunecker S. Breaking the needle: A rare complication on EZ-IO removal. Eur J Anaesthesiol 2014;31:172-80

742

This letter to the editor describes a single case of a needle breaking off after a proximal tibial insertion of the EZ-IO into a volunteer (one of the letter's authors) during a training session. "Divergent from manufacturer instructions the sterile steel stylet was put back into place to achieve better grip for a manual pull-out. Under steady pull in strict axial alignment and gentle clockwise turn, the needle broke away from the plastic connector". The needle was extracted using combination pliers and there is no evidence of damage to the leg. Authors acknowledge this can be avoided by adherence to manufacturer's directions for use.

Germany

Intraosseous Vascular Access Bibliography

Case Studies

- Fowler RL, Lippmann MJ. Benefits vs risks of intraosseous vascular access. Patient Safety Network** 977
<https://psnet.ahrq.gov/webmm/case/331> Published July-August 2014. Accessed August 6, 2018
 This is a discussion of a case study involving a hospitalized woman who had an IO line placed during a code after becoming unresponsive. Several unsuccessful attempts at peripheral venous access were made prior to IO access. The patient was diagnosed 3 hours later with compartment syndrome due to extravasation that required complex ongoing care in the ICU for 2 months.
- Lewis P, Wright C. Saving the critically injured trauma patient: a retrospective analysis of 1000 uses of intraosseous access.** 714
Emerg Med J 2014;31(9):784. doi:10.1136/emmermed-2014-203588
 This retrospective study reported IO use over a 7-year period during combat operations in Afghanistan by the UK Defence Medical Services. The EZ-IO and FAST1 IO devices were available for use; IO use data was collected from the front line, during helicopter evacuation and at the combat hospital. A total of 1014 IO devices were inserted into 830 adult patients; various medications infused via IO access are listed. Across all cases there were no serious IO complications and 14 minor complications. The author concluded that in the pre-hospital setting in particular and in severely injured trauma patients, IO access should be considered a primary method of obtaining vascular access.
- Lingner M, Niederer O, Majolk J, Kromholz K. Kasuistik: Die intraossare infusion als alternative in der sepsistherapie beim erwachsenen [Case report: Intraosseous infusion as an alternative solution in the therapy of septicemia in an adult]. Anesthesiol Intensivmed Notfallmed Schmerzther.** 698
 2014;49(2):100-3. doi:10.1055/s-0034-1368674
 Case study of 36 year-old in septic shock with co-morbidities of IV drug abuse, endocarditis, tricuspid valve insufficiency and pulmonary embolism. Initially impossible to obtain PIV or CVC access; then unable to give desired fluids through 22 gauge PIV when finally placed. Proximal humerus IO access was established with the EZ-IO 45 mm needle set and the patient was resuscitated with 30 mL/kg fluids and multiple medications given in first hour. Conclusions included that CVCs are not always possible and volume treatment with an IO placed sooner rather than later, especially in children but also in adults, can be lifesaving. IO systems should be extensively available throughout the clinical setting. Article in German.
 Germany
- Oesterlie GE, Petersen KK, Knudsen L, Henriksen TB. Crural amputation of a newborn as a consequence of intraosseous needle insertion and calcium infusion. Ped Emerg Care** 699
 2014;30(6):413-4
 Case study of newborn girl resuscitated with 15 mm EZ-IO catheter placed to her right proximal tibia. Medications given included antibiotics, "fluids" and calcium. Demarcation of the infants skin was noted immediately post-calcium administration; with progression to necrosis. Trans-tibial amputation was performed 1.5 months after initial IO access. Authors concluded calcium extravasation most likely caused the injury but were unable to identify extravasation cause; citing possible needle displacement. Cautionary steps to reduce risk emphasized by authors.
 Denmark
- Swaney PM, Nayman BD, Cabanas JG, Myers JB. Fatal myocardial ischemia in a 12-year-old secondary to fibromuscular dysplasia. Am J Emerg Med** 693
 2014;32(7):812.e5-7. doi:10.1016/j.ajem.2013.12.027
 A case study report describing a 12-year-old male who expired following a fatal myocardial ischemia. The patient complained of severe chest pains within the week prior to the event and was misdiagnosed as having GERD. ECG by first responders showed STEMI; IO access was established in the PT for vascular access.
- YEAR: 2013**
- Ahrens KL, Reeder SB, Keevil JG, Tupesis JP. Successful computed tomography angiogram through tibial intraosseous access: a case report. J Emerg Med** 932
 2013;45(2):182-5. doi: 10.1016/j.jemermed.2012.11.091
 Case report of 54-year-old male obtunded patient requiring a CT angiogram to diagnosis a suspected massive pulmonary embolism. After several failed attempts to reestablish PIV access, 150mL of contrast were injected through the proximal tibia IO catheter placed by EMS. Excellent opacification of the pulmonary arteries was achieved and there were no immediate complications from the injection noted.
- d'Heurle A, Archdeacon MT. Compartment syndrome after intraosseous infusion associated with a fracture of the tibia. The Journal of Bone and Joint Surgery, Incorporated Case Connect** 651
 2013;3(1):e20. <http://dx.doi.org/10.2106/JBJS.CC.L.00231>
 Case study of adult multi-trauma patient that had an intraosseous device placed to a fractured left tibia and developed compartment syndrome. Authors concede it is unclear if the fluid infused through the IO device caused the compartment syndrome or if it was due to the multiple-fractures in the tibia. Authors advise against placing an IO line in an injured limb and mention the proximal humerus and sternum as alternative IO sites.

Intraosseous Vascular Access Bibliography

Case Studies

- Fetissov H, Nadaud J, Landy C, Millot I, Paris R, Plancade D. Amines on intraosseous vascular access: A case of skin necrosis. *Ann Fr Anesth Reanim* 2013;32(5):e89-90.<http://dx.doi.org/10.1016/j.annfar.2013.02.022>** 644
- A letter to the editor reporting a case study of skin necrosis after IO administration of norepinephrine following resuscitation of a 74 years old in septic shock. The EZ-IO was placed to the proximal tibia; approximately 45 minutes post- norepinephrine administration symptoms of necrosis were evident.
- Authors cite 3 hypotheses for the cause of necrosis and consider that amines' high level concentration could induce local toxicity in the bone matrix and artery spasm; suggesting it is necessary to define an upper limit of amines' concentration that should be administered through IO vascular access.
- Frascone RJ, Salzman JG, Ernest EV, Burnett AM. Use of an intraosseous device for invasive pressure monitoring in the ED. *Am J of Emerg Med* 2014;32(6):692.e3-692.e4.[doi:10.1016/j.ajem.2013.12.029](http://dx.doi.org/10.1016/j.ajem.2013.12.029)** 667
- A case study describing intraosseous pressure monitoring, through tibial IO access, using a standard arterial pressure monitoring transducer during resuscitation of a 31-year-old male in cardiac arrest. Pressure readings were recorded for approximately 53 minutes and were compared to non-invasive blood pressure cuff monitoring at the same time points. IO systolic, diastolic and mean IO pressures were approximately 40% of arterial pressures. This is the first case report demonstrating IO space has a measureable blood pressure and it correlates with pressure obtained through conventional techniques.
- Hamed RK, Hartmans S, Gausche-Hill M. Anesthesia through an intraosseous line using an 18-gauge intravenous needle for emergency pediatric surgery. *J Clin Anesth* 2013;25(6):447-51;[pii: S0952-8180\(13\)00202-X. doi: 10.1016/j.jclinane.2013.03.013](http://dx.doi.org/10.1016/j.jclinane.2013.03.013).<http://dx.doi.org/10.1016/j.jclinane.2013.03.013>. Accessed September 3, 2013** 670
- This 30 pediatric patient case series describes use of IO access in the perioperative setting when peripheral and central venous access failed during anesthesia administration for emergency surgery. Due to unavailability of modern IO devices, a standard 18-gauge IV needle with a handmade IV extension set were used to establish IO access. The authors reported administering ketamine, succinylcholine, pancuronium, atracurium, halothane, neostigmine, atropine, blood products, fluids and hydrocortisone through the IO line without complication. The authors concluded that although it is not the first-line method for anesthesia, IO access should be considered by pediatric anesthesiologist when peripheral and central venous access has failed or is difficult.
- Iraq*
- Plancade D, Millot I, Fetissov H, et al.. Sternal perforation with an intraosseous device and hemomediastinum infusion *Ann Fr Anesth Reanim* 2013;<http://dx.doi.org/10.1016/j.annfar.2013.01.009>** 616
- A 45-year-old woman in hemorrhagic shock with multiple injuries to the limbs, secondary to a war wound, received sternal IO access using the Jamshidi trocar (not specifically intended for sternal use). After initiating a blood transfusion through the IO line a contrast CT scan revealed sternal perforation and hemomediastinum, secondary to the transfusion, as well as drainage into the left pleural cavity. The catheter was removed, right thoracic drainage was performed, and the patient was released from ICU 48 hours later. The authors conclude this case report demonstrates the difficulty in selecting emergency insertion sites and the necessity of choosing an appropriate IO catheter.
- Pozza M, Lunardi F, Pflipsen M. Emergency intraosseous access: a useful, lifesaving device use in Afghanistan. *J Spec Oper Med* 2013;13(1):25-8** 684
- A case study describing use of the EZ-IO in Afghanistan by US military on 5 patients with traumatic injury including one pediatric patient. Access was obtained in the proximal tibia on first attempt and was used to administer crystalloids in all patients along with opioids, analgesics and antibiotics. All ultimately received central venous access and peripheral access was established in one patient. There were no IO complications.
- Spencer TR. Intraosseous administration of thrombolytics for pulmonary embolism. *J Emerg Med* 2013;45(6):e197-e200. <http://dx.doi.org/10.1016/j.jemermed.2013.05.057>** 682
- A case report describing administration of thrombolytics via tibial IO vascular access for pulmonary embolism in a 36-year-old woman. Due to the emergent nature of the situation, IO access was determined to be the best option for immediate vascular access. Alteplase was administered through the IO line at 100 mg over 2 hours without complication. The patient successfully recovered and was discharged from the hospital on day 7 without long-term disability. The author concluded that this case study raised the potential use of IO lines to deliver thrombolytics in patients with massive pulmonary embolism and that further evaluation is needed to compare the risk and benefits of the alternative method of administration.
- Weiser G, Poppa E, Katz Y, Bahouth H, Shavit I. Intraosseous blood transfusion in infants with traumatic hemorrhagic shock - a case report and review of the literature. *Am J Emerg Med* 2013;31(3):640.e3-4. [doi: 10.1016/j.ajem.2012.10.036](http://dx.doi.org/10.1016/j.ajem.2012.10.036)** 646
- This article describes a case study of a 5-month old infant that suffered a head injury resulting in shock. She received 100 mL of red blood cells via the EZ-IO in the proximal tibia, resulting in rapid hemodynamic improvement. A literature search was completed for cases of IO blood transfusion in pediatric trauma. Authors note IO availability and knowledge play an important role in hemorrhagic shock; and RBC infusions via the IO route are feasible in this age group.

Intraosseous Vascular Access Bibliography

Case Studies

YEAR: 2012

Cote C, Dumont M, Gagnon JA. Abnormal bone scanning following intraosseous access. *Medecine Nucleaire* 2012; doi:10.1016/j.mednuc.2012.02.175 537

This case study describes a 12 month boy who received IO access for administration of anticonvulsant therapy. Three days post IO infusion sensitivity to the leg was noted and the child returned to the ED. Blood work showed elevated white blood counts and C-reactive protein. A bone scan showed a small round lucency at the site of IO access. Two weeks later, x-rays were normal. The authors suggest that IO access may cause an increased uptake on bone scan in absence of osteomyelitis.

Goodman IS, Lu CJ. Intraosseous infusion is unreliable for adenosine delivery in the treatment of supraventricular tachycardia. *Pediatr Emerg Care* 2012;28(1):47-8 524

Physicians from two different emergency department settings reported 2 cases of supraventricular tachycardia (SVT) in infants (2 and 4 month old) in which IO administration of adenosine failed to convert SVT to a normal rhythm.

Helm M, Goller R, Hackenbroch C, Hossfeld B. A complication of the use of an intra-osseous needle. *Emerg Med J* 2012;29:923. doi: 10.1136/emmermed-2011-200139 1054

This is a case report of needle sheering associated with the use of the FAST-1 intraosseous infusion system. A soldier successfully placed a FAST-1 needle in the sternum of a healthy volunteer soldier during a training session. Upon completion of the training session, the soldier was unable to remove the needle. The retained needle was later removed surgically at a field hospital.

Landy C, Plancade D, Gagnon N, Schaeffer E, Nadaud J, Favier JC. Complication of intraosseous administration of systemic fibrinolysis for a massive pulmonary embolism with cardiac arrest. *Resuscitation* 2012;83(6):e149-50. doi: 10.1016/j.resuscitation.2012.01.044 547

This letter to the editor describes a case in which a 53-year-old male in ventricular fibrillation received IO access via the EZ-IO in the ED with suspected massive pulmonary embolism. The patient was successfully resuscitated. Necrosis of the anteromedial side of the leg, at the IO site, presented 48 hrs post IO use. After 18 weeks the patient underwent surgical grafting. The authors linked the necrosis to adrenaline extravasation and local ischaemia. While the authors conclude that thrombolysis or repeated high doses of adrenaline should be given via the IO route when needed, it is not without the risk of complication.

Plancade D, Nadaud J, Lapierre M, et al. Feasibility of a thoraco-abdominal CT with injection of iodinated contrast agent on sternal intraosseous catheter in an emergency department. *Annales Francaises d'Anesthesie et de Reanimation* 2012;http://dx.doi.org/10.1016/j.annfar.2012.10.009 580

This letter to the editor describes a case in which sternal IO access was established using a Jamshidi needle to administer iodinated contrast for a thoraco abdominal CT on a 61-year old male who presented to the ED with respiratory distress. Picture quality was deemed excellent by the radiologists. The authors conclude that the sternal IO route can be used with excellent picture quality but it should be used only in exceptional cases due to the potential risks of a high-power injection through the bone. EZ-IO is mentioned as an alternative IO device available.

Severyn FA. Complication after intraosseous needle removal following successful systemic thrombolysis for a massive pulmonary embolism. *Resuscitation* 2012;83(11):e207. doi:10.1016/j.resuscitation.2012.07.014 575

This letter to the editor is written in response to the case report by Landy titled, Complication of intraosseous administration of systemic thrombolysis for a massive pulmonary embolism with cardiac arrest. The author suggests that the tissue necrosis described by Landy may have been due to the removal of the IO needle while there was still significant fibrinolytic activity at the needle insertion site. The author suggests a change in medical care after return of spontaneous circulation (ROSC) in patients following thrombolytic administration through IO access to convert the functioning IO line to a non-flowing saline lock. The EZ-IO was used to provide IO access in the case report by Landy.

YEAR: 2011

Auerhammer J. [Lebensbedrohliche arterielle blutung aus der a. carotis communis: Fallstricke bei der intraossaren punktion]. *Notfall Rettungsmedizin* 2011;14(2):147-150;doi 10.1007/s10049-010-1380-1. German 490

This article in German presents a case of a 67-year-old female patient with an arterial bleed and venous access difficulties in whom IO access was attempted unsuccessfully two times using two different IO systems. The author concluded that IO success is dependent upon IO anatomy and physiology knowledge as well as knowledge of the device being used.

Brisson M. Trauma and the military medic. *EMS1.com* 12/01/2011 528

This article describes use of IO access along with other prehospital interventions in a traumatically wounded soldier in a combat zone. The IO site used was the proximal humerus as the patient had 3 of 4 limbs traumatically amputated.

Intraosseous Vascular Access Bibliography

Case Studies

- Chatterjee DJ, Bukunola B, Samuels TL, Induruwage L, Uncles DR. Resuscitation in massive obstetric haemorrhage using an intraosseous needle. *Anaesthesia* 2011;66(4):306-10. doi:10.1111/j.1365-2044.2011.06629.x** 472
- The case report describes a woman experiencing massive hemorrhaging following emergency caesarean delivery. Though the patient possessed a peripheral IV catheter, additional IV access was needed and gained through the proximal humerus IO space using an EZ-IO. This vascular stabilization and additional filling of the central volume through the IO route allowed placement of a subclavian central line. Authors concluded that a key to the resuscitation process was the rapid utilization of the IO.
- Cotte J, Prunet B, d'Aranda E, Asencio Y, Kaiser E. [A compartment syndrome secondary to intraosseous infusion]. *Ann Fr Anesth Reanim* 2011;30(1):90-1. doi: 10.1016/j.annfar.2010.05.038. French** 691
- A case study report in French describing compartment syndrome secondary to intraosseous infusion in a 57-year-old burn patient. IO access was established in the proximal tibia on second attempt; both attempts were made in the same limb though it was noted that the first attempt did not penetrate the cortex. Drug and fluid infusion was initiated; ten hours later the limb was found to appear ischemic. The IO catheter was removed and compartment release was performed. The author concluded that IO access remains an important mode of vascular access and that adherence to contraindications and careful clinical monitoring should decrease risk of complications.
- France
- de Vogel J, Heydanus R, Mulders AGM, Smalbrakk DJC, Papatsonis DNM, Gerritse BM. Lifesaving intraosseous access in a patient with a massive obstetric hemorrhage. *Am J Perinatol Rep* 2011;1(2):119-122. doi: <http://dx.doi.org/10.1055/s-0031-1293514>** 541
- Case study of a 42 year-old woman with massive obstetric hemorrhage ultimately resulting in postpartum hysterectomy. Massive blood loss and inability to stop bleed prevented sufficient resuscitation via established PIV lines. IO access was established with the EZ-IO and used for fluid replacement and administration of cardiac resuscitation drugs. Fluid administered through IO access was 75% of the total infusion volume.
- Henson NL, Payan JM, Terk MR. Tibial subacute osteomyelitis with intraosseous abscess: an unusual complication of intraosseous infusion. *Skeletal Radiol* 2010;40(2):239-42. doi:10.1007/s00256-010-1027-9** 462
- This report describes the case of a 62-year-old man who received emergency tibial IO infusion without complication in the pre-hospital setting and presented to the ED 6 months later complaining of shin pain. MRI and culture findings were diagnostic of subacute osteomyelitis with IO abscess. The patient had a history of multiple chronic health problems including diabetes type II, MGUS, and positive MRSA colonization dating back two years prior. The authors concluded that the occurrence of osteomyelitis with IO abscess may increase as a result of increased pre-hospital use of IO infusion in adult patients with multiple comorbidities.
- Heyder-Musolf J, Giest J, Straub J. Kasuistik-Intraossärer Zugang bei einem 1300 g schweren septischen Neugeborenen[Case history-Intraosseous access on a 1300 g septical premature infant]. *Anesthesiol Intensivmed Notfallmed Schmerzther* 2011;46(10):654-7. doi: 10.1055/s-0031-1291943. [German]** 864
- Case description of a critically ill 15 day old premature infant weighing 1300 g. Tibial IO access was placed perioperatively for an urgent surgery.
- Howarth D. Adult intraosseous access: experiences in a remote emergency department. *Australian Family Physician* 2011;40(7):510-1** 483
- In this article, the author makes a supporting case for remote emergency departments to stock adult intraosseous kits by referencing two adult septic shock cases in which IO access was used for rapid IV fluid replacement as well as IV antibiotics and inotrope support.
- Khan LAK, Anakwe RE, Murray A, Godwin Y. A severe complication following intraosseous infusion used during resuscitation of a child. *Inj Extra* 2011;doi:10.1016/j.injury.2011.05.015** 485
- This article describes the case of an 11-year-old boy who suffered compartment syndrome of the lower leg following use of the EZ-IO for resuscitation and 24 hours of intraosseous infusion of adrenaline, calcium and potassium. The author concluded that further work is needed to develop recommendations for maximum duration, dose, volume and rates for intraosseous infusion.
- Knuth TE, Paxton JH, Myers D. Intraosseous injection of iodinated computed tomography contrast agent in an adult blunt trauma patient. *Ann Emerg Med* 2011;57(4):382-6. doi:10.1016/j.annemergmed.2010.09.025** 463
- This article reports a case in which IO access was used to deliver intravenous contrast agent in an adult blunt trauma patient. After placement in the proximal humerus, contrast agent was administered via the IO route, and clinicians found the CT scans of the thorax, abdomen, and pelvis to be adequate for diagnostic purposes and subjectively equivalent to those of studies using central venous access. There were no complications and the authors concluded that IO access appeared to be an effective alternative to traditional venous access for administering contrast agents for CT evaluation in adult blunt trauma patients.

Intraosseous Vascular Access Bibliography

Case Studies

Navarro Suay R, Bartolome Cela E, Hernandez Abadía de Barbará A, Tamburri Bariain R, Rodriguez Moro C, Olivera Garcia J. *[Intraosseous access for fluid therapy in combat situations: use by Spanish military medical staff in Afghanistan]. Rev Esp Anestesiología y Reanimación 2011;58(2):85-90* 645

This article in Spanish describes the Spanish military medical staff's experience with the use of intraosseous lines for fluid therapy in a combat zone from March 2007 to June 2008. Twenty-five patients had an IO placed with the Bone Injection Gun (BIG). Placement success rates were 76% for the 19 pre-hospital placements and 100% for the 6 in-hospital placements. There were no complications during insertion. Conclusion was intraosseous access can provide an alternative to venous access for treating trauma patients in combat zones.

Ruiz-Hornillos PJ, Marínez-Camara F, Elizondo M, et al. *Systemic fibrinolysis through intraosseous vascular access in ST-segment elevation myocardial infarction. Ann Emerg Med 2011;57(6):572-4. doi:10.1016/j.annemergmed.2010.09.011* 496

This article describes a case in which systemic fibrinolysis was administered through the intraosseous route in a patient with ST-segment elevation myocardial infarction. Fibrinolytics and antiarrhythmic drugs were administered through the IO line, resulting in resolution of coronary ischemia and electrical instability, without complications. Authors concluded that intraosseous cannulation represents a novel route for administration of systemic fibrinolysis in cases of difficult peripheral venous access in the out-of-hospital setting.

Taylor CC. *Amputation and intraosseous access in infants. BMJ 2011;342:d2778. doi:10.1136/bmj.d2778* 484

This article describes two cases of leg amputation after intraosseous infusion in a 5-month-old girl and a 17-month-old boy. The author concluded that fluid extravasation, exacerbated by tibial fracture and needle dislodgement during transportation, caused limb ischemia in these two patients, and that adherence to the principles of careful needle placement, splinting/securing the catheter and limb, limited length of infusion and repeated monitoring of the limb will help avoid this devastating complication.

Wechselberger G, Radauer W, Schimpl G, et al. *Lower limb salvage in a 7-month-old infant using free tissue transfer. J Ped Surg. 2011;46:1852-4. Doi:10.1016/j.jpedsurg.2011.06.037* 625

A 7-month-old male infant in septic shock from *Neisseria meningitidis* experienced a complication of bilateral extravasation of noradrenalin at the proximal tibia intraosseous infusion site resulting in severe soft tissue necrosis. Necrosectomy was performed bilaterally and surgical interventions were successfully performed to salvage both limbs. At 19 months the patient was able to crawl without extension deficit.

YEAR: 2010

Dasgupta S, Playfor S. *Intraosseous fluid resuscitation in meningococcal disease and lower limb injury. Pediatr Rep 2010;2(1):e5:18-9* 426

Authors reviewed two complications (extravasation and compartment syndrome) associated with IO access in children with meningococcal disease. Authors concluded that IO systems need formal evaluation to assess safety and complication profiles.

Hiller K, Jarrod MM, Franke HA, Degan J, Boyer LV, Fox FM. *Scorpion antivenom administered by alternative infusions. Ann Emerg Med 2010;56(3):309. doi:10.1016/j.annemergmed.2010.04.007* 471

This letter to the editor describes 2 cases in which IV administration of antivenom was not possible and was thereby administered via IO route, and in one case via the intramuscular route as well. In both cases the patients recovered.

Mitchell C, Tauferner D, Huebner K. *Placement of the EZ-IO sternal and EZ-IO manual needle sets with and without chemical protective equipment: a cadaveric study. Prehosp Emerg Care 2010;14:14-5* 448

In this abstract of a study presented at the 2010 National Association of EMS Physicians Meeting, researchers describe a study in which sternal and tibial IO devices were evaluated with and without chemical protective equipment. Researchers concluded that the use of the protective equipment did not affect the success rate or time to placement for the two IO devices.

Mosier JM, Hiller K, Franke H, Degan J, Boyer LV. *Scorpion antivenom administered via alternative infusions. J Med Toxicol 2010;6:249* 799

A case study describing administration of scorpion antivenom via intraosseous (IO) vascular access in a 16-month old female. Following failure to obtain IV access in pre-hospital and upon arrival at the ED, IO vascular access was established in the proximal tibia and 3 vials of antivenom in 50 mL saline were administered over 10 minutes. Within 5 minutes, the patient's respiratory status improved, intubation was averted, and vital signs stabilized immediately; nystagmus and writhing resolved. The patient was discharged home after a short observation period. The authors concluded that when IV access is difficult, IO access may be a rapid and reasonable rescue maneuver for patients requiring scorpion antivenom.

Navarro K. *Intraosseous infusion. Texas EMS Magazine 2010;Nov/Dec:34-9* 447

This article provides a brief history of IO infusion and further discusses this vascular access technique in terms of anatomy and physiology, indications and contraindications, performing the manual procedure, and possible complications. A case study is discussed in which a 7-month-old male was treated under emergency circumstances with IO infusion in the lower limb and developed compartment syndrome, resulting in a below the knee amputation.

Intraosseous Vascular Access Bibliography

Case Studies

Valdes M, Araujo P, de Andres C, Sastre E, Martin T. Intraosseous administration of thrombolysis in out-of-hospital massive pulmonary thromboembolism. *Emerg Med J* 2010;27(8):641-4. doi:10.1136/emj.2009.086223 434

This case study describes a 25 year-old woman who had a massive pulmonary thromboembolism and was administered thrombolysis via IO route (internal tibial malleolus) in the air-transfer pre-hospital setting. The patient recovered.

Werner M, Daniel HP, Hoitz J. [Intraossärer zugang beim innerklinischen notfall intensivmedizinischer fallbericht]. *Der Anaesthetist* 2010;59(7):628-32. German 448

This article in German reports a case of IO access performed in the ICU due to difficult peripheral access. The authors suggested that based on this case different strategies of critical care and possible improvements should be made. .

YEAR: 2009

Burgert JM. Intraosseous infusion of blood products and epinephrine in an adult patient in hemorrhagic shock. *AANA J* 2009; 77: 359-63 435

Case report of IO infusion in 79-year old woman with hematemesis after intestinal surgery.

Fenton P, Bali N, Sargeant I, Jeffrey SLA. A complication of the use of an intra-osseous needle. *J R Army Med Corps* 2010;155(2):110-1 450

This case report describes a complication of use of a sternal IO device (FAST-1, Pyng Medical Corporation, Richmond, Canada) in a 21-year-old soldier who suffered multiple soft tissue fragmentation injuries, in which the needle tip broke in situ. The author concluded the complication resulted from the IO needle being placed when the patient was lying in a lateral position with the skin over the manubrium displaced from the midline.

Fortin JL, Capellier G, Manzon C, Giocanti J, Gall O. Intraosseous administration of hydroxocobalamin in the acute treatment of cyanide poisoning. *Burns* 2009;35(S1):S15-6. doi: 10.1016/j.burns.2009.06.061. France 801

Case study of a 9- month old treated with IO hydroxocobalamin for suspected smoke inhalation cyanide poisoning. The patient was discharged from the ICU without neurological sequelae. Authors stated the IO route for hydroxocobalamin warrants further exploration to improve ease and speed of treatment.

Nutbeam T, Fergusson A. Intraosseous access in osteogenesis imperfecta (IO in OI). *Resuscitation* 2009;80(12):1442-3. doi:10.1016/j.resuscitation.2009.08.016 408

This article describes a case in which IO access, using the EZ-IO, was attempted in a patient with osteogenesis imperfecta. In each of 3 attempts, the needle became loose immediately after IO insertion. The author acknowledged that during emergencies it is difficult to assess and consider every possible contraindication for every intervention; and that IO access using the EZ-IO is the author's choice for emergency vascular access when peripheral access is difficult or has failed.

Sarkar D, Philbeck T. The use of multiple intraosseous catheters in combat casualty resuscitation. *Mil Med* 2009;174:106-8 418

This case study describes injuries sustained in Iraq by an American soldier, and the concurrent use of 4 IO devices to resuscitate and stabilize him.

Semjen F, Dobremez E, Bordes H. How to assess the correct position of intraosseous access? A case report. *Arch Pediatr* 2009; 16: 1298-300. [French] 432

Article in French. English translation not available.

Tsung HW, Blaivas M, Stone MB. Feasibility of point-of-care colour Doppler ultrasound confirmation of intraosseous needle placement during resuscitation. *Resuscitation* 2009;80:665-8 425

Color Doppler ultrasound revealed extraosseous flow in incorrectly placed IO insertions. Recommends point-of-care Doppler machine to verify placement.

Weiss M, Henze G, Eich C, Neuhaus D. Intraossare infusion: Eine wichtige technik auch fur die kideranasthesie [Intraosseous infusion: an important technique also for paediatric anaesthesia]. *Anaesthetist* 2009;58(9):863-75.doi. 10.1007/s00101-009-1605-1 German 434

Discusses use of IO for pediatric anesthesia. Specifies importance of equipment, education, guidelines.

YEAR: 2008

Alawi KA, Morrison GC, Fraser DD, Al-Farsi S, Collier C, Kornecki A. Insulin infusion via an intraosseous needle in diabetic ketoacidosis. *Anaesth Intensive Care* 2008;36:110-2 408

Case report of resuscitation and insulin infusion in a 5-year old child with severe diabetic ketoacidosis.

Intraosseous Vascular Access Bibliography

Case Studies

- Gayatri J, Tobias JD T. The use of intraosseous infusions in the operating room. J Clin Anesth 2008;20:469-73** 979
This article presents a case study of an IO infusion during the anesthetic care of an infant with cyanotic congenital heart disease (CHD). The article also discusses the role of the IO route in perioperative care and reviews the adverse effect profile.
- Joseph G, Tobias JD. The use of intraosseous infusions in the operating room. J Clin Anesth 2008;20:469-73** 412
Case report of anesthetic use of IO infusion in a 8-month old infant during surgery.
- Langley DM, Moran M. Intraosseous needles: They're not just for kids anymore. J Emerg Nurs 2008; 34:318-9** 370
Case reports in which intraosseous (IO) vascular access was successfully used on adults. Summarizes indications for use, complications, and precautions/considerations.
- Moen TC, Sarwark JF. Compartment syndrome following intraosseous infusion. Orthopedics 2008; 31: 815** 411
Case report of compartment syndrome in a 6-year old girl after IO infusion during cardiac arrest.
- van Rijn RR, Knoester H, Maes A, van der Wal AC, Kubat B. Cerebral arterial air embolism in a child after intraosseous infusion. Emerg Radiol 2008;15:259-62. doi:10.1007/s10140-007-0681-2** 410
In this case study a 7-month-old female with comorbidities was taken to the ED in cardiopulmonary arrest. IO access was the only vascular access method available for resuscitation. Post mortem CT of the head showed a considerable amount of air within the arterial circulation; the cause of death was listed as undetermined. The authors conclude that considering the details of the patient, the only logical explanation for the cerebral arterial air embolism is that air was introduced into the bloodstream via the IO route.
- YEAR: 2007**
- Hillewig E, Aghayev E, Jackowski C, Christe A, Plattner T, Thali MJ. Gas embolism following intraosseous medication application proven by post-mortem multislice computed tomography and autopsy. Resuscitation 2007;72:149-53** 530
This case study describes a 4-month-old boy that was found unresponsive. Resuscitation was started and continued through arrival to the ED; IO access at the proximal tibia was established using a 15 gauge aspiration needle as the only vascular access. Post mortem multislice CT examination showed gas in the hepatic veins, the right atrium, right ventricle, the upper pole of the right kidney and the cerebral vessels. Though air embolism was ruled out as the cause this death, it could have caused death in another case. The authors conclude that gas may have entered the body during resuscitation due to IO needle disconnections and that resuscitation with an inserted, disconnected IO needle should be avoided.
- YEAR: 2006**
- Tomar S, Gupta BA. Resuscitation by intraosseous infusion in newborn. MJAFI 2006;62(2):202-3** 393
Two case studies of neonates that successfully received IO infusion.
- YEAR: 2005**
- Koschel MJ. Emergency: Sternal intraosseous infusions. Am J Nurs 2005;105(1):66-8** 333
Nursing article discussing the utility of the sternum as a site for IO infusion. Includes clinical indications, insertions techniques, contraindications, potential complications, post-insertion care and considerations for discontinuing the sternal device.
- Ritz J. [Vascular access in emergency paediatric anaesthesia]. Anaesthesist 2005;54(1):8-16. German** 336
Case studies in 2 children reviewed by 89 members of the Swiss Pediatric Anesthesia and heads of Anesthesia Departments of Swiss Teaching hospitals, IO was determined to be the safest method of vascular access on 1 of the cases.
Abstract only
- YEAR: 2004**
- Dogan A, Irmak H, Harman M, Ceylan A, Akpınar F, Tosun N. Tibial osteomyelitis following intraosseous infusion: a case report. Acta Orthop Traumatol Turc 2004; 38:357-60** 324
Case report of acute osteomyelitis developing 10 days after IO infusion in a 5-month-old infant admitted for sepsis.
- Schwartz SB, Kleid DM. Fictitious fracture after infusion of intravenous contrast material via an intraosseous needle. Pediatr Emerg Care 2004;20:829-31** 388
Case report of misdiagnosis of a bone fracture as a result of IO infusion of radiographic contrast material in the involved extremity.

Intraosseous Vascular Access Bibliography

Case Studies

YEAR: 2003

Bowley DM, Loveland J, Pitcher GJ. Tibial fracture as a complication of intraosseous infusion during pediatric resuscitation. J Trauma 2003; 55: 786-7 298

Case report of IO infusion complicated by iatrogenic fracture at the IO insertion site. Concludes that multiple attempts to achieve IO access weakened the bone cortex and that "considerable force" applied by an anxious 100-kg emergency room doctor led to the fracture.

Frascone R, Kaye K, Dries D, Solem L. Successful placement of an adult sternal intraosseous line through burned skin. J Burn Care Rehabil 2003;24:306-8 304

Case report of a patient in asystolic arrest successfully resuscitated with an IO line inserted through deeply burned skin without complication. After multiple failed IV attempts, IO access was the only viable method of vascular access.

Lake W, Emmerson AJB. Use of a butterfly as an intraosseous needle in an oedematous preterm infant. Arch Dis Child Fetal Neonatal Ed 2003;88(5):F409 307

An 18 gauge butterfly needle was inserted into the proximal tibia of a premature infant born at 25-weeks gestation, following inability to establish other modes of vascular access due to gross oedema. The intraosseous line was left in place for 6 days until it was lost; there were no adverse events reported however the author noted that no safety data on long term use of the device was collected.

Launay F, Paut O, Katchburian M, Bourelle S, Jouve JL, Bollini G. Leg amputation after intraosseous infusion in a 7-month-old infant: a case report. J Trauma 2003; 55(4):788-90 306

Case report of a 7-month-old infant who developed severe compartment syndrome associated with popliteal arterial thrombosis following IO fluid infusion resulting in limb amputation.

YEAR: 2002

Harty MP, Kao SC. Intraosseous vascular access defect: fracture mimic in the skeletal survey for child abuse. Pediatr Radiol 2002;32(3):188-90 294

Case report emphasizing that a cortical lesion in the proximal tibia corresponding to the site of IO insertion should not be mistaken for a radiographic sign of child abuse.

YEAR: 1999

Geller E, Crisci KL. Intraosseous infusion of iodinated contrast in an abused child. Pediatr Emerg Care 1999;15(5):328-9 247

This case study described administration of iodinated contrast via IO infusion in the tibia, for an abdominal CT scan in a 7 week old infant. CT imagining demonstrated adequate enhancement of the solid organs and vasculature.

Herman MI, Chyka PA, Butler AY, Rieger SE. Methylene blue by intraosseous infusion for methemoglobinemia. Ann Emerg Med 1999;33(1):111-3 244

Case report of a 6-week-old female infant with methemoglobinemia successfully treated with IO Methylene blue when other venous access was not feasible.

YEAR: 1998

McCarthy G, Buss P. The calcaneum as a site for intraosseous infusion. J Accid Emerg Med 1998;15:421.doi:10.1136/emj.15.6.421 445

A 3-year old male presented at the emergency department with rapidly progressing circulatory collapse clinically aligned with meningococcal septicemia. Attempts at peripheral and central venous access were unsuccessful. Attempts at tibial IO insertion were unsuccessful with a number of needles bending when cortical penetration was attempted. IO insertion was successfully achieved at the medial aspect of the calcaneum. IO infusion was continued for 6 hours and removed when no longer needed. The patient fully recovered and the calcaneal site healed without complication.

Nasimi A, Gorin P, Berthier M, Boussebart T, Follet-Bouhamed C, Oriot D. [Use of the intraosseous route in a premature infant]. Arch Pediatr 1998; 5: 414-7. French 231

Case report of a 34-week-old pre-term neonate with septic shock requiring emergency treatment. Umbilical vein was unusable. Resuscitation with IO access was successful. Concludes that IO access be used before attempting access with superior longitudinal sinus. Abstract

Ramet J, Clybouw C, Benatar A, Hachimi-Idrissi S, Corne L. Successful use of an intraosseous infusion in an 800 grams preterm infant. Eur J Emerg Med 1998; 5: 327-8 229

Case report of successful use of an IO access line in an 800 gm pre-term infant.

Intraosseous Vascular Access Bibliography

Case Studies

YEAR: 1997

Cambray EJ, Donaldson JS, Shore RM. Intraosseous contrast infusion: efficacy and associated findings. *Pediatr Radiol* 1997;27:892-3 222

Pediatric article detailing use of an IO line for bolus infusion of nonionic contrast material for CT contrast enhancement; a radiographic band may occur as a result of retained contrast material within the marrow.

Nafiu OO, Olumese PE, Gbadegesin RA, Osinusi K. Intraosseous infusion in an emergency situation: a case report. *Ann Trop Paediatr* 1997;17(2):175-7. Abstract 394

Case report of an 18-month-old boy with cardiopulmonary arrest secondary to penicillin anaphylaxis successfully resuscitated by IO administration of emergency medications.

YEAR: 1996

Friedman FD. Intraosseous adenosine for the termination of supraventricular tachycardia in an infant. *Ann Emerg Med* 1996;28(3):356-8 211

Case report of successful resolution of supraventricular tachycardia in an infant following IO administration of adenosine.

YEAR: 1995

Carbajal R, Paupe A, Lenclen R, Blanc P, Olivier-Martin M, Simon N. [Intraosseous infusion in children]. *Arch Pediatr* 1995;2:339-42. French 191

Case report of successful IO administration colloid, human albumin, and 1.4% sodium bicarbonate via the left hip of a 5-month-old infant with profound hypovolemia. Patient was discharged 4 days after admission.

Abstract only

Erb T, Hampl KF, Frei FJ. An unusual complication of intra-osseous infusion during paediatric resuscitation. *Anaesthesia* 1995;50(5):471 192

Case report describing extravasation of fluids through a previous IO puncture site in the same tibia.

Evans RJ, Jewkes F, Owen G, McCabe M, Palmer D. Intraosseous infusion--a technique available for intravascular administration of drugs and fluids in the child with burns. *Burns* 1995; 21: 552-3 193

Case report finding IO a viable method of venous access in a child with burns.

Hurren JS, Dunn KW. Intraosseous infusion for burns resuscitation. *Burns* 1995; 21: 285-7. Review 194

Describes 2 cases of resuscitation of a scalded child by IO infusion following failed IV attempts. Reviews IO techniques.

Rodriguez-Munez A, Martinez-Soto I, Martinon JM. Elective use of intra-osseous infusions in paediatrics. *Eur J Pediatr* 1995; 154: 755 202

Case report of IO access in a non-emergency situation. A blood transfusion was performed with no complications in a severely anemic 1-month old infant with an 18 G IO needle (Cook).

YEAR: 1994

Alba RM, Ruiz Lopez MJ, Flores JC. Use of the intraosseous route in resuscitation in a neonate. *Intensive Care Med* 1994; 20: 529-33 170

Case report of resuscitation of a 10-day-old female infant with 2 IO infusion sites. Patient received 240 ml fluids, epinephrine, dopamine, sodium bicarbonate, human albumin, packed red cells, fresh frozen plasma, glucose, ampicillin, gentamicin, vitamin K, and pancuronium.

Barron BJ, Tran HD, Lamki LM. Scintigraphic findings of osteomyelitis after intraosseous infusion in a child. *Clin Nucl Med* 1994; 19: 307-8 186

Case report of unilateral tibial osteomyelitis in a 20-month-old child following bilateral IO infusion. Reviews clinical indications, potential complications, and scan findings.

Rosovsky M, FitzPatrick M, Goldfarb CR, Finestone H. Bilateral osteomyelitis due to intraosseous infusion: case report and review of the English-language literature. *Pediatr Radiol* 1994;24:72-3 171

Case report of bilateral osteomyelitis secondary to intraosseous infusion.

Review

Intraosseous Vascular Access Bibliography

Case Studies

Simmons CM, Johnson NE, Perkin RM, van Stralen D. Intraosseous extravasation complication reports. *Ann Emerg Med* 1994;23(2):363-6 178

Case reports of 2 children with severe complications of IO infusions. One child developed severe tissue necrosis after IO placement. A second child developed compartment syndrome requiring fasciotomy.

Wright R, Reynolds SL, Nachtsheim B. Compartment syndrome secondary to prolonged intraosseous infusion. *Pediatr Emerg Care* 1994;10:157-9 172

Case report of compartment syndrome after prolonged intraosseous infusion (53 hours). Recommends that IO lines be used only temporarily until more permanent vascular access is established.

Review

YEAR: 1993

Kelsall AW. Resuscitation with intraosseous lines in neonatal units. *Arch Dis Child* 1993;68:324-5 146

Case reports of 2 infants in the neonatal unit in which IO access was used for successful resuscitation from collapse.

Platt SL, Notterman DA, Winchester P. Fungal osteomyelitis and sepsis from intraosseous infusion. *Pediatr Emerg Care* 1993;9:149-50 141

Case report of fungal osteomyelitis following IO infusion in a child. Cautions that physicians consider both bacterial and fungal sources for infection.

Ribeiro JA, Price CT, Knapp DR Jr. Compartment syndrome of the lower extremity after intraosseous infusion of fluid. A report of two cases. *J Bone Joint Surg Am* 1993;75A(3):430-3 155

This article presented two case studies in which pediatric patients received emergency IO infusions that ultimately resulted in compartment syndrome. In both cases the patients underwent a four-compartment fasciotomy and recovered without deficit. The authors conclude that though compartment syndrome is a risk of IO infusion, insertion of an IO line in emergency situations is a valuable technique.

Salino D, Cottin X, Bordenet M. [Intraosseous infusions in pediatric life-threatening emergencies]. *Ann Fr Anesth Reanim* 1993; 12: 469-73. Review. French 154

Case reports of 2 9-month-old infants with severe dehydration treated with IO infusions after failed IV attempts. IO lines were replaced shortly after venous access was obtained.

Abstract only

Schwartz RE, Pasquariello CA, Stayer SA. Elective use in pediatric anesthesia of intraosseous infusion: proceed only with extreme caution. *Anesth Analg* 1993; 76: 918-9 159

Letter to the editor recommending intraosseous infusion only for truly urgent situations.

Selby IR, James MR. The intraosseous route for induction of anaesthesia. *Anaesthesia* 1993;48:982-4 157

Case report of a 6-week-old infant with a head injury resulting in a fractured skull and scalp haematoma who was successfully resuscitated and anesthetized with IO infusions of colloid, blood, midazolam, suxamethonium and atracurium.

Vidal R, Kissoon N, Gayle M. Compartment syndrome following intraosseous infusion. *Pediatrics* 1993;91:1201-2 152

Case report outlining precautions to prevent compartment syndrome following IO infusion. Advocates early recognition and aggressive treatment to preserve function in the affected limb.

YEAR: 1992

Ghirga G, Ghirga P, Palazzi C, Befani P, Presti A. [Intraosseous route in pediatric emergencies. Description of 2 clinical cases and review of the literature]. *Minerva Pediatr* 1992; 44: 377-84. Italian 123

Case reports of resuscitation of 2 pre-term infants with medications administered via the intraosseous route. Also includes a short review of the history, physiology, technique, complications and contraindications of IO procedure.

Abstract only

Intraosseous Vascular Access Bibliography

Case Studies

YEAR: 1991

Brattebo G, Wisborg T, Mellesmo S. [Intra-osseous infusion--a simple, rapid and lifesaving method]. Nord Med 1991;106(1):13-5. Norwegian 118

Discussion of case reports of IO infusion, as well as physiology of IO and technique for IO access. Concludes that IO infusion is simple and safe. The technique can be successfully performed under field conditions by paramedical personnel, even by untrained personnel.

Abstract only

Christensen DW, Vernon DD, Banner W Jr, Dean JM. Skin necrosis complicating intraosseous infusion. Pediatr Emerg Care 1991;7:289-90 114

Case reports of 2 patients with local skin necrosis complicating IO infusion.

Galpin RD, Kronick JB, Willis RB, Frewen TC. Bilateral lower extremity compartment syndromes secondary to intraosseous fluid resuscitation. J Pediatr Orthop 1991;11:773-6 109

Case report of a child with severe compartment syndrome of both lower extremities following IO fluid resuscitation.

YEAR: 1990

Fries F, Rousset A, Bloom MC, Lelong-Tissier MC, Regnier C. [Intra-osseous route. Administration route of drugs in cardiac arrest]. Arch Fr Pediatr 1990;47(9):663-4. French 103

Case report of a 6-month-old infant in cardiac arrest successfully resuscitated with IO epinephrine.

Abstract

Goldstein B, Doody D, Briggs S. Emergency intraosseous infusion in severely burned children. Pediatr Emerg Care 1990;6:195-7 88

Case report of 2 severely burned children saved after IO was used to establish IV access.

Hopkins RL. Pediatric intraosseous infusion. J LA State Med Soc 1990;142(3):31-2 104

Concludes that infusion of fluids and drugs can be readily performed with the intraosseous technique.

Melker RJ, Miller G, Gearen P, Molliter L. Complications of intraosseous infusion. Ann Emerg Med 1990;19(6):731-2 97

This series of 3 letters to the editor are in response to the case report of bilateral fracture of the mid-tibial shaft in a 3-month old child following tibial IO insertion. It is noted that the insertions were made in the mid-tibial shaft rather than at the proximal or distal tibial insertion sites.

Miccolo MA. Intraosseous infusion. Crit Care Nurse 1990;10(10):35-47 100

Nursing article that describes benefits of intraosseous infusion. Recommends IO for cardiopulmonary arrest and other medical

Moscato R, Moore GP. Compartment syndrome with resultant amputation following intraosseous infusion. Am J Emerg Med 1990; 8: 470-1 91

Case report of compartment syndrome following IO infusion. Emphasizes IO to be useful for temporary vascular access. Advises that that IV lines be placed as soon as possible after IO infusion. Recommends that radiograph be performed after the procedure in very young children to check for bone abnormalities.

Tobias JD, Nichols DG. Intraosseous succinylcholine for orotracheal intubation. Pediatr Emerg Care 1990;6(2):108-9 468

This article describes two cases of IO administration of succinylcholine for emergency airway management in children that resulted in adequate intubating conditions within 45 seconds for both cases.

YEAR: 1989

La Fleche FR, Slepian MJ, Vargas J, Milzman DP. Iatrogenic bilateral tibial fractures after intraosseous infusions attempts in a 3-month-old infant. Ann Emerg Med 1989;18(10):1099-101 82

Case report of bone fracture following IO access in an infant.

Intraosseous Vascular Access Bibliography

Case Studies

YEAR: 1988

Katan BS, Olshaker JS, Dickerson SE. Intraosseous infusion of muscle relaxants. *Am J Emerg Med* 1988;6(4):353-4 62
Case report of anesthetic induction through IO administration of succinylcholine chloride, atracurium besylate, and thiopental sodium in a child with seizure activity.

Sacchetti A, Linkenhelmer R. On the effectiveness of intraosseous infusion. *J Emerg Med* 1988;6(5):433 61
Article discussing IO infusion and associated rapid intravascular absorption of solutions.

YEAR: 1987

McNamara RM, Spivey WH, Unger HD, Malone DR. Emergency applications of intraosseous infusion. *J Emerg Med* 1987;5:97-101 59
Several case reports illustrating the utility of IO in the emergency department. Includes discussion of IO administration of diazepam in succinylcholine.

YEAR: 1986

Glaeser PW, Losek JD. Emergency intraosseous infusions in children. *Am J Emerg Med* 1986;4:34-6 50
Case report illustrating value of familiarity with insertion technique for IO. Recommends that IO fluids and medications be considered early in patients requiring resuscitation.

McNamara RM, Spivey WH, Sussman C. Pediatric resuscitation without an intravenous line. *Am J Emerg Med* 1986;4:31-3 49
Case report of an unresponsive 3-month-old infant with no cardiac activity. Patient was resuscitated and achieved stable cardiac rhythm and blood pressure through IO administered medications.

Walsh-Kelly CM, Berens RJ, Glaeser PW, Losek JD. Intraosseous infusion of phenytoin. *Am J Emerg Med* 1986;4(6):523-4 52
Case report of child with status epilepticus. IO phenytoin resulted in seizure resolution and therapeutic serum levels of drug.

YEAR: 1984

Berg RA. Emergency infusion of catecholamines into bone marrow. *Am J Dis Child* 1984;138(9):810-1 40
Case report of continuous IO infusion of dopamine hydrochloride and dobutamine hydrochloride in a 6 month old infant. Concludes that IO infusion is efficacious and complications rare.

YEAR: 1983

Turkel H. Intraosseous infusion. *Am J Dis Child* 1983;137(7):706 37
Case report of 3-year-old child permanently blinded and brain damaged because of inability to administer anesthetic intravenously. Patient was on oxygen following an inhalation anesthetic. Concludes that IO administration of anesthesia would have prevented this poor outcome.

Turkel H. Intraosseous infusions. *South Med J* 1983;76(5):692 36
Recommends IO infusion of fluids in cases of shock, burns, mass casualties, and also for long term parenteral nutrition whenever peripheral veins cannot or should not be used.

YEAR: 1979

Shoor PM, Berryhill RE, Benumof JL. Intraosseous infusion: pressure-flow relationship and pharmacokinetics. *J Trauma* 1979; 19:772-4 32
Preclinical study of IO flow and pharmacokinetics in the bovine tibia. Mean time to initial effect of IO administration of epinephrine was 17 seconds with 90% maximal effect in 45 seconds. Concludes that experiment provides quantitative evidence of utility of IO infusion for resuscitation.

YEAR: 1958

Schoenherr WF. Intraosseous infusion of bone marrow. *JAMA* 1958;166(7):853 567
This letter to the editor is regarding the case of a 56 year-old man that ultimately developed aplastic anemia and required blood transfusions biweekly, and being considered for bone marrow transplants. The Editor's response briefly addressed the process of bone marrow transplantation.

Intraosseous Vascular Access Bibliography

Case Studies

YEAR: 1954

Marill F. Death from sternal puncture. JAMA 1954;155:1276

25

Case report of death following pericardial rupture with hemorrhage, associated shock, and peripheral circulatory collapse.

YEAR: 1951

Fortner JG, Moss ES. Death following sternal puncture: report of two cases. Annals of Internal Medicine 1951;34:809-15

23

Case reports of 2 deaths from sternal puncture. Discusses 4 additional cases from the medical literature. Comments of the mechanism of death.

YEAR: 1944

Bailey H. Bone marrow as a site for the reception of infusions, transfusion and anesthetic agents. Br Med J 1944;1:181-2

15

Recommends IO cavity of the manubrium as useful as IV for anesthetic infusion.

Bailey H. Bone marrow as a site for the reception of infusions, transfusions and anaesthetic agents: a review of the present position. Anesthesiology 1944;5(5):545-6

649

This abstract describes one physician's summary of experience using the sternum as an intraosseous vascular access site for 60 cases. Discusses potential benefits and complications compared to intravenous access.

YEAR: 1943

Ravitch MM. Suppurative anterior mediastinitis in an infant following intrasternal blood transfusion. Arch Surg 1943;47(3):250-7

1012

This article provides a brief history of intraosseous infusion beginning in 1903 with supportive literature through the writing of this article in 1943. An overview of mediastinitis, a complication of intrasternal blood transfusion, is also provided followed by a case report of anterior mediastinitis in an infant.

YEAR: 1941

Tocantins LM, O'Neill JF, Jones H. Infusion of blood and other fluids via the bone marrow: Application in pediatrics. JAMA 1941a; 117(5):1229-34

7

Describes emergency IO infusion of citrated blood and saline into the tibia or femur of 9 infants. IV access was impossible. Found no complications upon clinical or x-ray examination post-infusion.

Tocantins LM, O'Neill JF, Price AH. Infusions of blood and other fluids via the bone marrow in traumatic shock and other forms of peripheral circulatory failure. Ann Surg 1941;114:1085-92

4

Early study of 4 patients with acute failure of the peripheral circulation. IO infusion of blood, fluids, or drugs via the bone marrow resulted in a prompt recovery from the state of collapse. Recommends IO route when peripheral veins are not available and a fluids are urgently needed.

YEAR: 1934

Josefson A. A new method of treatment-Intraossal injections. Acta Medica Scandinavica 1934;81(5-6):550-64

687

This article describes one clinician's use of sternal IO access for infusion of campolon to treat anemia in 1930. The author performed over 50 injections without serious complications.

Sweden

Intraosseous Vascular Access Bibliography

Clinical, Observational and Other Studies

YEAR: 2019

- Itoh T, Lee-Jayaram J, Fang R, Hong T, Berg B. Just-in-time training for intraosseous needle placement and defibrillator use in a pediatric emergency department. *Pediatr Emerg Care* 2018;35(10):712-15. doi:10.1097/PEC.0000000000001516.** 984
- This article describes a study comparing medical students' comfort level in performing IO needle placement and defibrillator use in a pediatric ED before and after just-in-time training (JITT). JITT sessions were facilitated by ED attending physicians. Sessions for IO placement included group discussion of the location of IO needle set, indications, contraindications, locations on the body for placement, confirmation of placement, and selection of appropriate needle size. Participants then had hands-on practice using the EZ-IO task trainer for the humerus and tibia. The comfort level increased from pre survey 0% to post survey 48% (P<0.0001).
- Jousi M, Björkman J, Nurmi J. Point-of-care analyses of blood samples from intraosseous access in pre-hospital critical care. *Acta Anaesthesiol Scand* 2019;63(10):1419-25. doi: 10.1111/aas.13443** 1069
- Investigators conducted a prospective, observational study to compare intraosseous (IO) blood samples to arterial samples obtained from 35 patients in the prehospital setting. Blood gases, acid-base balance, electrolytes, glucose and hemoglobin results were obtained using an i-STAT® POC analyser. The analysis was successful for 23 of the 33 patients with 7 failures due to technical problems (clotting, inability of device to analyse). For the parameters of BE, pH, HCO₃, Gluc, iCa and Na the IO and arterial agreement was deemed acceptable enough that it may be useful for emergency patients until venous or arterial samples can be obtained; and limitations of IO sample use must be considered.
- Jousi M, Laukkanen-Nevala P, Nurmi J. Analysing blood from intraosseous access: A systematic review. *Eur J Emerg Med* 2018;26(2):77-85. doi:10.1097/MEJ.0000000000000569. [Epub ahead of print]** 986
- This study systematically reviewed the usability of IO blood samples for analyzing parameters relevant to emergency care. Animal studies and studies with ill and healthy adults and children were included. Twenty-seven studies were found in which IO blood samples were compared with arterial or venous samples. Only 3 studies followed the recommended statistical guidelines for method comparison studies, however. The authors concluded that the evidence supporting the analysis of IO samples is weak due to small sample sizes and insufficient statistical methods of the reviewed studies.
- Schindler P, Helfen A, Wildgruber M, et al. Intraosseous contrast administration for emergency computed tomography: A case-control study. *PLoS ONE* 2019;14(5): e0217629. <https://doi.org/10.1371/journal.pone.0217629>** 1067
- Retrospective case-control feasibility study comparing proximal tibial intraosseous (PTIO) and peripheral intravenous (PIV) delivery of contrast media in 24 patients receiving emergent CT scans as part of trauma diagnostics (n=4 PTIO, n=20 PIV). Delivery of contrast media was by power injection with rates of 5cc/sec for CT images of the head and neck, chest, abdomen and leg vessels. There were no significant differences in ability to complete imaging protocols or image quality. There were no complications. The study was limited by low patient numbers.
- Sørgjerd R, Sunde GA, Heltne JK. Comparison of two different intraosseous access methods in a physician-staffed helicopter emergency medical service - A quality assurance study. *Scand J Trauma Resusc Emerg Med* 2019;27(1):15 doi: 10.1186/s13049-019-0594-6** 1062
- This study compared IO insertions with the EZ-IO device (tibial/humeral insertions) to the FAST-R device (sternal insertions only) in a physician-staffed helicopter emergency medical service. Insertion time, insertion site, flow, indication for IO access, and complications were compared. Median insertion time was 15 seconds for EZ-IO and 20 seconds for FAST-R. Overall, 35.1% of EZ-IO insertions resulted in poor flow and required a pressure bag while 85.7% of FAST-R insertions had good or very good flow. EZ-IO complications included extravasation (2.4%), aspiration failure (11.9%), and insertion time >30 seconds (4.8%). Complications associated with FAST-R included user failure (12.5%) and insertion time >30 seconds (12.5%). The authors suggest that although EZ-IO is faster the FAST-R device may be more useful when high-flow infusion rates are required. The authors indicate that a low number of insertions were made with the FAST-R device and many outliers were observed in the data. However, the article does not present the total number of insertions per device.
- Wang J, Fang Y, Ramesh S, et al. Intraosseous Administration of 23.4%NaCl for Treatment of Intracranial Hypertension. *Neurocrit Care* 2019;30(2):364-71. <https://doi.org/10.1007/s12028-018-0637-2>** 1070
- Retrospective analysis of 76 patients exhibiting clinical symptoms of intracranial hypertension (ICH) that received 23.4% NaCl via the central venous catheter (CVC, n=38) or intraosseous (IO, n=38) access. IO insertion success was 97%; 33 were placed in the proximal humerus and 5 in proximal tibia. Transient hypotension was noted in 10 patients with IO devices and 3 with CVCs, an insignificant difference. No IO specific complications were noted. Time to delivery of 23.4% NaCl was faster with IO access; outcomes for CVC and IO were similar. Limitations include retrospective data, no ICP monitors, small numbers of patients.

Intraosseous Vascular Access Bibliography

Clinical, Observational and Other Studies

Wiegele M, Hamp T, Gratz J, Pablik E, Schaden E. Comparison of ROTEM parameters from venous and intraosseous blood. *Sci Rep* 2019;9(1):3741. doi: 10.1038/s41598-019-40412-0 1064

This study sought to investigate the reliability of ROTEM parameters in IO blood for the purpose of allowing a target-oriented administration of procoagulant agents in patients with IO access only. Healthy subjects and subjects undergoing minor surgery under anesthesia were enrolled. The EZ-IO device was used to obtain IO samples. Tibial and humeral sites were used. Due to clotting in a majority of samples, only 9/23 samples were evaluable and ROTEM was feasible in only 3/23. The authors conclude that ROTEM measurements from IO samples are not reliable and should not be used for guidance of procoagulant therapy in the emergency setting.

YEAR: 2018

Backman S, Angerman-Haasman S, Jousi M, et al. ABO and D typing and alloantibody screening in marrow samples: Relevance to intraosseous blood transfusion. *Transfusion* 2018;58(6):1372-75. doi: 10.1111/trf.14557 957

This article describes a study using prospective sampling of bone marrow (BM) to assess the feasibility of using bone marrow samples for blood group serotype analyses. Peripheral blood (PB) from each subject was used as that subject's control. 71 pairs of BM and PB samples were tested for ABO type, D type, and RBC alloantibody screening. All BM samples were successfully analyzed with no inconclusive results. The study concluded that BM samples collected from IO devices can be utilized for blood group serologic analyses.

Bjerkvig CK, Fosse TK, Apseth TO, et al. Emergency sternal intraosseous access for warm fresh whole blood transfusion in damage control resuscitation. *J Trauma Acute Care Surg* 2018;84(6S):S120-4. doi:10.1097/TA.0000000000001850. (Norway) 962

This article describes a prospective, comparative, nonrandomized study to compare flow rates using the sternal IO route with two different devices (EZ-IO and Fast1) when transfusing warm fresh whole blood as well as measuring post-infusion hemolysis when compared to IV infusion. Post procedure blood samples from all patients were within normal ranges with no statistically significant differences between groups. This study had a high catheter insertion failure rate in the IO groups. This was most likely due to subjects, healthy Norwegian military volunteers, performing the procedures on each other. The results suggest that infusion of fresh whole blood via the IO route is safe and reliable.

Chin SJ, Moore GA, Zhang M, et al. The AAHS clinical research award: Intraosseous regional prophylaxis provides higher tissue concentrations in high BMI patients in total knee arthroplasty: A randomized trial. *J Arthroplasty* 2018;33(7S):S13-8. doi:10.1016/j.arth.2018.03.013. 966

This study compared tissue concentrations of low-dose vancomycin via intraosseous regional administration (IORA) vs actual body weight-adjusted IV dosing in total knee arthroplasty (TKA) in obese patients (BMI>35). The obese patient population has an increased risk of periprosthetic joint infection after TKA. 22 patients were randomized to receive either 15mg/kg (max 2 g) of systemic vancomycin or 500 mg vancomycin via IORA. Fat and bone samples were taken and antibiotic concentrations measured. The overall mean tissue concentration in the subcutaneous fat was 39.3 µg/g in the IORA group vs 4.4 µg/g in the IV group (P<0.01). Mean tissue concentrations in bones were 34.4 µg/g in the IORA group vs 6.1 µg/g in the IV group (P<0.01). Low-dose IORA vancomycin was effective in providing tissue concentrations 5-9 times higher than IV administration in this high risk patient population.

Cho Y, You Y, Park JS, et al. Comparison of right and left ventricular enhancement times using a microbubble contrast agent between proximal humeral intraosseous access and brachial intravenous access during cardiopulmonary resuscitation in adults. *Resuscitation* 2018;129:90-3. doi:10.1016/j.resuscitation.2018.06.014 967

This study was a prospective, single-center, observational, cohort study of 10 patients comparing the ventricular enhancement time between humeral intraosseous (HIO) access and brachial intravenous (BIV) access during CPR in adult humans. HIO access was obtained with the EZ-IO device. Endpoints were right and left ventricular enhancement times after administration of a contrast agent. Results indicated that arrival times of medication at the right and left ventricles were significantly lower with HIO than BIV.

Chreiman KM, Dumas RP, Seamon MJ, et al. The intraosseous have it: A prospective observational study of vascular access success rates in patients in extremis using video review. *J Trauma Acute Care Surg* 2018;84(4):558-63. doi:10.1097/TA.0000000000001795 890

Prospective cohort study done by review of video footage which was taken over a 15 month period as part of a quality improvement initiative for patients in extremis (the absence of a palpable pulse or measurable blood pressure) undergoing thoracotomies during trauma resuscitation. Data recorded for vascular access included types intraosseous (IO), peripheral intravenous (PIV), central venous (CVC) and intracardiac (IC)) and site of attempted access, number of attempts and success rates, procedure time, demographics, and mechanism of injury. 145 access attempts were made in 38 patients (median 3.8 (SD 1.4) attempts per patient). Time to access was similar for PIV and IO but longer for CVC and success rates for IO insertion were significantly higher than for PIVs or CVCs (95% vs. 42% vs. 46%, p<0.001). Authors "recommend placement of IO cannulae as a best practice to rapidly establish first line vascular access for resuscitation and as a bridge to additional access."

Ding S, Meystre NR, Campeanu C, Gullo G. Contrast media extravasations in patients undergoing computerized tomography scanning: A systemic review and meta-analysis of risk factors and interventions. *JBI Database System Rev Implement Rep* 2018;16(1):87-116. doi:10.11124/JBISIRIR-2017-003348 970

This article is a systematic review and meta-analysis of risk factors and interventions related to IV administration of contrast media.

Intraosseous Vascular Access Bibliography

Clinical, Observational and Other Studies

- El-Nawawy AA, Omar OM, Mona Khalil M. Intraosseous versus intravenous access pediatric septic shock patients admitted to Alexandria University Pediatric Intensive Care Unit. J Trop Pediatr 2018;64(2):132-40. doi:10.1093/tropej/fmx061** 932
- Prospective randomized clinical trial in which IO access was compared to peripheral intravenous access (PIV) in pediatric patients with septic shock. Children's ages ranged from 1 month to 36 months old and weights ranged from 4 to 14 kg with similar characteristics in both groups; 30 patients in each subset. The IO group had significantly shorter vascular access insertion times, shorter length of stay and reduced mortality. IO access was achieved in the proximal tibia on first attempt for all insertions; 50% of PIV attempts failed on first attempt. There were no complications for the IO subset compared to 26.7 % for PIV. There was a reduced ability to aspirate for labwork via the IO access. This study supports existing literature that early use of IO insertion is safe and effective with minimal complications.
- Feinstein BA, Stubbs BA, Rea T, Kudenchuk PJ. Intraosseous compared to intravenous drug resuscitation in out-of-hospital cardiac arrest [Letter to the Editor, Authors' Reply]. Resuscitation 2018;127:e2** 974
- This letter to the editor is the authors' response to another letter to the editor by Drs. Soar and Hormis for their review of the authors' study comparing initial access between IV and IO during out-of-hospital cardiac arrest (OHCA) resuscitation. Reference: Feinstein BA, Stubbs BA, Rea T, et al. Intraosseous compared to intravenous drug resuscitation in out-of-hospital cardiac arrest. (Initial publication: Resuscitation 2017;117:91-96)
- Feldman O, Nasrallah N, Bitterman Y, et al. Pediatric intraosseous access performed by emergency department nurses using semiautomatic devices: A randomized crossover simulation study. Pediatr Emerg Care 2018;00:1-5. doi:10.1097/PEC.0000000000001621** 975
- This study evaluated emergency department (ED) nurses' success rate, compared with paramedics, in establishing pediatric IO access using semiautomatic devices. The NIO and EZ-IO devices were used by both nurses and paramedics on uncooked bones of 8- to 12-week old piglets. A total of 34 and 30 insertion attempts were performed by 17 ED nurses and 15 paramedics, respectively. First attempt success rates were 79.4% for nurses and 83.3% for paramedics. 82.3% of nurses and 73.3% of paramedics recorded the EZ-IO as their "first choice device". The findings of this study suggest that ED nurses have the competence to perform IO insertions and this technique should be used in nursing school curriculum.
- Fenwick R, Nutbeam T, Lowther A, Mann T. Maximising flow in intraosseous: An in vitro study. Poster presented at: Trauma Care Conference; April 15, 2018; Staffordshire, United Kingdom** 976
- This poster presents the findings of an in-vitro study to measure the time taken to administer 500 mL of saline via the intraosseous (IO) route using three different methods of administration: fluid giving set placed directly on the IO needle hub (DTO), fluid giving set connected to the EZ-IO device extension set (EVS), and fluid giving set connected to a simple 3-way extension set (TWS). The EVS set produced the slowest administration times. The authors concluded that clinicians may be able to increase IO flow rates by replacing the extension set that is supplied with the EZ-IO.
- Kawano T, Grunau B, Scheuermeyer FX, et al. Intraosseous vascular access is associated with lower survival and neurologic recovery among patients with out-of-hospital cardiac arrest. Ann Emerg Med 2017;71(5):588-96. doi:10.1016/j.annemergmed.2017.11.015** 946
- A retrospective analysis of data collected in the prehospital setting to evaluate the effect of either intravenous (IV) or intraosseous (IO) vascular access management of non-traumatic, adult, out-of-hospital cardiac arrest (OOHCA) cases on patient (pt) outcomes. Results: 23.9% IO patients achieved ROSC vs 38.3% IV; 3.8% IO subjects survived to hospital discharge vs 10.3% IV subjects. The authors concluded that in patients with non-traumatic OOHCA, use of IO access is associated with lower survival and poor neurologic outcomes as compared to IV access. Limitations: 660 pts received IO access (5%) and 12,495 received IV access (95%); selection bias by paramedics choosing the vascular access method based upon presenting conditions; and IO access had a higher proportion of non-shockable initial rhythms, fewer public location and witnessed arrests and shorter times from call to first ALS paramedics arrival.
- Kawano T, Grunau B, Scheuermeyer FX. In reply: Effect of time to vascular access in out-of-hospital cardiac arrest. Ann Emerg Med 2018;72(2):229-31** 987
- This letter to the editor is in response to Nurii et al.'s letter to the editor regarding Kawano et al.'s article on the effect of time to vascular access in out-of-hospital cardiac arrest (OHCA). Kawano et al. performed Nurii et al.'s suggested sensitivity analysis by modifying their multivariable logistic regression model to include duration of out-of-hospital resuscitation among patients with return of spontaneous circulation (ROSC) or termination of resuscitation as measured from the 911 call to either ROSC or termination of resuscitation. The authors conclude that the model continued to demonstrate that IO access, when compared to IV access, was associated with a decreased probability of a favorable neurologic outcome.
- Nurii T, Crandall C, Braude D. Effect of time to vascular access in out-of-hospital cardiac arrest [Letter to the Editor]. Ann Emerg Med 2018;72(2):228-9. https://doi.org/10.1016/j.annemergmed.2018.03.031** 1003
- This letter to the editor is in response to Kawano et al.'s article on the effect of time to vascular access in out-of-hospital cardiac arrest (OHCA). Kawano et al. found an association between intraosseous vascular access and lower survival and worse neurologic outcome in OHCA. Nurii et al. express concern regarding selection bias and confounding factors not being accounted for in the original study. Nurii et al. suggest accounting for time from call to vascular access or return of spontaneous circulation (ROSC). Nurii et al. also suggest considering whether ROSC is an appropriate outcome. Reference: Kawano T, Grunau B, Scheuermeyer FX, et al. Intraosseous vascular access is associated with lower survival and neurologic recovery among patients with out-of-hospital cardiac arrest. (Initial article: Ann Emerg Med. 2018;71:588-596).

Intraosseous Vascular Access Bibliography

Clinical, Observational and Other Studies

- Petrie A, Lubin J. Assessment of intraosseous needle placement by EMS providers. *Prehosp Emerg Care* 2018;22(1):28** 925
Investigators assessed the ability of EMS providers with various skill levels to correctly identify the insertion sites for both the proximal tibia and proximal humerus. Participants were attending a state EMS conference. The distances from the sites identified to correct site was significant. The study concluded the accuracy of landmark identification was low and proper training is important.
- Pifko E, Price A, Busch C, et al. Observational review of paediatric intraosseous needle placement in the paediatric emergency department. *J Paediatr Child Health* 2018;54(5):546-50. doi:10.1111/jpc.13773** 1011
This study compared the success rates and time to placement for Manual IO versus EZ-IO needles in pediatric emergency department (PED) patients ≤ 8 kg and >8 kg at a single institution. It was a retrospective, cross-sectional, descriptive study. All identified patients with an IO attempted in the PED were included. Fifty patients were identified. In patients ≤ 8 kg, overall success rates were 55% (17/31) for Manual IO and 47% (8/17) for EZ-IO. In patients >8 kg, Manual IO success rates were 100% (2/2) and EZ-IO success rates were 93% (14/15) for overall attempts. Time (minutes) to successful placement in patients ≤ 8 kg was 4.5 for Manual IO vs 12.8 for EZ-IO ($P=0.02$). In patients >8 kg, time to successful placement was 8.5 for Manual IO vs 10.2 for EZ-IO ($P=0.70$). Overall success rates in this study were poor in both groups, most likely due to lack of experience at IO insertion or inadequate device training. Access in smaller patients was more difficult and required greater time to insertion.
- Redfield C, Suarez S, Daniels, Sanchez C, Siples H, Landry K. The effect of IV vs. IO access in prehospital cardiac arrest ROSC rates. *Prehosp Emerg Care* 2018;22(1):38** 926
Retrospective study reviewing data from one EMS service that compared return of spontaneous circulation (ROSC) in cardiac arrests when intraosseous (IO) or intravenous (IV) access was obtained. An IV was placed in 361 patients with a ROSC in 148 (41.1%); and 360 patients had an IO placed with a ROSC in 80 (22.2%). The difference for greater ROSC rates with IV vs. IO use was significant.
- Rodda LN, Volk JA, Moffat E, et al. Evaluation of intraosseous fluid as an alternative biological specimen in postmortem toxicology. *J Anal Toxicol* 2018;42(3):163-9. doi: 10.1093/jat/bkx096** 1014
This article investigates intraosseous fluid (IOF) as an alternative matrix for drug testing in deceased patients, especially in cases where the cadaver is severely compromised following death. IO access was obtained at 4 sites, bilateral proximal tibia and bilateral proximal humerus, using the EZ-IO device. Samples in 29 subjects were collected and screened for a host of illicit substances. Study results support the possible use of IOF as an alternative postmortem specimen for toxicological investigations when necessary.
- Sawyer T, Nishisaki A. Intraosseous access during newborn resuscitation: It may be fast, but is it safe? *Pediatr Crit Care Med* 2018;19(5):499-501. doi:10.1097/PCC.0000000000001513** 1017
This article examines emergency vascular access during newborn resuscitation. It discusses the time needed to place an emergency umbilical vein catheter (eUVC) and intraosseous kits (EZ-IO) in a series of simulated newborn resuscitations across 4 studies. In all 4 studies IO placement was significantly faster than eUVC placement. An additional study found eUVC placement to be significantly faster with real human umbilical cords than with simulated umbilical cords as used in the aforementioned studies. While IO access in newborns appears faster than eUVC in simulated models, to date, no randomized trials or large case-cohort studies have systematically evaluated the short and long-term safety of IO placement during newborn resuscitation. Current guidelines still support eUVC as the preferred method of obtaining vascular access during newborn resuscitation. The authors suggest further studies are needed to determine short and long-term safety of IO access in newborns before widespread adoption of the process can be recommended.
- Soar H, Hormis A. Comments on published Resuscitation article [Letter to the Editor]. *Resuscitation* 2018;127:e1 doi:10.1016/j.resuscitation.2017.07.032** 1021
This letter to the editor provides a response to Feinstein et al and refutes their findings, from comparison of IO and IV drug resuscitation in out-of-hospital cardiac arrest (OHCA), that a tibial IO access was associated with a decreased likelihood of return to spontaneous circulation (ROSC) in OHCA patients. Author A Hormis provides a conflict of interest stating he has undertaken educational cadaveric teaching on behalf of Teleflex. Reference: Feinstein BA, et al. Intraosseous compared to intravenous drug resuscitation in out-of-hospital cardiac arrest. *Resuscitation*. 2017;117:91-96.
- Szarpak L, Ladny JR, Dabrowski M, et al. Comparison of 4 pediatric intraosseous access devices: A randomized simulation study. *Pediatr Emerg Care* 2018;00:1-5. doi:10.1097/PEC.0000000000001587. [Epub ahead of print]** 1026
This study aimed to compare the success rates of 4 commonly used IO devices (NIO Pediatric, BIG Pediatric, EZ-IO, and a manual Jamshidi IO needle) in a pediatric model. Speed of insertion, ease of use, and complications were secondary outcomes. Seventy-five novice physicians from Warsaw, Poland participated in this study; none of whom had prior experience with IO devices. First attempt success rates were 43% (Jamshidi), 90% (BIG), 97% (EZ-IO), and 100% (NIO-P). Median time to achieve IO access was 18 seconds (NIO), 23 seconds (EZ-IO and BIG), and 34 seconds (Jamshidi). 39/68 participants preferred the NIO device, 18/68 preferred the EZ-IO device, 11/68 preferred the BIG device, and none of the participants preferred the Jamshidi needle.
- Wehbi NK, Wani R, Yang Y, et al. A needs assessment for simulation-based training of emergency medical providers in Nebraska, USA. *Adv Simul (Lond)*. 2018;3:22. doi: 10.1186/s41077-018-0081-6** 1063
This paper describes a project where information was collected using a paper survey from EMS and ED providers in Nebraska. The purpose of the survey was to identify gaps in their skills, knowledge and abilities in order to aid curriculum development for a mobile training unit to be used in rural areas of the state. Intraosseous placement is a clinical skill in which the participants would like further training.

Intraosseous Vascular Access Bibliography

Clinical, Observational and Other Studies

Young SW, Zhang M, Moore GA, Pitto RP, Clarke HD, Spangehl MJ. The John N. Insall Award: Higher tissue concentrations of vancomycin achieved with intraosseous regional prophylaxis in revision TKA: A randomized controlled trial. Clin Orthop Relat Res. 2018;476:66-74

1066

This is a prospective, randomized, controlled trial of patients undergoing revision total knee arthroplasty (TKA). Twenty patients were randomized to receive systemic IV or IO regional administration (IORA) of vancomycin as prophylaxis. Higher tissue and bone concentrations were consistently achieved in the IORA group with tissue concentrations during the procedure 5 to 20 times higher in the IORA group versus the IV group. The EZ-IO device was used to gain IO access in this study.

YEAR: 2017

Afzali M, Kvisselgaard A, Viggers S. Early introduction of intraosseous access ought to be emphasized. Am J Emerg Med 2017;35(2):355-6. doi:10.1016/j.ajem.2016.10.062

897

This journal article discusses the importance of early in medical school and/or residency training of intraosseous access by use of cadaver courses can help increase the skills for IO use needed for use in real life situations thus improving patient safety.

Afzali M, Kvisselgaard AD, Lyngeraa TS, Viggers S. Intraosseous access can be taught to medical students using the four-step approach. BMC Medical Education 2017;17(50):doi:10.1186/s12909-017-0882-7. (Denmark)

831

This study evaluated the ability to teach the skill of IO access in a four hour timeframe to medical students using a modified Walker and Peyton's four-step approach teaching method and a cadaveric model. The learner's competencies were evaluated with an objective structured clinical examination checklist. This study found the teaching method was successful. Authors recommend repetitive training to be integrated to medical curriculum for maximal skill retention.

Bielski K, Szarpak L, Smereka J, Ladny J, Leung S, Ruetzler K. Comparison of four different intraosseous access devices during simulated pediatric resuscitation. A randomized crossover manikin trial. Eur J Pediatr 2017;176(7):865-71. doi:10.1007/s00431-017-2922-z

899

This study compared success rate, procedure time and user satisfaction of pediatric NIO vs. Pediatric BIG, EZ-IO and Jamshidi intraosseous access devices in pediatric manikins. Study was randomized, crossover trial with 87 paramedics participating. The study evaluated each device on the ease of use in performing their procedures. Results of this study found that paramedics favored the NIO in ease of use in the pediatric manikins.

Clemency B, Tanaka K, May P, et al. Intravenous vs. intraosseous access and return of spontaneous circulation during out of hospital cardiac arrest. Am J Emerg Med 2017;35:222-6. doi:10.1016/j.ajem.2016.10.052

943

A retrospective chart review was done to analyze data of three EMS agencies over an 18 month timespan. Analysis was done on charts from adults who suffered OOHCA and received epinephrine through EMS established IV or IO access. An IO first approach was found non-inferior to an IV first approach based on the end point ROSC at time of emergency department arrival.

Collins T. Intraosseous access is effective whilst wearing CBRN protective equipment [abstract 31]. BMJ Open 2017;7(Suppl3):A1-A18. doi: 10.1136/bmjopen-2017-EMSabstracts.31

1048

This is an abstract of a cross-over study comparing the ease-of-use and success rates of cadaver IO insertions performed by paramedics while wearing their standard pre-hospital clothing or Chemical, Biological, Radiation and Nuclear (CBRN) personal protective equipment. There were no statistically significant differences between groups for ease-of-use scores, however, scores were generally lower in the CBRN group. Insertion times were significantly longer while wearing CBRN (25 seconds vs 34.38 seconds). IO access was obtained using the EZ-IO device.

Elliott A, Dubé P, Cossette-Côté A, et al. Intraosseous administration of antidotes-a systematic review. Clin Toxicol 2017; 55(10):1025-54. doi:10.1080/15563650.2017.1337122

917

This study reviews current IO administration of antidotes for patients that have presented to the emergency department with serious poisoning and IV access is not available. The study concluded that the evidence supporting the use of IO route for administering antidotes for poisoning patients is rare. Most evidence of IO access administration of antidotes has occurred in animal studies and case reports. Per author, despite lack of evidence, IO access is a potential option for antidotal treatments for resuscitation for patients where IV access is not available.

Faudeux C, Tran A, Dupont A, et al. Development of reliable and validated tools to evaluate technical resuscitation skills in a pediatric simulation setting: resuscitation and emergency simulation checklist for assessment in pediatrics. J Pediatr 2017;188:252-57. doi:10.1016/j.jpeds.2017.03.055

920

This study addresses the need for the development of a reliable and validated tool to evaluate technical resuscitation skills in a pediatric simulation setting. The authors created four resuscitation and emergency simulation checklist and evaluation tools were created, (RESCAPE). Study found that use of the RESCAPE tools are reliable and validated tools for evaluation of resuscitation skills in pediatric simulation-based educational programs.

Intraosseous Vascular Access Bibliography

Clinical, Observational and Other Studies

- Feinstein B, Stubbs B, Rea T, Kudenchuk P. Intraosseous compared to intravenous drug resuscitation in out-of-hospital cardiac arrest. *Resuscitation* 2017;117:91-6. doi:10.1016/j.resuscitation.2017.06.014** 922
- This retrospective cohort study evaluated emergency medical services (EMS) that treated adult patients with atraumatic out of hospital cardiac arrest (OHCA) in order to compare drug administration via intraosseous (IO) versus intravenous (IV) and the effectiveness. Study endpoints were survival to hospital discharge, return of spontaneous circulation (ROSC), and survival to hospital admission. The study included 1,800 patients, 1,525 of whom received IV access and 275 who received IO access. The practice for OHCA management in the EMS system from which the data was obtained was to attempt tibial IO access after failed IV attempts. The authors concluded that use of IO access was associated with a lower likelihood of ROSC and hospitalization; and acknowledged that further study of how vascular access routes affect OHCA patient outcomes is warranted.
- Iskrzycki L, Smereka J, Szarpak L. Knowledge, skills, and attitudes concerning intraosseous access among hospital physicians. *Crit Care Med* 2017;45(1):e117** 876
- This letter to the editor describes a manikin study that compared use of the Teleflex EZ-IO to the Persys Medical NIO intraosseous vascular access devices. Insertion times were statistically different, favoring the NIO but not considered clinically relevant. The authors concluded that, while hospital physicians' knowledge of intraosseous access was limited, with simple training they could learn the procedure and place IO needles safely in less than 30 seconds.
- Jansen G, Leimkuhler K, Mertzlufft F. Intramedullary placement of intraosseous cannulas inserted in the preclinical treatment of polytrauma patients: A retrospective, computed tomography-assisted evaluation. *Anaesthesist* 2017;66(3):168-76. doi:10.1007/s00101-016-0257-1** 985
- This article describes a retrospective, CT-assisted evaluation of IO cannula placement. Over a 5 year period all multislice-CT trauma scans performed in a trauma center were monitored for intraosseous devices in situ. 982 patients were evaluated and 13 IO cannulas were found in 11 patients. In all cases, the EZ-IO device was used. Evaluation of placement found that all applications were placed correctly, but none were according to current guidelines. The site of puncture deviated in all cases with the most common error of overshooting during needle introduction. (Article in German)
- Jousi M, Saikko S, Nurmi, J. Intraosseous blood samples for point-of-care analysis: Agreement between intraosseous and arterial analyses. *Scand J Trauma Resusc Emerg Med* 2017;25(1):92. doi.10.1186/s13049-017-0435-4** 945
- Study using 31 healthy volunteers to evaluate IO blood samples drawn from the proximal tibia compared to arterial and venous samples using a POC lab device. Two samples were drawn from each site with no significant difference observed in the results with or without waste blood. Results varied particularly between the arterial and IO samples; and for several parameters. Authors concluded that IO blood samples may be evaluated using the i-STAT® point-of-care analyser; and results should be interpreted with care in the clinical situation context.
- Liu SX, Liu YG, Wang PH, Qi MF, Luo M. Efficacy of shengxue mixture combined with intraosseous infusion for treatment of aplastic anemia. *J Exp Hematol* 2017;25(5):1493-7** 990
- This study evaluated the efficacy and safety of Shengxue mixture when combined with IO blood infusion for the treatment of aplastic anemia patients at Shaanxi Medical University in China. Patients were treated with oral Shengxue mixture, stanozolol tabs, mycophenolate and IO infusion of recombinant human EPO, G-CSF, IL-11, and dexamethasone. After 1 month of treatment the response rate was 90.57%. After 3-6 months the response rate was 96.23%. The authors concluded that Shengxue mixture combined with IO infusion was a fast, efficient, and safe method of treatment of aplastic anemia. Article in Chinese.
- Meyers BL, Kramer SA, Field AE, et al. Unexpected procedural complications during intraosseous infusions. *J Am Assoc Lab Anim Sci* 2017;56(5):P98, pg. 598** 994
- This poster presents a complication and unexpected ultrasound findings associated with IO infusions attributed to fat embolization. At necropsy, lung histology of 35 female swine revealed numerous large fat emboli consisting of bone marrow cellular elements and adipose cells within medium-sized arteries. High IO infusion rates also contributed to fat embolism in the femoral vein. Providers should be aware of the potential for pulmonary embolism.
- Osbin N, Rogers MJ, Walsh TJ, Yang C. Peripheral rapid infusion via the corpus cavernosum: An investigation of penile vascular access flow rates. *J Trauma Acute Care Surg* 2017;83(5):975-7. doi:10.1097/TA.0000000000001668** 1005
- This study investigates infusion flow rates through a standard 16-gauge peripheral angiocatheter inserted into a single corpus cavernosum of the penis to support the hypothesis that the penis can be an efficient means of providing rapid fluid resuscitation. This study suggests that the penis may be an alternative to traditional vascular access routes (peripheral IVs, IO insertion, central venous catheters, and vein cutdown procedures) when vascular access is difficult. Flow rates in the study were comparable and in some cases superior to other alternative means of vascular access.

Intraosseous Vascular Access Bibliography

Clinical, Observational and Other Studies

Salzman JG, Loken NM, Wewerka SS, et al. Intraosseous pressure monitoring in healthy volunteers. *Prehosp Emerg Care* 2017;21(5):567-74. doi:10.1080/10903127.2017.1302529

927

This article describes a prospective, observational study that attempted to establish baseline values of IO pressure (IOP) in a healthy human population. Subjects had an IO device placed in the tibia and humerus. IO pressures, vital signs, and pain scores were monitored for 60 minutes. Absolute IOP values were not consistent between subjects. Future research is needed to determine how IO pressure can be used to guide therapy in ill and injured patients.

Shina A, Baruch EN, Shlaifer A, et al. Comparison of two intraosseous devices: The NIO versus the EZ-IO by novice users- a randomized cross over trial. *Prehosp Emerg Care* 2017;21(3):315-21. doi:10.1080/10903127.2016.1247201

817

Using a porcine hind leg model authors compared the success rate and ease-of-use ratings of an IO device, the NIO® in comparison to the Arrow® EZ-IO by novice users. NIO success rates were comparable to those of EZ-IO; 54% of the participants preferred using the EZ-IO over the NIO.

Sotomayor T, Maraj C, Mott J, et al. Humeral head intraosseous access: Filling the military gap. *J Def Model Simul* 2017;14(4):361-9. doi: 10.1177/1548512916646888

1022

This article assesses the usability of the Partial Task Trainer (PTT) to train certain military medical providers on the technique of humeral head intraosseous infusion (HHIO). The PTT consists of an arm with functional structures and characteristics that allow trainees hands on practice locating anatomical landmarks, inserting the IO needle, and introducing the catheter into the humerus. Currently the US Army utilizes the EZ-IO Intraosseous Infusion System for HHIO infusions.

Tallman CI, Darracq M, Young M. Analysis of intraosseous blood samples using an EPOC point of care analyzer during resuscitation. *Am J Emerg Med* 2017;35(3):499-501. doi:10.1016/j.ajem.2016.12.005

805

A prospective study comparing results of intravenous (IV) and intraosseous (IO) blood specimens when analyzed using an EPOC point of care analyzer during resuscitation of non-traumatic cardiac arrest and critically ill patients. Seventeen patients who had IO and IV specimens collected within 5 minutes of each other were included in the study; IO samples were collected before administration through the IO catheter in the proximal tibia or proximal humerus. Results showed that based upon Bland Altman plots, there was reasonable agreement between IV and IO values for PH, bicarbonate, sodium and base excess, and moderate agreement for lactic acid. The intraclass correlation co-efficient was excellent for sodium and reasonable for pH, pO₂, bicarbonate and glucose. The primary limitation noted was the small sample size (n=17) and the substantial impact of single outliers in the data.

Winkler M, Talley C, Woodward C, et al. The use of intraosseous needles for injection of contrast media for computed tomographic angiography of the thoracic aorta. *J Cardiovasc Comput Tomogr* 2017;11(3):203-7. doi: 10.1016/j.jcct.2017.03.001

825

This retrospective study of a quality and safety database compared procedures performed by use of intraosseous vascular access for contrast media infusion to a control group of the studies in the database performed with antecubital intravenous access. The quality metrics of the two groups were similar, with the intraosseous needle group being slightly better. There were no complications related to IO use in general or specifically associated with the procedures. Limitations included this was a single-center study with small sample size and possible selection bias due to unfamiliarity with IO access.

Wolfson DL, Tandoh MA, Jindal M, Forgione PM, Harder VS. Adult intraosseous access by advanced EMTs: A statewide non-inferiority study. *Prehosp Emerg Care* 2017;21(7):7-13. doi:10.1080/10903127.2016.1209262

816

This retrospective non-inferiority study examined EMS data extracted from a statewide EMS data system over a two year period. IO insertions performed by advanced EMTs (AEMT) and Paramedics were compared for insertion success rates. The majority of IO placements were with the EZ-IO®. The investigators concluded successful IO access was not different among AEMTs and Paramedics lending evidence in support of expanding the scope of practice of AEMTs to include establishing IO access in adults.

Young S, Zhang M, Moore GA, et al. Higher tissue concentrations of vancomycin with low-dose intraosseous regional versus intravenous systemic prophylaxis in revision total knee arthroplasty: A randomized trial. Paper presented at: American Academy of Orthopaedic Surgeons Annual Meeting; March 14-18, 2017; San Diego, CA. Abstract P118

1036

This is an abstract of a study that compared tissue concentrations of vancomycin administered intravenously (IV) versus intraosseous regional administration (IORA) in revision TKA. Twenty patients were randomized to 2 groups: 1 g IV vancomycin or 500 mg IORA vancomycin. Overall geometric mean tissue concentrations in fat samples were 3.7 µg/g in the IV group vs 49.3 µg/g in the IORA group (P<0.001) while mean tissue concentrations in the femoral bone were 6.4 µg/g in the IV group vs 77.1 µg/g in the IORA group (P<0.001). IORA of low-dose vancomycin provided tissue concentrations 5-20 times higher than IV administration. IO access was obtained using the EZ-IO device. This study was sponsored by Teleflex Incorporated.

Intraosseous Vascular Access Bibliography

Clinical, Observational and Other Studies

Young SW, Clarke HD, Moore GA, Zhang M, Spangehl MJ. Higher tissue concentrations of vancomycin are achieved with intraosseous versus intravenous administration in revision TKA. The Knee 2017;24(6):XIV (Abstract 0018). <https://doi.org/10.1016/j.knee.2017.08.045>.

1038

This abstract describes a study that compared tissue concentrations of vancomycin administered intravenously (IV) versus intraosseous regional administration (IORA) in revision TKA. Twenty patients were randomized to 2 groups: 1 g IV vancomycin or 500 mg IORA vancomycin. Mean tissue concentrations in fat samples were 4.1 µg/g in the IV group vs 115 µg/g in the IORA group (P<0.001) while tissue concentrations in the femoral bone were 7.2 µg/g in the IV group vs 101 µg/g in the IORA group (P<0.001). IORA of low-dose vancomycin provided tissue concentrations 5-20 times higher than IV administration. IO access was obtained using the EZ-IO device. This study was sponsored by Teleflex Incorporated.

Young SW, Clarke HD, Pitto R, et al. Higher tissue concentrations of vancomycin with low-dose intraosseous regional versus intravenous systemic prophylaxis in revision TKA. ePoster presented at: International Society of Arthroscopy, Knee Surgery and Orthopaedic Sports Medicine Biennial Congress; June 4-8,2017; Shanghai, China. ePoster 1230

1037

This e-poster describes a study that compared tissue concentrations of vancomycin administered intravenously (IV) versus intraosseous regional administration (IORA) in revision TKA. Twenty-two patients were randomized to 2 groups: 1 g IV vancomycin or 500 mg IORA vancomycin with 20 patients analyzed. Mean tissue concentrations in fat samples were 4.1 µg/g in the IV group vs 115 µg/g in the IORA group (P<0.001) while tissue concentrations in the femoral bone were 7.2 µg/g in the IV group vs 101 µg/g in the IORA group (P<0.001). IORA of low-dose vancomycin provided tissue concentrations 5-20 times higher than IV administration. IO access was obtained using the EZ-IO device. This study was sponsored by Teleflex Incorporated.

Young SW, Zhang M, Moore GA, Pitto RP, Clarke HD, Spangehl MJ. Higher tissue concentrations of vancomycin with intraosseous regional prophylaxis in revision TKA- A randomized controlled trial. Manuscript submitted for publication

930

A randomized controlled study comparing antibiotic tissue concentrations when vancomycin is administered for total knee arthroscopy via IO and IV access. Ten subjects were randomized to each group. The IO group received 500 mg vancomycin injected directly into the proximal tibia IO insertion site below an inflated thigh tunicate, and the IV group received 1 gram vancomycin, both were given before skin incision. Results showed IO tissue concentrations of vancomycin were 5-20 times higher than systemic IV despite the lower dose. This study was sponsored by Teleflex Incorporated.

YEAR: 2016

Adams TS, Blouin D, Johnson D. Effects of tibial and humerus intraosseous and intravenous vasopressin in porcine cardiac arrest model. Am J Disaster Med 2016;11(3):211-8. doi:10.5055/ajdm.2016.0241

896

This study compared maximum concentration time (Cmax) to maximum concentration mean (Tmax) of mean serum concentration of vasopressin, return of spontaneous circulation (ROSC), time to ROSC, with odds of survival to vasopressin administration by tibial intraosseous, proximal humerus intraosseous (PHIO), and intravenous (IV) routes in a cardiac arrest model. Authors concluded TIO and PHIO provide rapid and reliable access in administration of life-saving medications during cardiac arrest and may be faster due to IV difficulty.

Bramlett E, Fales W, West B, LaBond V. Rate of return of spontaneous circulation in relation to primary vascular access during out-of-hospital adult cardiac arrest. Ann Emerg Med 2016;68(4S):S120

812

Investigators conducted a retrospective prehospital study over a 3 month time period comparing IV vs. IO access for return of spontaneous circulation (ROSC). With approximately 800 cases of out-of-hospital cardiac arrest (OOHCA) they found a significantly greater success rate for IO access but no difference between IO and IV for ROSC or time to first epinephrine.

Burgert JM, Johnson AD, Garcia-Blanco J, et al. The effects of proximal and distal routes of intraosseous epinephrine administration on short-term resuscitative outcome measures in an adult swine model of ventricular fibrillation: A randomized controlled study. Am J Emerg Med 2016;34:49-53. doi:10.1016/j.ajem.2015.09.007

778

Preclinical RCT evaluating the relationships between the anatomical distance of IO epinephrine and measures of resuscitative outcome in an adult swine model of ventricular fibrillation (VF). There were no significant differences between the HIO, TIO, and IV groups relative to the occurrence of ROSC, 30-minute post-ROSC survival, and time to ROSC. The anatomical distance of IO epinephrine injection from the heart did not affect short-term measures of resuscitative outcome in an adult swine model of VF including the occurrence of ROSC, 30 minute post-ROSC survival, and time to ROSC. Rapidly administered epinephrine, irrespective of route of administration, increased the chance of ROSC and survival to 30 minutes post-ROSC in this study.

Chin YX, Kiat Tan KB, Koh ZX, et al. Comparing intraosseous and intravenous access for out-of-hospital cardiac arrest in Singapore. Resuscitation 2016;106(S1):e25

813

The objective of this study was to determine if there would be a difference in rates of vascular access and ROSC if paramedics were able to use IO access after two initial IV attempts failed. Investigators found higher vascular access success and prehospital epinephrine administration rates with the addition of IO access but no significant difference for ROSC.

Singapore

Intraosseous Vascular Access Bibliography

Clinical, Observational and Other Studies

- Cornell M, Kelbaugh J, Todd B, et al. Pharmacokinetics of sternal intraosseous atropine administration in normovolemic and hypovolemic swine. *Am J Disaster Med* 2016;11(4):233-6. doi:10.5055/ajdm.2016.0244** 911
- This prospective, experimental study was to characterize and compare the pharmacokinetics of atropine that is administered via sternal intraosseous (IO) route in hypovolemic and non-hypovolemic swine. Main outcomes PK parameters, maximum concentration (Cmax) and time to reach maximum concentration (Tmax). Authors concluded sternal IO route is effective for administration of atropine and data gained from this study was found to be similar to previous information reported on tibial IO and IV administration even in situations of significant hemorrhage.
- Davilantes C, Miller LJ, Montez DF, Puga TA, Philbeck TE. Intraosseous catheter dwell-time appears safe for up to 48 hours: A preliminary report. *The Journal of Vascular Access* 2016;17(4):e26** 782
- The abstract describes the interim results of an investigational device exemption study evaluating use of EZ-IO in volunteers for a 48 hour dwell time period. At the time of the report, 39 subjects completed the study with no serious adverse event reports. Subjects were randomized to receive IO insertion in the proximal tibia or proximal humerus insertion sites. Pain has been managed using oral hydrocodone/acetaminophen and/or intravenous/intramuscular ketorolac. This study is sponsored by Teleflex Incorporated.
- Davilantes C, Puga T, Montez D, Philbeck T, Miller L, DeNoia E. 48 hours dwell time for intraosseous access: A longer-term infusion using a temporary solution. *Crit Care Med* 2016;44(12)Suppl.:140** 820
- This study conducted as an IDE was conducted to evaluate the safety of IO access for a period up to 48 hours, in healthy or stable health-compromised (with diabetes or renal failure stage 2) adult volunteer subjects. The IO site was randomized to the proximal humerus or proximal tibia, and once placed the catheter was left in place with an infusion of 0.9% sodium chloride for 48 hours. 120 subjects completed the study with no serious complications. Investigators also found infusion pain can be managed with oral analgesics and an infusion of 30 mL/ hour maintained patency. This study was sponsored by Teleflex Incorporated.
- Engels P, Erdogan M, Widder S, et al. Use of intraosseous devices in trauma: A survey of trauma practitioners in Canada, Australia and New Zealand. *Can J Surg* 2016;59(6):374-82 doi:10.1503/cjs.011215** 918
- This study was conducted to determine the level of experience as well as the beliefs and attitudes of trauma practitioners in Canada, Australia and New Zealand about using IO devices in adult trauma patients. The study used a web-based survey submitted to 1771 to all members of 4 national emergency and trauma organizations. Surveys were completed by 425 participants and most participants surveyed were comfortable using the IO device in resuscitation of adult trauma patients.
- Johnson M, Inaba K, Byerly S, et al. Intraosseous infusion as a bridge to definitive access. *Am Surg* 2016;82(10):876-80** 826
- This retrospective study examined indications and outcomes associated with IO use at a Level 1 trauma center from 2008-2015. All 68 IO placements were with the EZ-IO device; most patients had trauma diagnoses. Most IO placements were successful on first attempt within 3 minutes of arrival. Non-serious extravasation was the most common complication. Authors concluded IO access "should be considered as a rapid, low risk, high yield aid to long-term IV access in both adults and children, and is an important bridge to definitive access in resuscitation".
- Kehrl T, Becker BA, Simmons DE, Broderick EK, Jones RA. Intraosseous access in the obese patient: Assessing the need for extended needle length. *Am J Emerg Medicine* 2016;34(9):1831-4. doi:10.1016/j.ajem.2016.06.055** 780
- This study examined the relationship between body mass index (BMI), the ability to palpate the tibial tuberosity (TT), and soft tissue depth at recommended IO insertion sites in obese patients using ultrasound. Authors concluded in obese adults with a palpable TT or BMI \leq 43, a 25 mm IO needle is likely adequate at the proximal and distal tibial insertion sites; and at the proximal humerus site a 45 mm is recommended.
- Kudenchuk PJ, Brown SP, Daya M, et al. Amiodarone, lidocaine, or placebo in out-of-hospital cardiac arrest. *N Engl J Med* 2016;274:1711-22** 880
- Authors described a randomized, double-blind trial, comparing parenteral amiodarone, lidocaine, and saline placebo, along with standard care, in adults who had non-traumatic out-of-hospital cardiac arrest, shock-refractory ventricular fibrillation or pulseless ventricular tachycardia after at least one shock, and vascular access (N=3026). The focus of the study was not intraosseous access, but eligible patients had intravenous or intraosseous access (n=661).
- Martinez AM, Pardo ML, Ricarcdio JH.. Perception of discomfort during injection and the need for supplemental anesthesia in the intraosseous technique using 4% articaine. *Acta Odontol Latinoam* 2016;29(3):214-8.** 953
- This article describes an experimental study to determine patient perception of discomfort during IO injection for dental procedures involving the mandibular molars. Subjects (N=70) received either IO injection (N=35) or inferior alveolar nerve block (N=35) with articaine/epinephrine. Both groups reported similar rates of supplemental injection (P=0.80) while the IO group reported less perceived discomfort (P=0.00), differing statistically.
(Colombia)

Intraosseous Vascular Access Bibliography

Clinical, Observational and Other Studies

- Mittiga MR, FitzGerald MR, Kerrey BT. A survey assessment of perceived importance and methods of maintenance of critical procedural skills in pediatric emergency medicine. *Pediatr Emerg Care* 2016;0(0):1-6.[Epub ahead of print]** 996
- This paper describes a survey of pediatric emergency medicine physicians assessing the perceived importance of six critical procedural skills, including intraosseous line placement, in pediatric emergency medicine. IO line placement was perceived as extremely important by 80% of physicians surveyed.
- Montez D, Puga T, Davlantes C, Philbeck T. IO infusion pain mitigation in the sternum and proximal humerus: Establishing a regimen. *Crit Care Med* 2016;44(12 Suppl):154** 822
- A prospective study with 30 evaluable healthy volunteers receiving PH and sternal IO access (Arrow® EZ-IO® Vascular Access System and T.A.L.O.N.™, Teleflex, Wayne, PA) was conducted to determine if there is a significant difference between pain after a total of 60mg or 40mg of 2% preservative- free and epinephrine- free lidocaine. Endpoints were subject reported pain scores during 5 minutes of rapid infusion at 300 mmHg and 15 and 30 minutes at a rate of 125 mL/hour per pump. Authors concluded infusion pain through a PH IO may be managed with a single 40mg lidocaine prior to infusion, but a total of 60mg may be considered for sternal IO infusion. This study was sponsored by Teleflex Incorporated.
- Penketh J, McDonald M, Kelly FE. EZ-IO® intraosseous access teaching in the workplace using a mobile 'tea trolley' training method. *Resuscitation* 2016;99:e17-8. doi:10.1016/j.resuscitation.2015.11.016** 860
- This letter to the editor describes a novel training technique employed to provide training to clinicians on use of the EZ-IO system, in 15-minute sessions. Implementation of this program has resulted in 97% of participants reporting an increase in confidence using the EZ-IO system and 100% were able to correctly identify the locations of the devices for their clinical areas.
- United Kingdom
- Philbeck TE, Montez DF, Puga TA, Davlantes C, Miller LJ. Infusion flow rates and insertion success through the sternum using a multi-site intraosseous device. *J Vasc Access* 2016;17(4):e131** 784
- This abstract describes the results of a healthy volunteer study evaluating use of the EZ-IO TALON in the sternal IO insertion site. IO infusion flowrate was measured and reported for gravity infusion, as well as pressured infusions at 100, 200, and 300 mmHg. The authors concluded the TALON device may be used safely and successfully in the sternum with excellent infusion flow rates. This study was sponsored by Teleflex Incorporated.
- Puga T, Montez D, Philbeck T, Davlantes C. Adequacy of intraosseous vascular access insertion sites for high-volume fluid infusion. *Crit Care Med* 2016;44(12 Suppl):143** 821
- This study was completed on 30 healthy subjects to evaluate infusion rates via the sternum (SIO) and proximal humerus (PH) sites under 300 mmHg via pressure bag. The mean SIO infusion rate was 9,587±2,706mL/hr (n=27); mean PH infusion rate was 6,292 ±3,277mL/hr (n=52). There were no serious complications; minor complications were 5 cases of excess pain, 2 cases vagal response, and mammary tissue engorgement. The mean PH flow rate was significantly lower than that of SIO, but placing IO catheters in each humeri with simultaneous infusion could result in fluid delivery of 13,000mL/hr, surpassing that of the sternum. This study was sponsored by Teleflex Incorporated.
- Ramirez JG, Truszewski Z, Drozd A. Comparison of two intraosseous access devices employed during simulated cardiopulmonary resuscitation. *Disaster Emerg Med J* 2016;1(1):24-9. doi:10.5603/DEM.J.2016.0004** 857
- A study comparing use of the Bone Injection Gun (B.I.G.) and the NIO by paramedics in a manikin model simulation of CPR. Following training, 40 paramedics performed device insertion in the manikin using both devices; and completed a questionnaire regarding their knowledge of indications and contraindications of IO access and experience with each device. Successful insertion was achieved 100% with the NIO and 95% with the B.I.G. Authors concluded that after a short training program, paramedics can perform intraosseous injection with a high degree of efficacy.
- Ross EM, Mapp J, Kharod CU. Time to epinephrine in out-of-hospital cardiac arrest: A retrospective analysis of intraosseous versus intravenous access. *Ann Emerg Med* 2016;68(4S):S61** 811
- This retrospective study evaluated 3 years of data in an urban EMS system to determine if out-of-hospital intraosseous (IO) access results in shorter time to epinephrine than peripheral intravenous (PIV) access. The proximal humerus was the most common IO access site with a first pass IO success rate of 95.6%; and a significantly lower complication rate when compared to the tibia. Authors reported the time to epinephrine administration was faster in the IO access group; and concluded the out-of-hospital use of IO vascular access for time-dependent medical conditions is recommended.
- Savelli S, Mora AG, Perez CA, Bebart VS, Maddry JK. En route intraosseous access performed in the combat setting. *Am J Disaster Med* 2016;11(4):225-31. doi:10.5055/ajdm.2016.0243** 847
- A retrospective study evaluating vascular access routes used for US Military personnel injured in combat and transported by MEDEVAC. Medical records were reviewed for intravenous (IV) and intraosseous (IO) use including, number of attempts and rates of success; along with events occurring in transit, hospital and ICU stays and 30 day outcomes. Results showed IV and/or IO access was attempted in 832 patients. PIV was first line of attempt in 758 cases with 93% success; IO access was first line of attempt in 74 cases with 85% success. There were 25 attempts to establish IO as the second line of access with 100% successful placement. Success rates were 100% with tibia (29); 94% with humerus (21/22); and 89% with the sternum (41/46). The overall IO success rate was 88% for all attempts made.

Intraosseous Vascular Access Bibliography

Clinical, Observational and Other Studies

- Singh S, Aggarwal P, Lodha R, et al. Feasibility study of a novel intraosseous device in adult human cadavers. Indian J Med Res 2016;143:275-80. doi:10.4103/0971-5916.182616** 861
A cadaveric study evaluating the function and safety of a manual, screw IO device designed to gain access to the medullary space. Twelve insertions were performed by the same device operator, of which 10 were successful. The 2 failed insertions were due to overshooting of the needle. The authors concluded the new device could successfully penetrate the bone cortex in adult cadaver bones, and that further testing and comparison to commercially available devices is needed.
India
- Smereka A, Stawicka I, Czyzewski L. Nurses' knowledge and attitudes toward intraosseous access: Preliminary data. Am J Emerg Med 2016;34(8):1724. doi:10.1016/j.ajem.2016.06.031** 850
A survey study evaluating the perception and use of intraosseous vascular access among nurses in Poland. The study included 210 respondents. Fifteen (15) had previous experience with IO access and 10.9% had received intraosseous access training, suggesting a low level of knowledge. The authors concluded that providing intraosseous vascular access training to nurses will help improve their perception of IO access.
Poland
- Smereka J, Madziala M, Szarpak L. Are firefighters able to perform intraosseous access and start fluid resuscitation in an anaphylactic patient. Am J Emerg Med 2016;34(8):1707-8. doi: 10.1016/j.ajem.2016.05.068** 851
This letter to the editor describes a simulation study evaluating use of the NIO device by 47 firefighters in a simulated anaphylactic shock model. The firefighters were trained on use of the device and standard anaphylactic shock management. An improvement in knowledge of intraosseous vascular access and anaphylactic shock protocol was demonstrated by the group.
- Szarpak L, Czyzewski L, Woloszczuk-Gebicka B, Krajewski P, Fudalej M, Truszewski Z. Comparison of NIO and EZ-IO intraosseous access devices in adult patients under resuscitation performed by paramedics: A randomized crossover manikin trial. Am J Emerg Med 2016;34(6):1166-7. doi:10.1016/j.ajem.2016.03.017.** 774
This randomized crossover manikin trial compared the NIO and EZ-IO devices for time to placement and ease of use. For both parameters the NIO performed better.
Poland
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A questionnaire study among sixty junior doctors, in Poland, regarding their knowledge of intraosseous vascular access. The authors concluded the level of knowledge was insufficient.
- Szarpak L, Ramirez JG, Buljan D, Drozd A, Madziala M, Czyzewski L. Comparison of Bone Injection Gun and Jamshidi intraosseous access devices by paramedics with and without CBRN person protective equipment. A randomized, crossover, manikin trial. Am J Emerg Med 2016;34(7):1307-8. doi:10.1016/j.ajem.2016.04.032** 843
A manikin study in which 40 paramedics dressed with and without CBRN PPE attempted to establish tibial intraosseous (IO) access using the jamshidi and BIG devices, time to placement was measured. Results showed that in participants with and without CBRN PPE, BIG access was faster than Jamshidi.
- Szarpak L, Truszewski Z, Smereka J, et al. A randomized cadaver study comparing first-attempt success between tibial and humeral intraosseous insertions using NIO device by paramedics. Medicine 2016;95(20):e3724. doi:10.1097/MD.0000000000003724** 845
A prospective study comparing use of the NIO device by 84 paramedics to establish proximal humerus and proximal tibia intraosseous (IO) access for first attempt success rate, time to access, and user feedback on ease of use and preference. IO access was established in fresh (within 72 hours of expiration) cadavers. The first attempt success rate with tibial IO access was 89.3% vs 73.8% humeral; procedure time was significantly faster for the tibial IO site; and participants found IO access in the proximal tibia as easier to obtain than the proximal humerus IO site.
- Szarpak L, Truszewski Z, Smereka J, Krajewski P, Fudalej M. Ability of paramedics to perform intraosseous access. A randomized cadaver study comparing EZ-IO and NIO devices. Resuscitation 2016;104:e5-e6. doi:10.1016/j.resuscitation.2016.04.011** 795
This letter to the editor describes a prospective, randomized, cross-over cadaveric study that evaluated use of the EZ-IO and NIO devices by novice paramedic device users. Following a brief in-service on use of both devices and practice insertions using a leg-trainer manikin, each participant attempted to establish IO access using each device in a resuscitation simulation with in an adult cadaver with CPR in progress. Results showed first attempt success rates of 97.4% with the NIO and 100% with the EZ-IO; and mean time to insertion was 16.8 seconds with the NIO and 42 seconds with the EZ-IO.

Intraosseous Vascular Access Bibliography

Clinical, Observational and Other Studies

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- This article describes a questionnaire study regarding knowledge and application of intraosseous vascular access among 420 clinical medical staff in 8 Beijing Hospitals. Based upon results of the questionnaire, the authors concluded that the awareness rate of intraosseous infusion in Chinese medical staffs and carry-out rate in the hospital is very low and strengthening of knowledge and training is necessary.
- Woodhart B, Shaw J. A study to determine the EZ-IO intraosseous infusion system success rate, including impact on return of spontaneous circulation. Emerg Med J 2016;33:e5. doi: 10.1136/emered-2016-206139.19** 1034
- This is an abstract of a study conducted in the UK to determine the success rate of the EZ-IO Intraosseous Infusion System on return of spontaneous circulation (ROSC). Patient records were examined for 195 cardiac arrest patients who had an EZ-IO placement attempt. ROSC was achieved for 29% of patients. In patients who received IV administration of medications, 46% achieved ROSC. While IV access appears more favorable in this study, there may be other factors associated with achieving ROSC that were not taken into account.
- Zasko P, Szarpak L, Kurowski A, Truszewski Z, Czyzewski L. Success of intraosseous access procedure in simulated adult resuscitation. Crit Care Resusc 2016;18(2):134** 834
- A simulation study comparing use of peripheral IV access and tibial intraosseous access via the NIO device, by internal medicine specialists. Forty-three participants attempted to establish access using the two methods in a manikin; first attempt success, time to access and ease of procedure were measured. The NIO device was superior to IV access with regard to all endpoints.
- YEAR: 2015**
- Chreiman KM, Kim PK, Garbovsky LA, Schweickert WD. Blueprint for implementing new processes in acute care. J Trauma Nurs 2015;22(5):266-73** 793
- This article describes the strategies used at one hospital (Penn Presbyterian Medical Center) to increase the use of intraosseous catheter to rescue patients in all care settings.
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- This crossover study using mature mini-swine was performed to assess the efficacy of intraosseous administration of contrast agents for CT (computed tomography) imaging of the chest and abdomen. Authors concluded that in the model used, an injection intraosseous (IO) of contrast through the proximal humerus resulted in improved quality of trauma-protocol CT images.
- Douma M, Bara G, O'Dochartaigh D, Brindley P. Double-barrelled resuscitation: a feasibility and simulation study of dual-intraosseous needles into a single humerus. Injury 2015;46(11):2239-42. doi:10.1016/j.injury.2015.08.029** 915
- This study examined whether the use of dual-intraosseous needles to deliver fluid and medication when vascular access is insufficient. The study used a single porcine humerus. The authors concluded that dual intraosseous needles are feasible and may help the rapid resuscitation of patients.
- Eriksson M, Strandberg G, Lipcsey M, Larsson A. Intraosseös provtagning kan vara vardefull i akuta lagen [Intraosseous sampling can be valuable in emergency situations]. Lakartidningen 2015 Feb 24;112pii:DCR3. Swedish** 789
- This article in Swedish describes a study evaluating use of aspirate obtained from the IO space for laboratory analysis. The authors note that point-of-care equipment should be used for analysis. Creatinine, morphine and troponin was successfully analyzed; leucocytes and platelets were noted to possibly cause falsely elevated values.
- Eriksson M, Strandberg G, Lipcsey M, Larsson A. Troponin I can be determined in intraosseous aspirates in a porcine shock model. Clin Lab 2015;doi:10.7754/Clin.Lab.2015.141212** 758
- A preclinical study in which 8 anesthetized swine were put into an induced septic shock state to allow troponin I level measurements to be compared from serial venous plasma, arterial plasma and intraosseous aspirate specimens collected hourly. Two milliliters of IO aspirate were wasted before collecting each IO specimen for analysis. The levels of IO troponin I increased during the first 3 hours of shock but then plateaued at a high level while the venous and arterial levels continued to increase. Authors concluded that troponin I can be analyzed in bone marrow aspirates in a shock model and that this information may be useful in medical emergencies where cardiac damage is suspected to be involved.
- Hammer N, Möbius R, Gries A, Hossfeld B, Bechmann I, Bernhard M. Comparison of the fluid resuscitation rate with and without external pressure using two intraosseous infusion systems for adult emergencies, the CITRIN (comparison of intraosseous infusion systems in emergency medicine)- study. PLoS ONE 2015;10(12):e0143726. doi:10.1371/journal.pone.0143726** 791
- A cadaveric study performed by twenty-seven medical students, inexperienced with IO vascular access, that compared use of the EZ-IO for access in the proximal humerus and proximal tibia insertion sites and the FASTR for access in the sternum. First pass insertion success, insertion times, and one minute flow rates using external pressures from 0 to 300 mmHg were evaluated. The authors concluded that both the EZ-IO and FASTR devices may be effective IO devices and are likely suitable for fluid resuscitation using a pressure bag.

Intraosseous Vascular Access Bibliography

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- Retrospective analysis of IO needle insertions performed in all HEMS missions during the first three years (2009-2011) using the EZ-IO® system. Overall success rate of EZ-IO procedures (N=348) was 99.6%, with a first attempt success rate of 85.9%; and high user satisfaction rate of 93%. IO as access was mostly second line overall but first line in children <7, trauma and cardiac arrest. There was one failure and four needle insertion problems noted; no serious complications.
- Germany
- Lantos D, Goforth D. Intraosseous needles reduce time to first medication for coding inpatients without intravenous access. *Crit Care Nurse* 2015;35(2):e69** 948
- This abstract describes data from a small hospital study after a 2013 policy change which allowed rapid response team nurses to place IO access for in-hospital cardiac arrests. Prior to the change the mean time to first medication was 4.3 minutes with 53.1% patients surviving to ICU. Post-policy change patients that received IO access had a mean time to medication of 1.7 minutes and 85.7% survival to ICU.
- Lee PMJ, Lee C, Rattner P, Wu X, Gershengorn H, Acquah S. Intraosseous versus central venous catheter utilization and performance during inpatient medical emergencies. *Crit Care Med* 2015;doi: 10.1097/CCM.0000000000000942** 762
- This single center, prospective, observational clinical study compared use of intraosseous (IO) access to central venous catheter (CVC) access for inpatient medical emergencies, managed by the medical emergency team (MET), within an urban teaching hospital. CVC access training included percutaneous, landmark-guided CVC placement without ultrasound guidance, using the femoral vein as the primary site. For IO access, the proximal tibia was the primary site and proximal humerus was secondary. Results showed IO access was significantly superior to CVC access with regard to first pass success rates, overall success rates, time to placement, and number of attempts for proper placement. On average more CVC kits were used per patient; complications were greater with CVC. There was one serious complication of tissue necrosis secondary to extravasation in the IO group.
- Montez DF, Puga T, Miller L, et al. Intraosseous infusions from the proximal humerus reach the heart in less than 3 seconds in human volunteers. *Ann Emerg Med* 2015;66(4s):S47. <http://dx.doi.org/10.1016/j.annemergmed.2015.07.165>** 771
- In a healthy adult volunteer study contrast media was injected through the proximal humerus site and captured under fluoroscopy as it entered the heart. The mean time it took from injection at the insertion site to visualize contrast entry into the superior vena cava and the right atrium was 2.42 seconds. Abstract presented at ACEP 2015. This study was sponsored by Teleflex Incorporated.
- Ohchi F, Komazawa N, Mihara R, Minami T. Comparison of mechanical and manual bone marrow puncture needle for intraosseous access; a randomized simulation trial. *Springer Plus* 2015;doi:10.1186/s40064-015-0982-y** 766
- A simulation study comparing use of manual (Cook Medical) and mechanical (Arrow EZ-IO) intraosseous (IO) devices to establish IO access in mannequin bones representing infant, pediatric and adult tibias. Twenty-two anesthesiologists with no prior experience with IO devices participated in the study. The outcome measures were success rate, insertion time and operator reported difficulty of use. Results were in favor of the mechanical device for insertion time in each category, and success rate in the adult tibia group; there was no statistical difference in the difficulty of use evaluation.
- Overbaugh R, Davlantes C, Miller L, Montez D, Puga T, Philbeck TE. Intraosseous vascular access catheter appears safe during extended dwell: a preliminary report. *Ann Emerg Med* 2015;66(4):S5** 772
- Abstract describing preliminary results for the first 24 subjects of an EZ-IO study evaluating catheter dwell times for 48 hours. Initial data indicate that IO vascular access can be safely maintained for a period up to 48 hours without risk of osteomyelitis or other serious adverse events. Authors also noted that additional analgesics for IO infusion pain management may be more effective than the current solely administering lidocaine into the IO space. This study was sponsored by Teleflex Incorporated.
- Pasley J, Miller CHT, DuBose J, et al. Intraosseous infusion rates under high pressure: a cadaveric comparison of anatomic sites. *J Trauma Acute Care Surg* 2015;78(2):295-9. DOI: 10.1097/TA.0000000000000516** 750
- A cadaveric study evaluating intraosseous (IO) vascular access insertion sites for attainable flow rates under 300 mmHg. The EZ-IO was used to establish IO access at the proximal humerus and proximal tibia sites; the FAST1 was used to establish sternal IO access. The total volume of fluid infused at the three IO access sites was 469 ± 190 mL for the sternum; 286 ± 218 mL for the humerus; and 154 ± 94 mL for the tibia. The mean flow rate infused at each site was as follows: 93.7 ± 37.9 mL/min for the sternum; 57.1 ± 43.5 mL/min for the humerus; and 30.7 ± 18.7 mL/min for the tibia. First attempt placement success was 100% for the sternum and proximal humerus and 81% for the tibia.
- Paxton J, Wilburn J, Ottolini J, Sherwin R. Does the choice of initial vascular access device delay cardiac arrest resuscitation? *Crit Care Med* 2015;43(12 Suppl):46. doi: 10.1097/01.ccm.0000474007.72329.42. abstract 179** 862
- This abstract describes pilot data regarding initial vascular access device use in emergency department management of patients with out-of-hospital cardiac arrest. Twenty-six patients were included, and only 10 arrived to the ED with venous access established in the field: 4 via intraosseous and 6 via peripheral IV. Of the 16 subjects without access upon ED arrival, PIV was selected for 12 and IO was selected for 4. Nine patients experienced a delay in obtaining access attributed to the selection of PIV as the initial mode of gaining access. Median time required for access was reported as: 50 seconds for IO; 95 seconds for PIV and 780 seconds for CVC. The authors concluded that selection of PIV as the initial access method may be associated with delayed vascular access in the ED.

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- Paxton JH, Ottolini J, Wilburn JM, Sherwin RL, Courage C. Does the choice of vascular access device delay appropriate emergency department resuscitation of adult out-of-hospital cardiac arrest patients? *Ann Emerg Med* 2015;66(4s):s35** 924
- This abstract describes a pilot observational study of vascular access devices (VAD) and their use in management of 20 out of hospital cardiac arrest patients. VAD selected, number of attempts for successful placement and time to insertion were recorded. Twenty patients were included in this study, 10 of whom received IO access upon ED arrival.
- Paxton JH, Ottolini J, Wilburn JM, Sherwin RL, Courage C. Does the choice of vascular access device delay appropriate emergency department resuscitation of adult out-of-hospital cardiac arrest patients? *Ann Emerg Med* 2015;66(4s):s35** 863
- An abstract describing preliminary data evaluating the effect of initial vascular access device selection on the management of out-of-hospital cardiac arrest (OOHCA) patients by the ED. Twenty patients were included. Success rate by vascular access device selected was: 66% IO lines (2/3); 25% for PIV lines (3/12); and 100% for CVC (1/1). Eight patients experienced a delay in access due to initial method selected, 7 were attributed to PIV and 1 to IO. The authors concluded that the results suggest use of PIV as the initial mode of access may be associated with delays in access when compared to IO access in patients with OOHCA.
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- A healthy volunteer study evaluating use of the EZ-IO TALON in the sternal IO insertion site. Military trained medics performed all device insertions. IO infusion flowrate was measured and reported for gravity infusion, as well as pressured infusions at 100, 200, and 300 mmHg. The authors concluded the TALON device may be used by military and tactical medicine personnel to safely and successfully establish IO access in the sternum with excellent infusion flow rates. This study was sponsored by Teleflex Incorporated.
- Pifko EL, Busch C, Price A, et al. An observational review of pediatric intraosseous needle placement in the pediatric emergency department. *Ann Emerg Med* 2015;66(4s):S87** 754
- A retrospective study evaluating attempts to establish intraosseous vascular access in pediatric patients using a manual device and the EZ-IO, in a tertiary care pediatric emergency department. Results showed 35 patients had IO access attempted using manual and EZ-IO devices. In patients greater than and less than 8kg the EZ-IO had a higher success rate but time to placement was longer. Overall success rate including both devices was 64%. There were 2 complications of transient leg swelling after EZ-IO placement in 2 patients.
- Reuter-Rice K, Patrick D, Kantor E, Nolin C, Foley J. Characteristics of children who undergo intraosseous needle placement. *Adv Emerg Nurs J* 2015;37(4):301-7. doi:10.1097/TME.0000000000000077** 854
- A retrospective study evaluating the use of pre-hospital and emergency department placed IO access in children before transport to a children's hospital. Data were extracted from a Level 1 trauma, tertiary care children's hospital transport database from 1993-2009. There were 143 eligible patients with an average transport distance of 33 miles; all but 8 catheters were placed by the ED. The most common reasons for IO placement were no IV access (53%) and no perfusion (33.6%); the most commonly reported complication was infiltration (27.3%); 46.9% of patients experienced no complication. The authors concluded IO access plays a significant role in promoting life-saving efforts when IV access is unachievable or no perfusion is determined.
- Rubal BJ, Meyers BL, Kramer SA, Hanson MA, Andrews JM, DeLorenzo RA. Fat intravasation from intraosseous flush and infusion procedures. *Prehosp Emerg Care* 2015;19(3):376-90. doi: 10.3109/10903127.2014.980475** 748
- This preclinical study evaluated the occurrence of fat intravasation resulting from intraosseous (IO) flush and infusion in anesthetized swine. Intravasated fat was assessed using a lipophilic fluoroprobe (Nile red) and by vascular ultrasound imaging. Fat intravasation was observed during all IO infusion regimens, with subclinical pulmonary fat emboli persisting 24 hours post infusion. It was noted that initial flush was a significant factor in fat intravasation, low levels of intravasation occurred with infusions ≤ 300 mmHg, fat intravasation and bone marrow shear-strain increased with IO infusion rates, and intravasation was influenced by cannula insertion site.
- Salzman J, Burnett A, Frascione R, et al. Intraosseous pressure monitoring in critically ill and injured patient. *Crit Care Med* 2015;43(12 Suppl):abstract 183:47. doi: 10.1097/01.ccm.0000474011.25695.a8** 848
- A pilot study evaluating the relationship between intraosseous (IO) pressure measurements and blood pressure obtained via external blood pressure cuff in ICU patients. Patients with IO access established by EMS or in the emergency department with planned admission to the ICU or surgical ICU were included in the study. External pressures were recorded every 15 minutes and IO pressure was monitored via a transducer for 12 continuous hours. Results showed IO pressures were approximately 30% of external blood pressure cuff readings.
- Salzman JG, Frascione RJ, Zagar AE et al. Intraosseous pressure monitoring in critical care patients. *Ann Emerg Med* 2015;66(4s):S148** 755
- The authors described a proof of concept pilot study conducted to determine intraosseous (IO) pressure measures and their relationship to blood pressure obtained using an external blood pressure cuff in ICU patients. The average IO systolic blood pressure, IO diastolic blood pressure, and IO mean were 39.5 ± 12.7 mm Hg, 31.5 ± 7.6 mmHg, and 35.0 ± 8.8 mm Hg respectively. The ratio of IO systolic blood pressure to cuff systolic blood pressure, IO diastolic blood pressure to cuff diastolic blood pressure, and IO mean to cuff mean are $34.5 \pm 13.4\%$, $40.5 \pm 22.3\%$, and $40.1 \pm 17.1\%$ respectively. There were no adverse events reported. Investigators concluded that in their convenience sample of severely ill and injured patients, IO pressure was reliably obtained and appeared to be 35% to 40% of blood pressure readings obtained via external blood pressure cuff; and that this method of pressure monitoring may be an appropriate alternative to invasive monitoring option in the future. This study was sponsored by Teleflex Incorporated.

Intraosseous Vascular Access Bibliography

Clinical, Observational and Other Studies

Stimac J, Paxton J. The "Golden Hour" of volume resuscitation: Pilot data from the shock access for emergent resuscitation (SAFER) study. *Ann Emerg Med* 2015;66(4s):S110

1010

This abstract describes a study (SAFER) reporting initial emergency department efforts in obtaining adequate vascular access (AVA) and initiating appropriate fluid resuscitation for hypovolemic patients with undifferentiated hypotension within the first 60 minutes following ED arrival. AVA was defined as any two of the following: PIV, IO, or CVC catheter. No data was given regarding time to IO access in the results

Suominen P, Nurmi E, Lauerma K. Intraosseous access in neonates and infants: Increased risk of compartment syndrome and leg amputation. *Resuscitation* 2015;96(Suppl 1):S131-2. <http://dx.doi.org/10.1016/j.resuscitation.2015.09.313>

1024

This is an abstract of a study that analyzed possible technical and anatomical factors leading to the complication of amputation as a result of IO placement. The study was prompted by a case report of amputation in a neonate after IO access using the EZ-IO device. The study measured medullary diameter of the proximal tibia at the recommended IO access site in three groups: 1-28 day old full term neonates, 1-12 month old infants, and 3-4 year old children. The mean diameter in each group was 7.7 mm, 9.9 mm, and 12.4 mm, respectively. The small size of the IO space, especially in neonates and infants, makes correct placement difficult. As such, complications should be taken into consideration in this patient population.

Ventura AMC, Shieh HH, Bouso A, et al. Double-blind prospective randomized controlled trial of dopamine versus epinephrine as first-line vasoactive drugs in pediatric septic shock. *Crit Care Med* 2015;43(11):2292-302. doi:10.1097/CCM.0000000000001260

840

This article describes a prospective double-blind randomized controlled study evaluating the difference between use of dopamine and epinephrine as first-line vasoactive drug in pediatric septic shock patients. This study conducted in the pediatric intensive care unit (PICU) of Hospital Universitario da Universidade de Sao Paulo, Brazil. One hundred twenty-one patients aged 1 month to 15 years who met criteria were randomized to receive either epinephrine (n=57) or dopamine (n=63) via IV or intraosseous (IO) vascular access (via EZ-IO). The authors concluded dopamine was associated with an increased risk of death and healthcare-associated infection; whereas administration of epinephrine via IV or IO routes was associated with increased survival.

YEAR: 2014

Abbal B, Perbet S, Pereira B, et al. Utilisation de la voie intraosseuse chez l'adulte en France en 2012 [Use of the intraosseous access in adult patients in France in 2012]. *Annales Francaises d'Anesthesie et de Reanimation* 2014;33(4):221-6. <http://dx.doi.org/10.1016/j.annfar.2014.02.006>

696

This article in French is a survey of residents and doctors in France that practice in ED, ICU and anesthesiologists units seeking their opinions and practice habits in regard to IO access. Only 29% had ever used an IO kit; with a correlation between years of experience in practice and use of IO access. 555 had received some IO access training; 90% of untrained doctors believed training was necessary. The powered system was the most utilized (EZ-IO).

France

Anson JA. Vascular access in resuscitation: Is there a role for the intraosseous route? *Anesthesiology* 2014;120(4):1015-31

695

Literature review through August 1, 2013 with primary aim to determine whether there is a role for intraosseous vascular access in the resuscitation of critically ill patients. Secondary aims were to investigate the evidence regarding clinical use, drug administration, and complications of IO access. The authors concluded that IO access can be achieved quickly and accurately in emergency situations and there is clearly a role for it in resuscitation of ill patients; anesthesiologists should become familiar with IO access.

Barnard EBG, Moy RJ, Kehoe AD, Bebart VS, Smith JE. Rapid sequence induction of anesthesia via the intraosseous route: a prospective observational study. *Emerg Med J* 2014;32(6):449-52. doi:10.1136/emmermed-2014-203740

702

A prospective observational study that evaluated use of intraosseous vascular access for delivery of rapid sequence intubation (RSI) drugs. Data was collected between January and May 2012 at a combat hospital in Afghanistan. Thirty-four (34) patients underwent RSI with drug delivery via the IO route. Access was established in the proximal humerus and tibia using the EZ-IO and in the sternum using the FAST-1. All placements were successful on first attempt; first pass intubation success rate was 97%; a Cormack-Lehane (C-L) laryngoscopic grade view of 1 was reported 91%. Authors concluded that IO access is a safe and feasible route for delivery of anesthetic drugs for RSI.

Bebarta VS, Vargas TE, Castaneda M, Boudreau S. Evaluation of extremity tissue and bone injury after intraosseous hypertonic saline infusion in proximal tibia and proximal humerus in adult swine. *Prehosp Emerg Care* 2014;doi:10.3109/10903127.2014.912704

697

Randomized comparative study of adult pigs infused intraosseously with either: 7.5% hypertonic solution (HTS), 3% HTS or normal 0.9% isotonic saline. The animals were observed daily for infection, necrosis and gait up to 5 days, then necropsy and histological analysis was performed for tissue necrosis. Observations included regular tissue morphology and normal gait scores over the 5 day observation period; and absence of gross tissue necrosis and microscopic ischemia post IO HTS infusion in this swine model. Authors concluded this study confirms the clinical safety of IO HTS infusion and its use as an alternative lifesaving treatment.

Intraosseous Vascular Access Bibliography

Clinical, Observational and Other Studies

Burgert J, Mozer J, Williams T, et al. Effects of intraosseous transfusion of whole blood on hemolysis and transfusion time in a swine model of hemorrhagic shock: a pilot study. AANA Journal 2014;82(3):198-202 733

Preclinical study using a porcine model to determine whether there were differences in intraosseous (IO) and intravenous (IV) whole blood transfusion relative to hemolysis and transfusion time. IO transfusion does not significantly increase hemolysis (using free hemoglobin as outcome measure) or transfusion time compared with IV transfusion. Authors concluded transfusion of whole blood through an IO device is an effective transfusion method that may be used until other vascular access is obtained.

Cheung WJ, Rosenberg H, Vaillancourt C. Barriers and facilitators to intraosseous access in adult resuscitations when peripheral intravenous access is not achievable. Acad Emerg Med 2014;21:250-6. doi:10.111/ace.12329 705

This survey study sought to identify the barriers and facilitators to use of intraosseous vascular access for adult resuscitations when peripheral IV (PIV) access is not available, among physicians from various clinical care settings in 3 teaching hospitals in Ottawa, Ontario. Completed survey responses were received from 205 physicians; results suggest that to increase IO use educational interventions need to address their attitudinal, normative, and control beliefs. Specific beliefs that act as barriers are described.

Canada

Demir OF, Aydin K, Akay H, Erbil B, Karcioğlu O, Gulalp B. Comparison of two intraosseous devices in adult patients in the emergency setting: a pilot study. Eur J Emerg Med 2014;DOI:10.1097/MEJ.0000000000000187 735

This was a prospective, randomized controlled clinical pilot study comparing the BIG and EZ-IO intraosseous (IO) vascular access devices in 52 adult patients admitted to an emergency department with difficult peripheral venous access. Twenty-six patients were randomized to each device; results were first attempt insertion success BIG 92.3%, EZ-IO 84.6% ($P=0.668$); procedure time: BIG 2.8 ± 1.2 seconds, EZ-IO 5.2 ± 2.2 seconds ($P<0.001$), significant; difficulty of use (with visual analogue scale): BIG 8.6 ± 6.4 mm, EZ-IO 25.4 ± 12.6 mm ($P<0.001$), significant. Authors concluded both EZ-IO and BIG are shown to be reliable and safe methods for insertion of intravascular access in emergency conditions. There were no adverse events or complications reported.

Turkey

Derikx HJGM, Gerritse BM, Gans R, vander Meer NJM. A randomized trial comparing two intraosseous access devices in intrahospital healthcare providers with a focus on retention of knowledge, skill, and self-efficacy. Eur J Trauma and Emerg Surg 2014;doi:10.1007/s00068-014-0385-8 706

This article describes a randomized trial comparing the retention knowledge, skill and self-efficacy among anesthesiologists and registered nurses of anesthesia with use of the EZ-IO and Bone Injection Gun (B.I.G.). Participants were randomized to be trained on one device and were tested at 0, 3, and 12 months post training. The authors concluded that training anesthesiologists on use of the EZ-IO with the educational tools provided by the manufacturer will ensure optimal performance for a period of one year.

The Netherlands

Fischer H, Bachmann K, Strunk G, et al. Translation of ERC resuscitation guidelines into clinical practice by emergency physicians. Scand J Trauma Resusc Emerg Med 2014;22:9. doi:10.1186/1757-7241-22-9 708

The objective of this study was to use a competency exam to compare different emergency skills and knowledge between out of hospital emergency physicians (OOHEP) and those who are not OOHEP at the time of their mandatory biannual refresher courses. Results from 836 respondents suggested that OOHEP are significantly more likely to initiate intraosseous access, initiate mild-therapeutic hypothermia, and had higher knowledge about the used defibrillator.

Austria

Goldschalt C, Doll S, Ihle B, Kirsch J, Mutzbauer TS. Intraosseous vascular access through the anterior mandible- a cadaver model pilot study. PLoS ONE 2014;9(11):e112686. doi:10.1371/journal.pone.0112686 790

A cadaveric study performed by dentistry and medical students evaluating the feasibility of gaining vascular access via the anterior mandible bone.

Hagglund H, Remberger M, Ringden O. Twenty-year follow-up of a randomized trial comparing intraosseous and i.v. BM transplantation [letter to the editor]. Bone Marrow Transplant 2014;49(12):1541-2. doi: 10.1038/bmt.2014.184 982

This letter to the editor reports the 20 year follow-up of a randomized study comparing IO and IV transplantation of allogeneic hematopoietic stem cells from sibling donors conducted in 1998. At the 20 year follow-up the probability of graft versus host disease, treatment related mortality, and relapse probability were similar between the two groups. None of the patients in the trial developed a secondary malignancy.

Ibrahim M, Cairney K. A comparison of intravenous and intraosseous vascular access during simulated cardiac arrest on an Advanced Life Support course. Resuscitation 2014;85:S20 711

This abstract describes a simulation study that evaluated the time to access and rate of first attempt success for establishing IV and proximal humerus IO access in an ALS training course. Thirty-three participants had a first attempt IV success rate of 70% compared to a 100% success rate with IO access. The authors concluded that successful humeral IO access can be achieved following a short education intervention.

UK

Intraosseous Vascular Access Bibliography

Clinical, Observational and Other Studies

Johnson D, Dial J, Ard J, et al. Effects of intraosseous and intravenous administration of Hextend on time of administration and hemodynamics in a swine model. J Spec Oper Med 2014;14(1):79-85

713

A preclinical study comparing intraosseous (IO) and intravenous (IV) administration of Hextend in 27 swine for time of administration and hemodynamics. IO access was established in the proximal humerus using the EZ-IO. Results showed time for administration was not significant; there were no significant differences between IV and IO relative to hemodynamics. The author concluded that the IO route is an effective method of administering Hextend

Kurowski A, Timler D, Evrin T, Szarpak T. Comparison of three different intraosseous access devices for adults during resuscitation: randomized cross-over manikin study. Am J Emerg Med 2014;32:1490-3. DOI: <http://dx.doi.org/10.1016/j.ajem.2014.09.007>

739

Manikin study conducted in Poland with 107 paramedic operators designed to investigate the success rate, time of insertion and perceived difficulty of intraosseous access devices during simulated resuscitation using the EZ-IO, Bone Injection Gun and Jamshidi needles. Results were first attempt success: B.I.G.: 91.59%; EZ-IO: 82.66%; Jamshidi: 47.66%; mean procedure time: B.I.G.: 2.0 min \pm 0.7; EZ-IO: 3.1 min \pm 0.9; Jamshidi: 4.2 min \pm 1.0; and ease of use (1-very easy to 5-very hard): B.I.G.: 1.83; EZ-IO: 2.92; Jamshidi: 4.68.

Poland

Kwon OY, Park SY, Yoon TY. Educational effect of intraosseous access for medical students. Korean J Med Educ. 2014;26(2):117-24. <http://dx.doi.org/10.3946/kjme.2014.26.2.117>

757

The objective of this study was to evaluate inclusion of IO access in Korean medical education with a selected group of 50 medical students. Students received 1 hour of didactic lecture and a 1 hour hands on session using the EZ-IO and artificial tibias and were tested. Results showed an insertion success rate of 88%. The authors concluded IO access was adequate for medical education in Korea.

Lee BK, Jeung KW, Lee HY, et al. Confirmation of intraosseous cannula placement based on pressure measured at the cannula during squeezing the extremity in a piglet model. Resuscitation 2014;85(1):143-7. doi: 10.1016/j.resuscitation.2013.09.001

678

In this pre-clinical study, investigators sought to determine if the pressure readings at the proximal tibia IO site served as a good indicator of proper IO placement when the foot of the limb was squeezed. Traditional methods used to determine correct IO placement, including needle stability, aspiration of blood, and easy infusion, were used as comparators. Results showed the increased pressure reading at the IO site successfully predicted correct IO placement in all cases; traditional methods did not consistently correctly identify proper IO needle placement.

Lewis P, Wright C. Saving the critically injured trauma patient: a retrospective analysis of 1000 uses of intraosseous access. Emerg Med J 2014;31(9):784. doi:10.1136/emmermed-2014-203588

714

This retrospective study reported IO use over a 7-year period during combat operations in Afghanistan by the UK Defence Medical Services. The EZ-IO and FAST1 IO devices were available for use; IO use data was collected from the front line, during helicopter evacuation and at the combat hospital. A total of 1014 IO devices were inserted into 830 adult patients; various medications infused via IO access are listed. Across all cases there were no serious IO complications and 14 minor complications. The author concluded that in the pre-hospital setting in particular and in severely injured trauma patients, IO access should be considered a primary method of obtaining vascular access.

Lottenberg L, Lovato L, Bloch S, Puga T, Philbeck T. The proximal humerus may be a viable site for contrast injection using a power infuser for CT exam. Crit Care Med. 2014;42(12):abstract 1075.

759

This abstract describes the results of an observational clinical study that evaluated the use of IO vascular access via the proximal humerus insertion site for administration of contrast media for computed tomography examination. Eight subjects were enrolled into the study, 7 procedures were performed successfully with adequate opacification of the images. One subject experienced extreme pain with the contrast injection, the procedure was terminated and an alternative vascular access route was utilized. There were no serious complications reported. This study was sponsored by Teleflex Incorporated.

Loughren M, Banks S, Naluan C, Portenlanger P, Wendorf A, Johnson D. Onset and duration of intravenous and intraosseous Rocuronium in swine. West J Emerg Med 2014;XV(2):241-5

721

A preclinical study comparing the time to onset, time to onset peak, and time to recovery of peripheral intravenous and tibial intraosseous administration of Rocuronium. Study results demonstrated there was no statistical difference from the time of administration to complete neuromuscular blockade between the IO and IV administration of Rocuronium; and the recovery of neuromuscular function was significantly longer after IO administration, however was not deemed clinically significant. The authors concluded that Rocuronium can effectively be used via the IO route without the need for dose adjustments.

Martin Reyes B, Abolafia del Balazo R, Estepa Sanchez A, Garcia Cazalilla M, camara Anguita S, Rojas Jimenez AM. Emergencies medical services: intraosseous drill in CPR. Resuscitation 2014;85(S):S24

715

This abstract describes an observational study evaluating use of the intraosseous drill (EZ-IO) in 20 patients assisted by EMS and receiving CPR within a 3 year period. The study includes 4 pediatric and 16 adult patients. The authors concluded that IO access is a reliable alternative to peripheral venous access and can be implemented fast and with high success rate of CPR in which drugs and fluids are given.

Spain

Intraosseous Vascular Access Bibliography

Clinical, Observational and Other Studies

- Mochizuki T, Yamashita K, Matsushima H, Yoshino A. A practical seminar on intraosseous needle placement (IO) and point-of-care color Doppler ultrasound confirmation. The Journal of Japan Society for Clinical Anesthesia 2014;34(3):429** 752
- This abstract describes a practice seminar held at the 32nd annual meeting of the Japanese Society of Reanimatology for establishing intraosseous vascular access in simulation using the EZ-IO and using Doppler ultrasound to confirm placement. The authors concluded the EZ-IO system enables immediate vascular access to the central circulation and the Doppler method enables objective recognition of needle misplacement.
- Montez D, Puga T, Garcia M, et al. Lactate levels in venous and intraosseous blood correlate; prothrombin time/INR levels do not. Aca Emerg Med 2014;21(5)Suppl1:S304.** 773
- In a series of studies using healthy adult volunteers the objective was to add to available data comparing IO marrow/blood (initial 1 mL aspirate), IO blood (subsequent aspirate), and venous and capillary blood to determine if there is a correlation between samples for serum lactate and PT/INR levels. Two point-of-care analysers were used. Conclusions were lactate levels obtained from IO blood appear comparable to lactate levels from venous blood; the PT/INR levels did not correlate. This study was sponsored by Teleflex Incorporated.
- Nadler R, Gendler S, Chen J, Lending G, Abramovitch A, Glassberg E. The Israeli Defense Force experience with intraosseous access. Military Medicine 2014;179(11):1254-7** 740
- Retrospective study of the Israeli Defense Force (IDF) registry from January 1999 through October 2012 to identify all cases in which IO access was attempted. The Bone Injection Gun (B.I.G.) was the device used for IO access. A total 37 attempts were made in 30 patients. First attempt success was 53% with an overall success rate 49% when factoring subsequent attempts. Most frequent cause for failure related to providers skill level, and due to the device design allowing little room for error. This study prompted the IDF to seek an alternative for the B.I.G.
- Israel
- Pasley J, Miller C, Dubose J, et al. Intraosseous infusion rates under high pressure: a cadaveric comparison of anatomic sites. 2014 Annual Scientific Assembly for the Eastern Assoc for the Surgery of Trauma meeting. <http://www.dtic.mil/cgi-bin/GetTRDoc?AD=ADA597324>. Published January 2014. Accessed May 12, 2014** 728
- This report describes a study conducted by the Air Force Research Laboratory comparing intraosseous infusion rates between IO sites in a cadaveric model to determine if there is a site that is most effective for volume resuscitation. Using 16 cadavers procured within 72 hours of death, IO access was established in the proximal tibia and proximal humerus using the EZ-IO and in the sternum using the FAST1. Results showed the mean flow rate in the sternum was 1.6 times greater than the humerus and 3.1 times greater than the tibia. An abstract describing this report was presented by oral presentation at the 2014 annual scientific assembly for the Eastern Association for the Surgery of Trauma meeting.
- Polat O, Oguz AB, Comert A, Demirkan A, Gunalp M, Tuccar E. Intraosseous access learning curve; is it really practical? Am J Emerg Med 2014; 32(12):1543-4. doi: 10.1016/j.ajem.2014.09.018** 747
- This letter to the editor describes a cadaver study performed by 50 interns who had never performed IO insertion, to determine if there is a learning curve associated with use of the EZ-IO for establishing IO vascular access in the proximal tibia. Following training each intern performed 10 IO insertions and were timed. The results showed a difference between the first and the eighth attempts resulting in a decrease in time to insertion by half. The authors concluded that practice insertions are necessary to become comfortable with the device.
- Turkey
- Rush S, D'Amore J, Boccio E. A review of the evolution of intraosseous access in tactical settings and a feasibility study of a human cadaver model for a humeral head approach. Mil Med 2014;179(8 Suppl):24-8. doi: 10.7205/MILMED-D-13-00484** 726
- This article explores use of IO vascular access in combat and tactical settings through a brief review of the literature describing this practice. A small feasibility study is discussed that evaluated the use of cadavers for training 26 U.S. Air Force Pararescuemen (PJs) on establishing IO access in the humeral head (proximal humerus is the descriptor used by EZ-IO for this site) using the EZ-IO powered driver and needle set system (pictured in the article) and needles inserted with a manual driver without power. First attempt placement success with the EZ-IO powered driver system was achieved in 25 of 26 attempts; first attempt placement success using the manual driver and needle set occurred in 19 of 21 attempts. The authors concluded that the humeral head (proximal humerus) IO site is the most appropriate site within the tactical setting; and that use of a human cadaver model for training is an appropriate model.
- Schlimp CJ, Solomon C, Keibl C, et al. Recovery of fibrinogen concentrate after intraosseous application is equivalent to the intravenous route in a porcine model of hemodilution. J Trauma Acute Care Surg 2014;76(5):1235-42** 717
- A preclinical study comparing the recovery of fibrinogen in a porcine model when fibrinogen concentrate is administered via IV and IO access. The study results suggested intraosseous administration of fibrinogen concentrate results in a recovery of fibrinogen similar to that of intravenous administration.

Intraosseous Vascular Access Bibliography

Clinical, Observational and Other Studies

- Sheils M, Ross M, Eatough N, Caputo ND. Intraosseous access in trauma by air medical retrieval teams. *Air Med J* 2014;33(4):161-4** 718
- This article explores the use of IO access in the prehospital setting to determine if IO access is sufficient for massive fluid resuscitation in trauma patients or if central venous cannulation should be considered. Massive transfusion is defined as 10 units of blood within 24 hours at a rate of more than 150 mL/minute. Through a review of the literature the authors determine that IO access is rapid with a high success rate, IO access allows a bridge to initiate resuscitation while minimizing on scene delays, and has a low complication profile, all benefits over central venous cannulation.
- Australia
- Sontgerath JS, Rubal BJ, DeLorenzo RA, Morgan TL, Ward JA. Variability in intraosseous flush practices of emergency physicians. *Am J Emerg Med* 2014;<http://dx.doi.org/10.1016/j.ajem.2014.03.001>** 719
- This prospective study sought to evaluate intraosseous flush practices of emergency physicians. Using cadavers, 15 emergency physicians were asked to flush an IO catheter placed in the proximal tibia and proximal humerus IO insertion sites with 10 mL normal saline as they would in clinical practice; IO pressure measurements were recorded using an IO catheter inserted in the diaphysis of the target bones. Results showed the median IO pressure generated was 903 mmHg and the median flush duration was 5.2 seconds. Result showed significant interoperator variability with greater than 35-fold difference in flush forces. The authors concluded that it may be prudent practice for providers to extend the flush over several seconds to limit the maximal pressures.
- Suzuki EH, Wiebe DJ, Mulugeta L, et al. The effect of information delivery method on patient comprehension and preference for ultrasound-guided intravenous versus intraosseous access. *Ann Emerg Med* 2014;64(4s):S133** 846
- A prospective study evaluating patient comprehension of and willingness to receive intravenous (IV) access over intraosseous (IO) access based upon the delivery method of the IO information. Patients were randomized to receive IV or IO access using standard text or video information. Results showed there was no difference in patient comprehension based upon education modality (text or video); all groups preferred ultrasound guided peripheral IV access over IO access.
- Vassallo J, Horne S, Smith JE. Intraosseous access in the military operational setting. *J R Nav Med Serv* 2014;100(1):36-9** 794
- This article describes a prospective, observational study conducted March – July 2011 at the emergency department, Camp Bastion, Afghanistan evaluating use of IO access in 117 patients established using the EZ-IO and the FAST1 devices (76% EZ-IO).
- Vincent-Lambert C, Carpenter AP. Factors affecting the frequency of vascular access via intraosseous cannulation performed by paramedics in Johannesburg. *J Vasc Access* 2014;15(6):503-6. doi:10.5301/jva.5000263** 838
- A questionnaire and interview study evaluating the reasons paramedics do not perform intraosseous (IO) vascular access more frequently. Twelve paramedics in Johannesburg, South Africa were interviewed for the study. Results suggested access to inappropriate equipment (pink hypodermic needles), inadequate training, lack of use in hospital Emergency Departments to which they serve, and the perceived invasiveness of the procedure and pain caused during infusion dissuaded paramedics from performing the procedure.
- West B, Jule M, Prescott N, Labond VA, Zettek K, Foland W. Out-of-hospital intraosseous versus intravenous access in return of spontaneous circulation. *Ann Emerg Med* 2014;64(4s):S70-1** 797
- Abstract reporting on retrospective prehospital study to evaluate the rate of out-of hospital return of spontaneous circulation (ROSC) in the cardiac arrest patient. The following were assessed and analyzed for direct or indirect correlation on ROSC; dispatch time to arrival, number of intravascular attempts per method (IV versus IO) and rate of success. Conclusions were that ROSC can be achieved more rapidly when IO access is used as the first attempt method in obtaining vascular access in prehospital cardiac arrest. There was a trend in shorter ROSC times among the first attempt IO group compared to the IV group; the difference did not reach statistical significance, most likely due to a lack of power from the smaller sample size of the IO group.
- Winkler M, Talley C, Landwehr K, et al. Use of intraosseous needles for power injection of iodinated contrast media for emergency computed tomography angiography. *J Cardiovasc Comput Tomogr* 2014;9th annual scientific meeting abstracts:S76-7** 701
- Abstract presented at the Society of Cardiovascular Computed Tomography on preliminary findings of an observational study done after training ER physicians and techs on intraosseous (IO) catheter use and implementation of a policy for IO access use. Authors report high injection rates and excellent computed tomography angiography (CTA) scans safety with use of an IO for power injection of iodinated contrast media (ICM). Authors concluded cardiovascular imaging physicians, surgeons, ER physicians, and CT technologists should be familiar with the techniques of IO needle placement and use for power injection of ICM for CTA. The diagnosis and treatment of critically ill and unstable patients may be hastened by this technique.
- Young SW, Zhang M, Freeman JT, Mutu-Grigg J, Pavlou P, Morre GA. The Mark Coventry Award: Higher tissue concentrations of vancomycin with low-dose intraosseous regional versus systemic prophylaxis in TKA. *Clin Orthop Relat Res* 2014;472(1):57-65. doi:10.1007/s11999-013-3038-z** 620
- This randomized, controlled study compared tissue concentrations at the surgical site of regionally and systemically administered prophylactic vancomycin, in 30 patients undergoing total knee arthroscopy. The antibiotic was administered using three methods: 250mg through IO regional administration in the proximal tibia (IORA); 500mg through IORA; and 1g administered systemically through IV. Results showed the tissue concentration of vancomycin was greater in the 250mg IORA group than the systemic IV group, and the 500mg IORA group had higher concentrations than both groups.

Intraosseous Vascular Access Bibliography

Clinical, Observational and Other Studies

YEAR: 2013

Barratt JW. Re: reasons for not using intraosseous access in critical illness. *Emerg Med J* 2013;30(6):516-7. doi:10.1136/emmermed-2012-202120

703

This article describes a questionnaire study that was given to UK Role One military clinicians deployed to Afghanistan to assess the level of experience and confidence rating with use of IO access, using the FAST-1 and EZ-IO, and IV access. Thirty-three responses were received; clinicians felt more confident with IV access over IO access; clinicians felt more confident with FAST-1 IO access than EZ-IO IO access.

UK

Bloch SA, Bloch AJ, Silva P. Adult intraosseous use in academic Eds and simulated comparison of emergent vascular access techniques. *Am J R Emerg Med* 2013. <http://dx.doi.org/10.1016/j.ajem.2012.11.021>

652

In a letter to the editor this study reports data collected (during a survey of one third of academic emergency medicine programs in the U.S.) regarding IO use in adults and comparing IO access with other vascular access techniques through simulation. Data suggest that IOs were used less than 5% of the time patients needed emergent access and a peripheral line was unobtainable. The EZ-IO was most often used IO device. Authors conclude IO use should be considered more frequently in critical, unstable patients. (This research was presented at the ACEP Research Forum in 2010).

Byars DV, Tsuchitani SN, Yates J, Knapp B. A multijurisdictional experience with the EZ-IO intraosseous device in the prehospital setting. *Am J Emerg Med* 2013;31(12):1712-3. doi: 10.1016/j.ajem.2013.08.056

656

This letter to the editor describes a prospective, observational, trial that evaluated use of the EZ-IO in critically ill and injured patients (adult and pediatric) in a multijurisdictional prehospital setting; 9 EMS agencies were included. The 25mm needle set was the only needle size allowed for the study. One-hundred-eleven EZ-IO placements were performed by EMT-Intermediates and EMT-Paramedics with 96 successful placements (86.5%); the most common cause for failure reported by the author was thought to be patient obesity and inadequate needle length. Cardiac arrest patients made up 74.7% of the study population and the most common site accessed was the proximal tibia. Device operators rated the ease of use 7.87 using a 0 to 10 scale where 10=extremely easy.

Dolister M, Miller S, Borron S, et al. Intraosseous vascular access is safe, effective and costs less than central venous catheters for patients in the hospital setting. *J Vasc Access* 2013;14(3):216-24. doi:10.5301/jva.5000130

583

An observational clinical study evaluating use of the EZ-IO in patients requiring urgent vascular access that would have otherwise received a central venous catheter due to a lack of other options. One hundred five (105) patients were enrolled across five hospitals. The authors concluded that use of IO access in place of CVCs provides time savings, safety, ease of use, and is effective at significant cost savings; IO access may be used as a bridge to CVC placement under optimal conditions; and IO access may be used to replace use of CVCs all together in selective patients. This study was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.

Erdmann L, Doll S, Ihle B, Kirsch J, Mutzbauer TS. Evaluation of the sternal intraosseous route as alternative emergency vascular access for the dental office: a manikin and cadaver model pilot study. *Oral Surg Oral Med Oral Pathol Oral Radiol* 2013;116(6):686-91

657

This article describes a mannequin and cadaver study that evaluated use of the EZ-IO sternal device and the Illinois needle to establish sternal IO vascular access by dental students. Results of the cadaver study showed two cases of perforation of the posterior sternal cortex when the Illinois needle was used and one EZ-IO insertion in the soft tissue without entering the IO space. The authors concluded use of the EZ-IO sternal device with the insertion site template and scalpel incision may be more efficient and less predisposed to complication than use of the Illinois needle.

Fenchel DD, Myers LA, Arteaga GM, Russi CS. Chart analysis of frequency and complications from intraosseous infusion in out-of-hospital pediatric and adult populations. *Ann Emerg Med* 2013;62(4S):S104

663

A retrospective study that evaluated use of IO access by one EMS system whose patients were transported to a level 1 trauma center over a period of 64 months. Results showed 140 IO attempts were made with 130 successful placements (92.9%); there were no long term complications.

Frascone RJ, Salzman JG, Bliss P, Adams A, Wewerka SS, Dries DJ. Decreasing intraosseous pressure and increasing respiratory variability track fluid volume reduction in a porcine hypovolemia model. *Ann Emerg Med* 2013;62(4S):S14

666

A pre-clinical study that evaluated use of intraosseous (IO) pressure as an indicator of changes in fluid volume status during a hemorrhagic shock protocol. Central venous and arterial pressures were used as comparators. Results showed IO pressure decreased consistently during the controlled shock protocol. Authors concluded IO pressure appears to be equivalent to CVP as an indicator of fluid volume status. This study was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.

Frascone RJ, Salzman JG, Bliss P, Adams A, Wewerka SS, Dries DJ. Intraosseous pressure tracings mimics arterial pressure tracings in timing and contour. *Ann Emerg Med* 2013;62(4S):S13 - 4

665

A pre-clinical study that compared intraosseous (IO), central venous and arterial pressure tracings in a porcine model. Results showed that IO pressure was approximately 25% of arterial pressure. A sampling of IO blood gases revealed oxygenation levels of venous blood. This study was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.

Intraosseous Vascular Access Bibliography

Clinical, Observational and Other Studies

Hafner JW, Bryant A, Huang F, Swisher K. Effectiveness of a drill-assisted intraosseous catheter versus manual intraosseous catheter by resident physicians in a swine model. *Western J Emerg Med* 2013;XIV(6):629-32

668

This is a preclinical study comparing the EZ-IO and the Cook manual IO needle when used by 21 resident physicians to establish IO access in anesthetized swine. Results showed the drill-assisted needle was successfully placed 100% of attempts vs 76.2% successful placement with manual; time to placement and user preference also favored the EZ-IO. Technical issues reported included bending of the manual needle 33% of attempts.

Hallas P, Brabrand M, Folkestad L. Complication with intraosseous access: Scandinavian users' experience. *West J Emerg Med* 2013;14(5):440-3. doi:10.5811/westjem.2013.1.1200

669

A questionnaire study in which Scandinavian emergency physicians, anesthesiologist and pediatricians reported complications they have experienced with IO vascular access based on recollection alone. Complications were reported related to establishing IO access and using established IO access. Out of 1,802 IO cases reported by 386 responders, the most frequently reported complications included difficulty with periosteum penetration and bone marrow aspiration when establishing IO access; and slow infusion and needle displacement with established IO access. Osteomyelitis and compartment syndrome were reported with an occurrence of 0.4% and 0.6%. Researchers concluded that potential complications following IO insertion should be addressed during training. Devices discussed included the EZ-IO, BIG, Cook-Surfast, and other unidentified IO devices

Denmar

Helm M, Richter D, Schramm A, Lampl L, Hossfeld B.. Ist die intraossare punktion ein alternativer gefabzugang beim notfall in der zahnarztlichen praxis? *Notfall Rettungsmed* 2013;16:27-32. Doi:10.1007/s10049-012-1629-y. German

612

This article in German explores use of intraosseous access in a dental practice emergency. In a simulation study, dental students attempted to establish standard peripheral IV access and IO access using 3 different devices: EZ-IO, BIG, and manual IO. Results showed the manual was the fastest to insert, however, the EZ-IO had the highest first-attempt success rate as well as the lowest number of total attempts to IO access.

German

Junkin R, Litchfield K. Intraosseous vascular access skill acquisition in labour ward staff: results of a training programme. *Int J Obstet Anesth* 2013;22(1):S31

674

This abstract describes a study in which 66 obstetric anesthetists, obstetricians and midwives were training on the EZ-IO and evaluated for successful application of the skill in a mannequin study. The participants also completed a survey following their insertion attempt regarding their perceived ease of use and likeliness to consider IO use in the future. Results showed first attempt success was 95.5%; respondents indicated they found the EZ-IO to be easier than establishing PIV access and 100% indicated they would consider IO use in the future.

UK

Junkin R, Selfridge J, Litchfield. Intraosseous vascular access in obstetric emergencies: an OAA approved national survey. *Int J Obstet Anesth* 2013;22(1):S31

673

This abstract describes the results of an online survey taken by members of the Obstetric Anaesthetists' Association, evaluating use of IO access in obstetric emergencies, and availability of IO equipment on UK labor wards. Results showed many members are trained on IO access, consider it a viable option during emergencies however have limited access to equipment.

UK

Lairet J, Bebart V, Lairet K, et al. A comparison of proximal tibia, distal femur, and proximal humerus infusion rates using the EZ-IO intraosseous device on the adult swine (*Sus scrofa*) Model. *Prehosp Emerg Care* 2013;17:280-4. Doi:10.3109/10903127.2012.755582

642

Pre-clinical study comparing flow rates achieved after insertion with the EZ-IO in the proximal tibia, distal femur, and proximal humerus in a swine model. IO catheters were placed in each site and normal saline was infused for 10 minutes using a pressure bag at the highest achievable pressures greater than 300mmHg. The flow rates through the proximal humerus were statistically greater than that of the femur or proximal tibia. The femur flow rates were higher than the proximal tibia but similar. Post-mortem histopathologic evaluations done to assess for damage due to the high infusion pressures were consistent with IO catheter placement.

Larsson T, Strandberg G, Eriksson M, Bondesson U, Lipcsey M, Larsson A. Intraosseous samples can be used for opioid measurements- and experimental study in the anesthetized pig. *Scand J Clin Lab Invest* 2013;73(2):102-6. doi:10.3109/00365513.2012.744088

605

In this preclinical swine study, investigators sought to evaluate whether intraosseous blood samples can be used to measure opioids, and if so, to determine the level of accuracy of those measurements. Blood samples were drawn from bilateral tibial IO catheters and from a central venous catheter for six hours. Authors concluded that IO blood samples can be used for the analysis of opioids if an IV route is not available.

Intraosseous Vascular Access Bibliography

Clinical, Observational and Other Studies

- Lee H, Park JB, Lee S, Baek S, Kim H, Kim SJ. Intra-osseous injection of donor mesenchymal stem cell (MSC) into the bone marrow in living donor kidney transplantation; a pilot study. J Transl Med 213;11:96. doi: 10.1186/1479-5876-11-96** 881
- Authors described a study in which adult living donor kidney transplantation recipients (N=7) were given mesenchymal stem cells (MSC) derived from the donor bone marrow to evaluate the safety and the feasibility of immunological changes related to the intraosseous injection of MSC into the bone marrow. They concluded that donor MSC injection into the iliac bone at the time of transplant was feasible and safe.
- Mills A, Pappin D, Field V, Thorp-Jones D. Intraosseous access in the peripartum patient: is your needle long enough? Int J Obstet Anesth 2013;22(1):S30** 675
- This abstract describes a study in which the investigators sought to determine the approximate patient population in which the 25mm EZ-IO needle set was sufficient length to establish IO access in peripartum patients. Ultrasound was used to determine the tissue depth at four insertion sites. Twenty-six women were recruited with a median gestation of 34 weeks. In 88% of patients with a BMI<40 kg/m² the 25mm needle is sufficient to reach the bone marrow at both tibial sites. For the humeral site, IO placement may be more difficult for patients with a BMI>25 kg/m².
- UK
- Mittiga MR, Geis GL, Kerrey BT, Rinderknecht AS. The spectrum and frequency of critical procedures performed in a pediatric emergency department: Implications of a provider-level view. Ann Emerg Med 2013;61(30):263-70. doi.org/10.1016/j.annemergmed.2012.06.021** 588
- This retrospective study evaluated the number and type of critical procedures, including IO line placement, performed in the ED of a tertiary care pediatric institution over a 12 month period. The authors concluded that critical procedures were rarely performed in a large academic pediatric ED; pediatric emergency medicine faculty are at significant risk for skill deterioration; and fellows are unlikely to achieve competence in performing critical procedures.
- Montez DF, Puga TA, Garcia MR, et al. Intraosseous blood correlates with venous blood in healthy subjects using point-of-care analyzers. Ann Emerg Med 2013;62(4S):S40** 676
- A clinical study evaluating the relationship between IO blood and peripheral venous blood lactate levels analyzed using the i-STAT point-of-care analyzer in healthy volunteers. Results showed IO blood lactate levels were comparable to venous blood lactate levels with a positive statistical correlation. This study was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.
- Myers LA, Arteaga GM, Kolb LJ, et al. Prehospital peripheral intravenous vascular access success rates in children. Prehosp Emerg Care 2013;17(4):425-8. doi: 10.3109/10903127.2013.818180** 1000
- This retrospective review of medical records submitted by paramedics identified patients 18 years or younger who had prehospital peripheral IV (PIV) attempts. Over 101 months at least 1 PIV attempt was made on 4188 patients ≤18 years old. The study demonstrated that success rates are significantly associated with patient age and each 1 year increase in age increased the odds of successful PIV placement by 11%. The authors suggest that IO access with the use of a semiautomatic IO device (EZ-IO) may be a more efficient first-line method for immediate treatment after 1 PIV access failure, especially in younger patients given their higher rate of PIV insertion failure.
- Oksan D, Ayfer K. Powered intraosseous device (EZ-IO) for critically ill patients. Indian Pediatr 2013;50(7):689-91** 685
- A retrospective chart review evaluating use of the EZ-IO in 25 pediatric patients between July 2008 and August 2010 at a Turkish university affiliated hospital. All attempts were made in the proximal tibia and IO access was attempted following failed PIV access within 60 seconds. First attempt success was 80%; the most reported complication was simple extravasation (3 cases) and needle dislodgement (1 case).
- Turkey
- Reinhardt L, Brenner T, Bernhard M, et al. Four years of EZ-IO system in the pre- and in-hospital emergency setting. Central European Journal of Medicine 2013;8(2):166-71. Doi:10.2478/s11536-012-0125-6** 618
- An observational study evaluating use of the EZ-IO by two ground and one air based physician staffed EMS and at a German surgical university hospital between January 1, 2008 and December 31, 2011. The EZ-IO was used to establish IO access 88 times in 87 patients; 83 insertions were performed in the EMS and 5 were performed in the hospital. The proximal tibia was the primary site used (97.7%) and the first attempt success rate was 94%. IO access was the first approach for vascular access in children compared to adults (38.9% vs. 86.2%). There were 5 failures attributed to missed insertions or extravasation and 2 for wrong needle length. There were no serious complications.
- Reiter DA, Strother CG, Weingart SD. The quality of cardiopulmonary resuscitation using supraglottic airways and intraosseous devices: a simulation trial. Resuscitation 2013;84:93-7. doi:10.1016/j.resuscitation.2012.07.003** 586
- A simulation study evaluating if use of a laryngeal mask airways (LMA) and intraosseous (IO) lines established using the EZ-IO leads to improved resuscitation in a simulated cardiac arrest when compared to standard endotracheal intubation and central line placement. Results showed mean time to airway, mean duration of airway attempt, and time to vascular access was shorter in the IO group than the CVL group. Time to defibrillation and percent hand off time was not significantly different between the groups.

Intraosseous Vascular Access Bibliography

Clinical, Observational and Other Studies

- Santos D, Carron PN, Yersin B, Pasquier M. EZ-IO intraosseous device implementation in a pre-hospital emergency service: a prospective study and review of the literature. Resuscitation 2013;84(4):440-5. <http://dx.doi.org/10.1016/j.resuscitation.2012.11.006>** 604
- An observational study evaluating use of the EZ-IO in a Swiss pre-hospital EMS system between January 1, 2009 and December 31, 2011 and comparing those results to the literature. Sixty IO insertions were performed on 58 patients; the proximal tibia was used in all attempts except 1 attempt made in the proximal humerus. Overall success rate was 90%; the 6 failures were attributed to impossibility to infuse, difficult needle insertion, and incorrect insertion site (tibial plateau). Some of the indications for IO access included cardiorespiratory arrest, major trauma, and shock; general anesthesia was successfully induced in 7 patients. Drugs infused are listed. There were no serious complications.
- Sherren PB, Burns B. Prehospital blood transfusion: 5-year experience of an Australian helicopter emergency medical service [abstract P295]. Critical Care 2013;17(S2):S112. doi: 10.1186/cc12233** 1019
- This is an abstract of a study that analyzed prehospital missions of the Greater Sydney Area Helicopter Emergency Medical Service (GSA-HEMS) involving a blood transfusion, with IO administration recorded as one possible route of administration. The study determined that the carriage and use of blood is both feasible and safe in a physician-led helicopter emergency medical service.
- Sherren PB, Hayes-Bradley C, Reid C, et al. Are physicians required during HEMS winch rescue missions [abstract P282]? Critical Care 2013;17(S2):S106. doi: 10.1186/cc12220** 1018
- This is an abstract of a study that analyzed the mission profiles and interventions performed during rescues involving the winching of a physician in the Greater Sydney Area Helicopter Emergency Medical Service (GSA-HEMS). A structured case-sheet for a predetermined list of physician-only interventions (POI) was conducted, of which IO access was an intervention. The study showed a high rate of POI thus supporting the winching of physicians.
- Strandenes G, Skogrand H, Spinella PC, Hervig T, Rein EB. Donor performance of combat readiness skills of special forces soldiers are maintained immediately after whole blood donation: A study to support the development of a prehospital fresh whole blood transfusion program. Transfusion 2013; 53(3):526-30. doi:10.1111/j.1537-2995.2012.03767.x** 570
- This study conducted by the Norwegian Navy evaluated the ability of 25 soldiers to perform buddy transfusion by starting phlebotomy, establishing sternal IO access using the FAST1, and infusing 1 unit of whole blood. Physical performance was evaluated pre and post blood donation and lactate levels were recorded. The authors concluded that physical and combat performances are preserved within limits post whole blood donation and that soldiers are able to learn the phlebotomy and sternal reinfusion with only a short lecture on the procedure.
- Torres A, Banister N, Fernandez M, Cox K, Fletcher J. Appropriateness and complications of intraosseous needle placements during pediatric transports. Crit Care Med 2013;41(12):abstract 215** 792
- A quality initiative study conducted evaluating use of the EZ-IO needles in pediatric patients and their associated complications rates when placed by EMS/ED staff compared Air Evac Lifeteam placement in 2012. The authors concluded that the powered IO device was appropriately utilized by ED/EMS staff as well as Air Evac staff and that there was no difference in the complication rate when the device was used by the two groups.
- Torres F, Galán MD, Alonso MD, Suarez R, Camacho C, Almagro V. Intraosseous access EZ-IO in a prehospital emergency service. J Emerg Nurs 2013;39(5):511-4. doi: 10.1016/j.jen.2012.03.005** 572
- This observational pre-hospital study conducted in Madrid, Spain prospectively evaluated use of the EZ-IO Jan 2007- Dec 2009 as an alternative to peripheral IV access. During the study period, 107 patients underwent 114 EZ-IO insertions and all were successful on first attempt. IO access was established in the proximal tibia (49%), distal tibia (25.2%), radius (14.9%), and humerus (10.5%) and all lines were the first form of vascular access established in the patient. There were no adverse events or complications.
- Veldhoen ES, de Vooght KMK, Sliker MG, Versluys AB, Turner NMB. Analysis of bloodgas, electrolytes and glucose from intraosseous samples using an i-STAT point-of-care analyser. Resuscitation 2013;<http://dx.doi.org/10.1016/j.resuscitation.2013.12.002>** 692
- A prospective study comparing IO and venous laboratory values obtained from a point-of-care analyzer (i-STAT) in 20 children. IO blood specimens were collected from the iliac crest; 2 ml were discarded before the sample was collected analysis. Results showed differences between venous and IO sample were clinically acceptable for pH, base excess, sodium, ionized calcium and glucose in hemodynamically stable patients. Authors concluded that analysis of IO samples with a bedside point-of-care analyzer is feasible and in emergency situations may be useful to guide treatment.
- Verma PK, Srivastava R, Ramesh KM. Anesthetic efficacy of X-tip intraosseous injection using 2% lidocaine with 1:80,000 epinephrine in patients with irreversible pulpitis after inferior alveolar nerve block: a clinical study. J Conserv Dent 2013;16(2):162-66. doi:10.4103/0972-0707.108202** 839
- A study evaluating the use of X-tip intraosseous injection of 2% lidocaine with 1:80,000 epinephrine in dental patients with irreversible pulpitis in whom inferior alveolar nerve block has failed. Thirty patients were included and 93% of X-tip injections were successful. Ninety-six percent of patients had subjective/objective increase in heart rate. Results showed X-tip intraosseous injection of 2% lidocaine was effective in achieving pulpal anesthesia in patients with irreversible pulpitis.

Intraosseous Vascular Access Bibliography

Clinical, Observational and Other Studies

- Young SW, Zhang M, Freeman JT, Vince KG, Coleman B. Higher cefazolin concentrations with intraosseous regional prophylaxis in TKA. Clin Orthop Relat Res 2013;471(1):244-9. doi:10.1007/s11999-012-2469-2** 576
- A clinical study comparing Cefazolin concentrations found at the operation site following total knee arthroscopy when prophylactic antibiotics are administered systemically, through IV administration, and regionally, through IO injection directly at the site using the EZ-IO. Subcutaneous fat and bone samples were collected for evaluation from 22 subjects. Authors concluded that regional IO administration of prophylactic antibiotics can achieve tissues levels higher than with systemic administration.
- YEAR: 2012**
- Abrams-Ogg AC, Defarges A, Foster RA, Bienzle D. Comparison of canine core bone marrow biopsies from multiple sites using different techniques and needles. Vet Clin Pathol 2012;41(2):235-42. doi: 10.1111/j.1939-165X.2012.00422.x** 664
- A pre-clinical study that compared the EZ-IO 15 gauge 25mm needle set and the 13 gauge Jamshidi aspiration/biopsy needle when used to obtain core biopsy specimens in canines.
- Canada
- Barker LT. In the child with gastroenteritis who is unable to tolerate oral fluids, are there effective alternatives to intravenous hydration? Ann Emerg Med 2012;60(5):607-8. doi: 10.1016/j.annemergmed.2012.04.003** 534
- This article, part of a Review Snapshot series in Annals summarizes a literature review (Rouhani et al in Pediatrics 2011) for evidence of alternatives to traditional IV hydration in a dehydrated child. Thirty-eight articles were included for the analysis with five of them randomized controlled trials; and one of those comparing IO to IV rehydration. (Banerjee et al, which found IO placement faster with no therapeutic outcome differences). The focus of this review was on nasogastric tube rehydration as effective when IV fails and as less invasive than IO or CVC placement.
- Burgert J, Gegel B, Loughren M. Comparison of tibial intraosseous, sternal intraosseous, and intravenous routes of administration on pharmacokinetics of epinephrine during cardiac arrest: A pilot study. AANA Journal 2012;80(4):S6-S10** 660
- Preclinical study using a porcine model comparing the maximum concentration and time to maximum concentration of epinephrine administered via the tibial IO, sternal IO and IV routes during CPR. The IV route of administration of 1mg of epinephrine resulted in a serum concentration 5.87 and 2.86 times greater than the tibial route and sternal route respectively. The times to peak concentration was similar for IV and sternal IO groups but delayed for the tibial route. Authors conclude that due to limitations of their study the guidelines of administering 1mg of epinephrine via the IO route should not be changed; further studies using larger sample size, larger volume flush, arterial blood samples and the use of a more precise method of measuring serum epinephrine should be done.
- Crowley M, Brim C, Proehl J, et al. Emergency nursing resource: difficult intravenous access. J of Emerg Nursing 2012;38(4):335-43** 602
- Manuscript of a literature review and critical analysis done to develop the Emergency Nurse's Association (ENA) December 2011 Emergency Nursing Resource (ENR) which focused on the clinical issue of difficult IV access. Graded recommendations and decision options are provided for alternatives to IV access, including IO.
- Duncan L, Cohen J, Triner W, Rea J, King C. Intraosseous administration of CT Contrast in a porcine model: a feasibility study. Ann Emerg Med 2012;60(4S):S92** 598
- This abstract presented at the 2012 ACEP Research Forum discusses a swine pre-clinical study evaluating CT image opacification when contrast is delivered via IV and proximal humerus IO access. The EZ-IO was used to facilitate IO access. Results showed that under blinded radiology review the IV and IO images were judged adequately opacified to meet diagnostic criteria. Authors concluded that IO administration of contrast material may be a viable alternative if other vascular access is unavailable or if establishing other access will lead to a delay in diagnostic evaluation. This study was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.
- Esteo OV. Intraosseous access in prehospital emergency care. Emergencias 2012;24:44-6** 764
- A prospective, observational study which evaluated use of the EZ-IO within the prehospital setting over the course of a 3 year period, in Barcelona, Spain. Included patients were in cardiac arrest or with hemodynamic instability, without peripheral venous access after 90 seconds or 3 attempts to establish access. Results showed IO access was attempted in 49 pediatric and adult patients with an overall success rate of 93.9%; complications included extravasation and pain. IO access sites included the proximal tibia (71.4%), proximal humerus (22.4%) and distal tibia (6.1%). The author concluded that IO access is a viable access route for the management of critical patients or those in cardiac arrest in the pre-hospital setting due to the ability to obtain rapid access and the high first attempt success rate.

Intraosseous Vascular Access Bibliography

Clinical, Observational and Other Studies

Isayama K, Nakatani T, Tsuda M, Hirakawa A. Current status of establishing a venous line in CPA patients by emergency life-saving technicians in the prehospital setting in Japan and a proposal for intraosseous infusion. *Int J Emerg Med* 2012;5(1):2. doi:10.1186/1865-1380-5-2

527

This article discusses a retrospective review of Japanese prehospital system for intravenous infusion success rates in cardiopulmonary arrest (CPA) patients and a prospective simulation study. A nationwide database was reviewed for CPA records from 1 January 2005 to 31 December 2008 yielding 431,968 cases. Results showed the IV infusion success rate in adults increased annually, however the rate in pediatrics did not; and while the administration of adrenaline increased the 1-month survival rate did not. In the simulation study, 100 EMS technicians used the Bone Injection Gun (BIG) in simulator adult, pediatric and infant legs. There was no difference in the time to establish IO access between the simulation models. The authors concluded that IO access should be considered when IV access is difficult or impossible.

Lairet JR, Bebart V, Mathis D, et al. Comparison of intraosseous infusion rates of blood under high pressure in an adult hypovolemic swine model in three different limb sites. *Ann Emerg Med* 2012;60(4S):S75

600

This pre-clinical study sought to compare the flow rates of blood administered through an IO needle in the proximal tibia, distal femur and the proximal humerus in an adult hypovolemic swine at an infusion pressure greater than 300 mmHg. Investigators also evaluated the presence of fat emboli in the lungs. Results showed that the mean rate of IO infusion of blood through the swine humerus (103 mL/min) was greater than the femur (49 mL/min) and tibia (78 mL/min); fat emboli were detected in the lungs of most animals (tibia: 14.14; humerus: 10/11; femur: 8/14).

Lammers R, Byrwa M, Fales W. Root causes of errors in a simulated prehospital pediatric emergency. *Acad Emerg Med* 2012;19(1):37-47. doi: 10.1111/j.1553-2712.2011.01252.x

590

This simulation study evaluated the ability of 2 person EMS crews to manage a pediatric emergency and sought to determine root causes of errors made. Participating EMS crews used the BIG for IO access. The authors concluded that cognitive, procedural, affective, teamwork errors and error-producing conditions were identified as root causes for the errors made in the simulation. Authors also concluded that simulation followed by facilitated debriefing is an effective tool for identifying underlying causes of active and latent errors.

Mazaheri-Khameneh R, Sarrafzadeh-Rezaei F, Asri-Rezaei S, Dalir-Naghadeh B. Comparison of time to loss of consciousness and maintenance of anesthesia following intraosseous and intravenous administration of propofol in rabbits. *J Am Vet Med Assoc* 2012;241(1):73-80

589

A pre-clinical study evaluating the time to loss of consciousness and effective maintenance of anesthesia following IO and IV administration of propofol in 24 rabbits. The authors concluded that in all evaluated aspects of anesthesia, IO administered propofol was as effective as IV administration in rabbits

Miller LJ, Montez DF, Puga TA, Philbeck TE. Intraosseous vascular access in the 21st century: improvements further reduce complication rates. *Ann Emerg Med* 2012;60(4S):S112

597

This abstract presented at the 2012 ACEP Research Forum discusses a literature review of intraosseous access publications since 1985 providing an updated safety profile for IO access. The search resulted in 192 articles describing IO access with 6 cases of osteomyelitis and 6 cases of compartment syndrome secondary to extravasation reported. Of the 192 articles identified, 140 described the EZ-IO. This study was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.

Miller LJ, Puga TA, Montez DF, Morgan J. New in therapeutic hypothermia: preclinical evidence validates the IO Route; chilled tubing works best. *Ann Emerg Med* 2012;60(4S):S90

601

This abstract presented at the 2012 ACEP Research Forum describes a preclinical swine study evaluating the ability to induce therapeutic hypothermia by infusing chilled saline via IV and IO access. The EZ-IO was used to facilitate IO access. Results showed statistical equivalence between IV and IO routes when used to deliver chilled saline to induce therapeutic hypothermia. Results also showed that use of chilled saline and infusion tubing submerged in an ice water bath provides the most effective means of cooling. This study was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.

Murray DB, Eddleston M, Thomas S, et al. Rapid and complete bioavailability of antidotes for organophosphorus nerve agent and cyanide poisoning in minipigs after intraosseous administration. *Ann Emerg Med* 2012;60(4):425-30. <http://dx.doi.org/10.1016/j.annemergmed.2012.05.013>

587

A pre-clinical study evaluating the systemic bioavailability of antidotes when administered via the intraosseous (IO), intravenous (IV), and intramuscular (IM) routes is described. Results showed rapid and substantial antidote bioavailability after IO administration similar to that of the IV route. Authors concluded that the IO route of antidote administration should be considered when IV access is difficult.

Olaussen A, Williams B. Intraosseous access in the prehospital setting: literature review. *Prehosp Disaster Med* 2012;27(5):468-72. doi:10.1017/S1049023X12001124. http://journals.cambridge.org/abstract_S1049023X12001124

582

A literature review of articles describing intraosseous vascular access devices used in the pre-hospital setting. Twenty articles met the inclusion criteria and described the manual devices, BIG, Fast-1 and the EZ-IO. The authors concluded that the literature suggests that semiautomatic IO devices may be more effective than manual devices.

Intraosseous Vascular Access Bibliography

Clinical, Observational and Other Studies

- Oriot D, Darrieux E, Boureau-Voultoury A, Ragot S, Scepi M. Validation of a performance assessment scale for simulated intraosseous access. *Simul Healthc* 2012;7(3):171-5. doi:10.1097/SIH.0b013e31824a5c20** 581
- This article describes the validation testing of a newly developed performance assessment scale for evaluating the intraosseous manual insertion process in the proximal tibia during simulated procedures. The authors concluded that the scale was a reliable tool to assess the overall IO insertion procedure and that with modifications this scale may be used with other IO devices and in the clinical setting.
- Papakonstantinou MK, Pan WR, Le Roux CM, Richardson MD. New approach to the study of intraosseous vasculature. *ANZ J Surg* 2012;82(10):704-7. doi:10.1111/j.1445-2197.2012.06142.x** 584
- This article describes a post mortem study evaluating a newly developed technique to study the intraosseous vasculature of the humerus involving injection of ink directly into the anterior circumflex humeral artery. This technique allowed visualization of the main nutrient artery to the proximal humerus vasculature until they reached articular cartilage or crossed cortical bone again to enter the rotator cuff tendons.
- Ribiero de Sa RA, Melo CL, Dantas RB, Delfim LVV. Vascular access through the intraosseous route in pediatric emergencies. *Rev Bras Ter Intensiva* 2012;24(4):407-14** 716
- The authors evaluated use of IO access in pediatric emergencies through a literature review. The objective was to describe the techniques, professional responsibilities, and care related to obtaining IO access.
Brazil
- Rubal BJ, McKay K, Armstrong KR, Rubal MP, Marbach MJ. Variability in intraosseous pressure induced by saline flush of an intraosseous cannula by multiple practitioners. *Lab Animal* 2012;41(8):224-9** 578
- This pre-clinical study sought to evaluate the various pressure levels obtained by 22 veterinary clinicians when administering a 10ml normal saline flush of an IO catheter. The EZ-IO was used to establish access in an isolated, cadaveric swine femur. The authors found the median peak intraosseous pressure was 615 mmHg with a range of 57 to 1,100 mmHg. Authors concluded that there is a great deal of variability between clinicians and their flush pressure and that a standardized flush protocol may be beneficial.
- Rush S, Bremer J, Foresto C, Rubin AM, Anderson PI. A magnetic resonance imaging study to define optimal needle length for humeral head IO devices. *J Spec Oper Med* 2012;12(2):77-82** 577
- This article describes a retrospective study in which 50 consecutive MRI images were evaluated of the humerus for the purpose of determining the optimal needle length necessary for successful proximal humerus IO insertion. Results showed the cortical thickness was 4mm in all cases and that an IO needle length ranging between 40-50mm should be used via the anterior approach. The EZ-IO is specifically discussed in relation to the proximal humerus IO insertion site; and a 24 patient post mortem review of the EZ-IO placed in the proximal humerus is discussed.
- Tan BKK, Chong S, Koh ZX, Ong MEH. EZ-IO in the ED: an observational, prospective study comparing flow rates with proximal and distal tibia intraosseous access in adults. *Am J Emerg Med* 2012;30(8):1602-6.doi.10.1016/j.ajem.2011.10.025** 519
- This prospective observational study compared flow rates between distal and proximal tibia IO access in adults, with each adult serving as their own control. The EZ-IO was used to facilitate IO access. IO infusion was performed with and without pressure. The authors concluded that infusion flow rates were significantly higher in the proximal tibia as compared to the distal tibia, and that flow rates are significantly higher with pressured infusion vs. non-pressured infusion. This study was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.
- Truemper EJ, Beamer CL, Miller LJ, et al. Distal femur site is a viable option for IO vascular access in pediatric patients. *Ann Emerg Med* 2012;60(4S):S90** 761
- This abstract presented at the 2012 ACEP Research Forum explored the viability of the distal femur as an IO insertion site with a literature review of IO vascular access and brief overview of a post-mortem study of pediatric distal femur insertion success. Authors concluded that clinical literature, clinical studies, and a post-mortem study confirm that the distal femur is a viable option for IO infusion in pediatric patients. This study was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.
- Vassallo J, Horne ST, Smith JE. Intraosseous access on military operations: a 4 month review. Poster presentation at International Conference on Emergency Medicine, Dublin, Ireland. June 27-30, 2012** 593
- This poster presented at the 2012 International Conference of Emergency Medicine described a 4 month review of intraosseous access in UK military operations in Afghanistan. During the timeframe the EZ-IO was used to establish IO access in the proximal humerus and tibia sites; the FAST1 was used to establish sternal IO access. Of the 87 EZ-IO applications there were 12 functional issues and the placement success rate for both sites combined was 86.3%. In 24 FAST1 applications there were 4 functional issues and the placement success rate was 83.4%.

Intraosseous Vascular Access Bibliography

Clinical, Observational and Other Studies

YEAR: 2011

- Aliman AC, Piccioni Mde A, Piccioni JL, Oliva JL, Auler Junior JO. Intraosseous anesthesia in hemodynamic studies in children with cardiopathy. Rev Bras Anesthesiol 2011;61(1):41-9** 654
- A comparative study evaluating the effectiveness of IO access in relation to IV access for infusion of anesthetics (ketamine, midazolam, and fentanyl) and fluids during hemodynamic studies in 21 infants with congenital heart disease. IO access was established in the proximal tibia (n=11). Results showed, time to access was significantly shorter with IO access (3.6 vs 9.6 minutes); anesthetic onset was shorter with IV access (56.3 vs 71.3 seconds); and no significant difference between groups for hydration volume and anesthesia recovery time. The authors concluded that due to its easy manipulation and efficiency, hydration and anesthesia by IO access was satisfactory without necessity of other infusion access.
- Brazil
- Baombe J, Foex B. Is intraosseous access a safe option in adult cardiac arrest? A review of literature. Critical Care 2011;15(S1):S105. doi:10.1186/cc9714** 594
- This abstract reports a literature review using both MEDLINE and Embase databases up to August 2010 to determine feasibility and safety of IO administration during adult cardiac arrest. Authors reported a lack of literature (only two studies met their level of evidence criteria) but concluded IO access in adults appears to be a fast, reliable method to deliver drugs and fluid during CPR allowing adequate drug concentrations and pharmacological response; and should be considered if other medication delivery methods have failed. (Presented at the March 2011 International Symposium on Intensive Care and Emergency Medicine)
- Brady M. Intraosseous infusion: A 'humerus' subject? J Paramed Pract. 2011;3(4):198.** 1045
- This paper summarizes a study comparing first attempt success rates between TIO and HIO insertions during out-of-hospital cardiac arrest (OHCA). Insertions were performed by paramedics using an EZ-IO device. During the first month insertions were first attempted via the HIO route followed by the TIO route if unsuccessful; and vice versa during the second month. The overall TIO insertion success rate was 84.5%. The overall HIO insertion success rate was 40%.
- Byars DV, Tsuchitani SN, Erwin E, Anglemeyer B, Eastman J. Evaluation of success rate and access time for an adult sternal intraosseous device deployed in the prehospital setting. Prehosp Disaster Med 2011;26(2):127-9** 655
- A prospective study evaluating use of the FAST-1 sternal IO device in critically ill or injured patients in cardiac arrest in the pre-hospital setting. In one year, 41 insertion attempts were performed using the FAST-1. Thirty (73%) of attempts were successful and the mean time to placement was 67 seconds from time of opening the packaging to ability to aspirate/infuse without infiltration. Of the 11 insertion failures, 7 were due to failure of the device to deploy; 2 infiltrations after insertion; 1 inability to aspirate; and 1 failure of the catheter to deploy though the needles were inserted.
- Dolister M, Miller ST, Borron S, Truemper E, Shah MR. Intraosseous vascular access can be used safely and effectively, and at a lower cost than central venous catheters, for pediatric and adult patients in the hospital setting. Ann Emerg Med 2011;58(4S):S311** 453
- This abstract describes the interim results of an observational clinical trial evaluating use of the EZ-IO to establish venous access in patients that would typically receive a central line due to lack of other options. At interim analysis, 50 patients had been enrolled in the study. First attempt IO access success rate was 96%; mean time to IO access was 95.1 seconds. The authors concluded that IO access in place of or as a bridge to central venous catheters is safe, fast, and effective for adult and pediatric patients in the hospital setting with substantial cost savings potential. This research was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.
- Hansen M, Meckler G, Spiro D, Newgard C. Intraosseous line use, complications, and outcomes among a population-based cohort of children presenting to California hospitals. Pediatr Emerg Care 2011;27(10):928-32** 710
- This retrospective cohort study evaluated data from 450 California hospitals and emergency departments to determine the rate of IO access use and related complications in the pediatric population from 2005-2007. Results showed 291 children had IO access placed in 90 hospitals out of 6.6 million pediatric ED visits and 2.2 million pediatric admissions; no complications were identified. The most frequent diagnosis related to IO use was cardiac arrest (34%).
- Harcke HT, Crawley G, Mabry R, Mazuchowski E. Placement of tibial intraosseous infusion devices. Mil Med 2011;176(7):824-7** 469
- This article describes a military study in which post-mortem preautopsy multidetector CT was used to assess placement of tibial IO needles in battlefield trauma deaths where IO was used as part of the medical intervention. Results showed 58 of 61 (95%) tibial IO needles were correctly placed. In this study, the device used for IO placement was not recorded, but may have been the manual device or EZ-IO as the Army has access to both.

Intraosseous Vascular Access Bibliography

Clinical, Observational and Other Studies

- Harcke T, Crawley G, Ritter B, Mazuchowski E. Feedback to the field: an assessment of sternal intraosseous (IO) infusion. *J Spec Oper Med* 2011;11(1):23-6** 544
- This article summarizes the case-based observations made by the Armed Forces Medical Examiner System on soldiers killed in action/died of wounds who had evidence of sternal intraosseous access. The Pyng Fast-1 is noted in the article as the sternal IO device most widely distributed by the department of defense (DOD); the EZ-IO is listed as another device that may be seen in emergency care facilities within the DOD. Of 98 cases, 78 (80%) showed proper placement; 20% were unsuccessful. It should be noted that the article incorrectly states that the EZ-IO using the powered driver is indicated for sternal placement.
- Luu JL, Wendtland CL, Gross MF, et al. Three-percent saline administration during pediatric critical care transport. *Pediatr Emerg Care* 2011;27(12):1113-7. doi: 10.1097/PEC.0b013e31823aff59** 866
- Retrospective study describing 3% saline administration during pediatric critical care transports. Primary indications for use included cerebral edema, intracranial bleed with edema and symptomatic hyponatremia. The primary infusion route was peripheral venous with 4 infusions via central line and 2 via the IO route. Most patients received one bolus enroute. No adverse reactions were noted for any route.
- Olaussen A. Best evidence topic reports: which intraosseous device is best in the prehospital setting? *Emerg Med J* 2011;28(8):717-8. doi: 10.1136/emj.2010.108381** 724
- This article describes a literature review study with the objective of establishing which intraosseous device is best for prehospital use. This short review searched Medline 1950-2010, CINAHL 1982-2010 and EMBASE 1980-2010 and identified two studies meeting their evidence search criteria, one study compared the BIG vs. manual; the second compared EZ-IO vs. FAST-1. The clinical bottom line asserted by the author was traditional manual IO devices have faster, better success rates in the pre-hospital setting; but that more randomized trials are needed to determine the best device.
- Australia
- Strandberg G, Larsson A, Lipcsey M, Eriksson M. Intraosseous blood aspirates analysed by a portable cartridge-based device. *Crit Care* 2011;15(S1):P138. doi:10.1186/cc9558** 571
- In this pre-clinical study, IO and arterial blood samples were collected over a 6-hour timeframe from the tibia of anesthetized swine, analyzed using an iStat and compared. Results showed compliant values between IO and arterial blood for electrolytes, hemoglobin, pH, and pCO₂. Lactate, BE, PO₂ and SO₂ were less compliant. There were high correlations between SO₂ and PO₂ although the levels in arterial blood were higher.
- YEAR: 2010**
- Craiu M, Iordachescu M, Stan I, et al. Alternative intraosseous infusion technique via spinal needle, valuable tool for pediatric resuscitation. *Resuscitation* 2010;81S:S76. doi:10.1016/j.resuscitation.2010.09.312** 609
- This abstract describes a retrospective case-series analysis of pediatric IO recipients from 1998-2009. Seventy-two (72) patients were included in the study; IO access was established in the proximal tibia (n=61), medial tibia (n=8), distal tibia (n=1), sternum (n=1), and iliac crest (n=1). IO access devices used in the proximal tibia included the Cook Critical Care needle (n=4), the Jamshidi needle (n=2), the BIG (n=1), and an 18 gauge spinal needle (n=54). The authors concluded that a spinal needle can be used to provide IO vascular access in children.
- Hartholt KA, van Lieshout EM, Theis WC, Patka P, Schipper IB. Intraosseous devices: a randomized controlled trial comparing three intraosseous devices. *Prehosp Emerg Care* 2010;14(1):6-13. doi: 10.3109/10903120903349861** 443
- This article describes a randomized, single-blind, controlled trial to determine which IO needle can be used best for gaining IO access in patients requiring acute administration of fluids or medication in a prehospital setting. The study was performed at a level 1 trauma center in the Netherlands with a Helicopter Emergency Medical Service (HEMS). Adult and pediatric patients meeting inclusion criteria were randomized between Jamshidi 15G, B.I.G. 15G/18G and F.A.S.T.1. Insertion time, success, aspiration of bone marrow, side effects, medication given, trauma mechanism, and user satisfaction were recorded. In the adult group Jamshidi was placed fastest, significantly faster than the F.A.S.T.1. (p=0.002). Time to insert the B.I.G. 15G did not differ statistically from other devices. In the pediatric group insertion time of the Jamshidi did not differ statistically from the B.I.G. 18G. On average, the devices (adult and pediatric) did not differ significantly with respect to success rate, complication rates, and user satisfaction. EZ-IO was not included in this study as it was not approved for use in the Netherlands at the time the trial began. Authors recommend comparison with EZ-IO in future research.
- Neuhaus D, Weiss M, Engelhardt T, et al. Semi-elective intraosseous infusion after failed intravenous access in pediatric anesthesia. *Pediatr Anesth* 2010;20(2):168-71. doi: 10.1111/j.1460-9592.2009.03244.x** 425
- Authors report an observational study of 14 children in whom semi-elective IO infusion was performed under anesthesia after peripheral IV had failed. IO infusion was successful for all 14 patients, using the EZ-IO system for 8 patients and the Cook system for 6 patients.

Intraosseous Vascular Access Bibliography

Clinical, Observational and Other Studies

Tobias JD, Ross AK. Intraosseous infusions: A review for the anesthesiologist with a focus on pediatric use. *Anesth Analg* 2010;110(2):391-401. 428

The authors describe literature that support the use of IO access for administering anesthesia in the ICU, perioperative and operating room, including a study in which IO access was used successfully for providing intraoperative anesthesia for 106 of 109 patients. Among their conclusions, the authors reported that, even though rarely reported in anesthesia literature, IO access is a technique anyone providing care to children should consider when the patient has difficult IV access. They also concluded that IO access should be a part of an algorithm that includes numbers of attempts at peripheral access, feasibility of central access and the need for continued postoperative access; and that considering that IO access may be occasionally used in the perioperative setting in both emergent and nonemergent scenarios, it may be beneficial to have appropriate IO needles in the OR.

Turkan H. How does the training effect the use of intraosseous access with a battery driven device? *Resuscitation* 2010;81(2):S93. doi:http://dx.doi.org.10.1016/j.resuscitation.2010.09.380 768

This abstract describes a study in which 60 physicians, nurses, and paramedics naïve to IO vascular access were trained on the Arrow EZ-IO system. After lecture and hands-on training, the clinicians attempted to perform the procedure using a bone model and evaluated the device for ease of insertion, number of attempts, time to insertion, and their opinion on the device. The authors concluded use of the EZ-IO system can result in high success rates of insertion with inexperienced device users.

Wampler DA, Shumaker J, Manifold C, Bolleter S, Frandsen J. Humeral intraosseous access success rate in adult out-of-hospital cardiac arrest. *Ann Emerg Med* 2010;56(3):S88 479

This retrospective study evaluated humeral IO placement success rates, using the EZ-IO, in the out of hospital cardiac arrest patient. Over a 9 month period, humeral placement was attempted in 247 patients. First attempt successful placement was 91%; successful placement within two attempts was 94%. The authors concluded that humeral IO is a reliable method of fluid and drug delivery in the out of hospital cardiac arrest population. This research was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.

YEAR: 2009

Frascone RJ, Jensen J, Wewerka SS, Salzman JG. Use of the pediatric EZ-IO needle by emergency medical services providers. *Pediatr Emerg Care* 2009;25:329-32 424

Prospective study of 246 EMS providers at 14 EMS agencies. Reports successful IO placement in 95% of cases (18 of 19).

Leidel BA, Kirchoff C, Bogner V, Stegmaier J, Mutschler W, Kanz KG, Braunstein V. Is the intraosseous access route fast and efficacious compared to conventional central venous catheterization in adult patients under resuscitation in the emergency department? A prospective observational pilot study. *Patient Saf Surg* 2009;3:24 436

This article describes a study conducted at an urban Level I trauma center in Munich, Germany. Ten consecutive patients for whom PIV was difficult or impossible were simultaneously given a central line and an EZ-IO. Procedure times were measured and defined as the time the device package was taken off the shelf until the first drug or solution was administered. First attempt success rate was 90% for EZ-IO and 60% for CVC. The mean procedure times were 2.3 minutes for EZ-IO and 9.9 minutes for CVC, a clinically and statistically significant difference. Investigators concluded, because CVC was slower and less efficacious, IO may improve the safety of patients requiring resuscitation in the ED.

Levitan RM, Bortle CD, Snyder TA, Nitsch DA, Pisaturo JT, Butler KH. Use of a battery-operated needle driver for intraosseous access by novice users: skill acquisition with cadavers. *Ann Emerg Med* 2009;54(5):692-4 438

This article describes a cadaver study to determine skill acquisition and performance by use of the EZ-IO system by novices. Overall success rate for the 99 operators was 97%, and mean insertion time was 6 seconds. All operators rated the device faster and easier than using a central line, and 99% expressed willingness to use the device for cardiac arrest patients.

Lo TY, Reynolds F. To use intraosseous access or not to use intraosseous access: Determinants of trainees' decision in paediatric emergencies. *Eur J Emerg Med* 2009;16(6):301-4. doi:10.1097/MEJ.0b013e32832b6360 991

This study sought to determine whether training and previous IO insertion experience influenced a trainee pediatrician's decision on emergency vascular access choice. Multivariate logistic regression analysis showed that previous real life IO insertion experience was the only significant factor to increase the likelihood of choosing IO as the first vascular access choice in an emergency situation. Prior IO insertion experience was more likely to be found among more experienced trainees.

MacKinnon KA. Intraosseous vascular access use at a Signature Healthcare Brockton Hospital Department of Emergency Services. *J Emerg Nurs* 2009; 35: 425-8 431

This article describes IO use in general, and the EZ-IO in particular. The author describes its use by the emergency staff at her hospital and how they became advocates for IO access in both emergent adult and pediatric patients. She found that its use improves the quality of our care by providing vascular access to our most critical patients.

Intraosseous Vascular Access Bibliography

Clinical, Observational and Other Studies

- Mukisi MM, Bashoun K, Burny F. Sickle-cell hip necrosis and intraosseous pressure. *Orthop Traumatol Surg Res* 2009;95(2):134-8. doi: 10.1016/j.otsr.2009.01.001** 999
- This study sought to show that intraosseous hyperpressure plays a role in the pathophysiology of sickle-cell like idiopathic osteonecrosis of the femoral head (ONFH). 10 ONFH patients underwent decompression drilling and pressure measurement resulting in 16 intraosseous pressure (IOP) measurements recorded. Six were sickle-cell patients, 2 were sickle-cell trait carriers with ONFH, and 2 were ONFH patients free of sickle-cell disease. Drilling was performed with a Jamishidi DJ4008X puncture needle. Results displayed elevated predrilling IOP-1 and IOP-2, which was reduced after drilling (IOP-3). IOP-1 and IOP-2 were found to be significantly higher in the sickle-cell disease and sickle-cell trait carrier groups ($P<0.05$).
- Ngo AS-Y, Oh JJ, Chen Y, et al. Intraosseous vascular access in adults using the EZ-IO in an emergency department. *Int J Emerg Med* 2009. Available at <http://www.springerlink.com/content/d16841757807k635/fulltext.pdf>. Accessed 09/09/20009** 411
- This article describes a prospective, observational study involving a convenience sample of 25 medical students, physicians and nursing staff recruited evaluate the EZIO powered drill device on a bone model. Twenty-three (92%) of the 25 study subjects required only one attempt at placing the EZ-IO. Investigators concluded that the device was easy to use with high success rates of insertion with inexperienced participants.
- Ong ME, Chan YH, Oh HH, Ngo AS. An observational prospective study comparing tibial and humeral intraosseous access using the EZ-IO. *Am J Emerg Med* 2009;27:8-15** 417
- Comparison of tibial and humeral IO use in 24 adults. Both sites suitable for IO infusion. This study was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.
- Ong ME, Ngo AS, Wijaya R. An observational prospective study to determine the ease of vascular access in adults using a novel intraosseous access device. *Ann Acad Med Singapore* 2009;38:121-4** 420
- This article describes a prospective, observational study involving a convenience sample of 25 medical students, physicians and nursing staff recruited evaluate the EZIO powered drill device on a bone model. Twenty-three (92%) of the 25 study subjects required only one attempt at placing the EZ-IO. Investigators concluded that the device was easy to use with high success rates of insertion with inexperienced participants. (Note: This study was also described in an earlier article published in American Journal of Emergency Medicine) This study was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.
- Ornato JP, Peberdy MA, Kurz MC. Abstract P134: A building block strategy for optimizing outcomes from out of hospital cardiac arrest. *Circulation* 2009;120:S1470-a** 404
- In this 1,598 patient case series, investigators studied the effects of serial standard of care changes in the EMS system over time. They concluded that IO access is an essential component for a proven algorithm for the management of OOH-CA.
- Plancade D, Ruttimann M, Boulland P, et al. [Evaluation d'un nouveau catheter pour perfusion intra-osseuse en OPEX]. *La Revue du CARUM-Réanoxyo* 2009;25(2):49-50. French** 410
- This article describes an observational study performed by the French military air surgical team in Chad. There were 11 patients with no insertion failures. For 7 patients, the insertion site was the proximal tibia and for the remainder the site was the proximal humerus. The authors concluded that the EZ-IO is a device that is simple, reliable and which gives satisfaction for the administration of drugs.
- Schutt RC, Bowman B, Cevik C, et al. Intraosseous line placement does not improve outcome in adults with out-of-hospital cardiac arrest. *Prehosp Emerg Care* 2009;13(1):102** 417
- This abstract describes a small study designed to determine if IO line placement improves outcome in adult patients with out-of-hospital cardiac arrest. This 165 patient study did not demonstrate improved survival.
- YEAR: 2008**
- Brenner T, Bernhard M, Helm M, et al. Comparison of two intraosseous infusion systems for adult emergency medical use. *Resuscitation* 2008;78(3):314-9** 380
- Study comparing manual intraosseous insertion with EZ-IO using adult human cadavers as a model. No significant difference in insertion time between 39 manual insertions and 45 EZ-IO insertions. Found a difference in the success rate (manual, 79.5% vs. EZ-IO 97.8%, $p<0.01$). The EZ-IO had fewer complications (manual, 15.4% vs. EZ-IO 0.0%, $p<0.01$) and scored higher on user friendliness (school grading system: manual, 1.9 ± 0.7 vs. EZ-IO 1.2 ± 0.4 , $p<0.01$).
- Fowler RL, Pierce A, Nazeer S, Philbeck TE, Miller LJ. 1,199 case series: Powered intraosseous insertion provides safe and effective vascular access for emergency patients. *Ann Emerg Med* 2008;52(4):S152** 418
- Large retrospective study of patients for whom emergency vascular access was obtained using the Vidacare EZ-IO intraosseous system. Insertion success was 92% and within 10 seconds for 84% of the one-attempt successful cases. Complication rate was low (4.8%), none were serious, and extravasation was the most frequent (0.8%). The device was rated easy to use 72% of the time, and researchers concluded that the powered IO device is safe and effective for achieving vascular access in the resuscitation and stabilization of emergency patients. This study was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.

Intraosseous Vascular Access Bibliography

Clinical, Observational and Other Studies

- Horton MA, Beamer C. Powered intraosseous insertion provides safe and effective vascular access for pediatric emergency patients. *Pediatr Emerg Care* 2008;24(6):347-50** 381
- A retrospective clinical study was conducted to demonstrate the safety and effectiveness of the EZ-IO intraosseous access device for pediatric patients. For the 95 eligible patients in the study, successful insertion and infusion was achieved in 94% of the patients. Insertion time was 10 seconds or less in 77% of the one-attempt successful cases reporting time to insertion. There were 4 minor complications (4%), but none significant. The results of this study support the use of the EZ-IO for children in emergency situations. The complication rate suggests that the powered IO device is safe and effective for the resuscitation and stabilization of pediatric patients. This study was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.
- Jensen J, Nusstein J, Drum M, Reader A, Beck M. Anesthetic efficacy of a repeated intraosseous injection following a primary intraosseous injection. *J Endod* 2008;34(2):126-30** 745
- The objective of this study was to determine the anesthetic efficacy of repeated intraosseous injections of 2% lidocaine with epinephrine given 30 minutes following a primary injection for pain management for dental procedures. Results found that a repeated injection provided 15 minutes of additional pulpal anesthesia.
- Paxton JH, Knuth TE, Klausner HA. Humeral head intraosseous insertion: The preferred emergency venous access. *Ann Emerg Med* 2008;52(4):S58** 419
- Interim report for quasi-controlled prospective study of emergency department patients for whom emergency vascular access using the Vidacare EZ-IO intraosseous (IO) system (n=6) inserted in the proximal humerus was compared to access using central or peripheral intravenous (IV) lines (n=60). Researchers concluded that proximal humerus IO insertion is significantly faster than central or peripheral intravenous (IV) line insertion. Complications and pain profiles were similar for IO and IV techniques. This study was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.
- Pfister CA, Egger L, Wirthmoller B, Grief R. Structured training in intraosseous infusion to improve potentially life saving skills in pediatric emergencies: results of an open prospective national quality development project over 3 years. *Paediatr Anaesth* 2008;26:31-8** 409
- Three-year study of IO training and use in 28 hospital and ambulance services in Switzerland. Standardized training improved IO success rate to 100%.
- Abstract only*
- Pointer JE, Vultaggio D, Schnepf R, Kleveno A. Fast or easy? Comparing two adult IO infusion devices. *JEMS.com* 2008** 382
- This article describes an observational study in which two intraosseous devices were compared: the Pyng Medical F.A.S.T.1 and the Vidacare EZ-IO. For the 117 patients on which the F.A.S.T.1 was used, there was an 84% success; compared to a 97% success rate for the EZ-IO (n=71).
- Available at http://www.jems.com/news_and_articles/articles/Fast_or_Easy.html. Accessed 01/24/2008
- Schwartz D, Amir L, Dichter R, Figenberg Z. The use of a powered device for intraosseous drug and fluid administration in a national EMS: a 4-year experience. *J Trauma* 2008;64(3):650-4; discussion 654-5. doi: 10.1097/TA.0b013e31814db2a6** 385
- Prospective observational study of the use of the Bone Injection Gun in Israel from 2000 to 2004. Of the 189 patients enrolled in the study, successful insertion on first attempt was accomplished in 91% of cases.
- Susi L, Reader A, Nusstein J, Beck M, Weaver J, Drum M. Heart rate effects of intraosseous injections using slow and fast rates of anesthetic solution deposition. *Anesth Prog* 2008;55(1):9-15** 720
- This article describes a prospective cross-over study that evaluated the effects on heart rate of intraosseous administration of 2% lidocaine at various deposition rates in dental practice. Results showed the mean maximum heart rate was statistically higher with the fast intraosseous injection over the two slow injections.
- YEAR: 2007**
- Beamer CL, Horton M. Powered needle insertion provides safe and effective vascular access for pediatric emergency patients. *Ann Emerg Med* 2007;50(3):S40** 395
- This abstract for a presentation at the 2007 American College of Emergency Physicians Research Forum describes an observational study in which the EZ-IO was used to provide emergency vascular access for 95 pediatric patients. Successful insertion and infusion was achieved in 94% of the patients, and insertion time was within 10 seconds for 81% of the placements. There were four minor and no serious complications.
- Cooper BR, Mahoney PF, Hodgetts TJ, Mellor A. Intra-osseous access (EZ-IO®) for resuscitation: UK military combat experience. *J R Army Med Corps* 2007;153(4):314-6** 379
- Describes the experience of the UK Defence Medical Service using the EZ-IO for emergency vascular access in Afghanistan. They used the device for 26 patients, including 10 children. Of the 26 EZ-IO placements, 23 were made in the emergency department. There was a 97% insertion success rate with no infection. Significant infusion pain was felt by three patients.

Intraosseous Vascular Access Bibliography

Clinical, Observational and Other Studies

Frascone RJ, Jensen JP, Kaye K, Salzman JG. Consecutive field trials using two different intraosseous devices. *Prehosp Emerg Care* 2007;11(2):164-71 357

This article describes authors' evaluation of provider performance using two IO devices; the Pyng Medical F.A.S.T.1™ and the Vidacare EZ-IO®. Of 89 insertions with each device, success rate for 72% for the F.A.S.T.1 and 87% for the EZ-IO, a significant difference (p=0.009). The time to fluid insertion for the EZ-IO was also faster (p=0.02). Authors noted that the EZ-IO is unique and much more useful than the F.A.S.T.1.

Harrington LL, Rehbolz C, Mitchell PM, Dyer KS, King K, Moyer P. Out-of-hospital placement of adult intraosseous access using the EZ-IO device. *Ann Emerg Med* 2007;50(3):S81-2 396

This abstract for a presentation at the 2007 American College of Emergency Physicians Research Forum describes an observational study done at Boston Medical Center in which the Vidacare EZ-IO was used to provide emergency vascular access for 50 critically-ill adult patients. Successful insertion was achieved in 92% of the patients; with 90% success on the first attempt. There was one immediate complication—a dislodgement during transport. Investigators concluded that the device is a safe and feasible device for adult patients requiring out-of-hospital vascular care.

Mathew N, McGinnis-Hainsworth D, Megargel R, Cleary A, O'Connor R. Trends in the usage of intraosseous access in the prehospital setting. *Prehosp Emerg Care* 2007;11(1):130 362

In this study, presented at the NAEMSP 2007 annual meeting, authors compared the success rate of conventional IO access with the EZ-IO during 245 cases in the prehospital setting. They concluded that using EZ-IO® results in a statistically significant increase in IO success rate, compared to conventional IO methods.

Abstract

Myers BJ, Lewis R. Induced cooling by EMS (ICE): year one in Raleigh/Wake County. *JEMS* 2007;32:s13-5 398

This article describes the experience of the Wake County (NC) EMS System in inducing hypothermia for patients with return of spontaneous circulation after cardiac arrest. Authors describe their use of the Vidacare EZ-IO (now Arrow® EZ-IO Intraosseous Vascular Access System) for the administration of chilled saline. In this report 56% of vascular access cooling was done utilizing the IO device and an additional 18 % utilized a combination of IO and IV induced cooling. The overall EZ-IO use in this program for all insertions were 414 with an insertion success rate of 94%.

Stone MN, Teismann NA, Wang R. Ultrasonographic confirmation of intraosseous needle placement in an adult unembalmed cadaver model. *Ann Emerg Med* 2007;49(4):515-9. doi:10.1016/j.annemergmed.2006.11.009 832

A cadaveric study evaluating the use of ultrasonography visualization of flow within the intraosseous space to confirm proper needle placement. In a sample of 4 freshly frozen, unembalmed cadavers with bilateral distal tibia IO access, ultrasonography accurately detected the flow of crystalloids through the IO space 100%.

Stouffer JA, Jui J, Acebo J, Hawks RW. The Portland IO experience: results of an adult intraosseous infusion protocol. *JEMS* 2007;32:S27-8 397

The article describes a prospective observational study conducted by several EMS agencies in Portland, OR to determine the safety, efficacy and benefits of using the Vidacare EZ-IO in the prehospital environment. The IO device was successfully placed in 95% of the 280 cases. In 98% of the cases, placement was made within six seconds.

Thomas RE, Crutcher R, Lorenzetti D. A systematic review of the methodological quality and outcomes of RCTs to teach medical undergraduates surgical and emergency procedures. *J Can Chir* 2007;50(4):278-90 1028

This paper presents a systematic review that assessed the quality of randomized controlled trials (RCTs) used in teaching undergraduate medical students in Canada surgical and emergency skills. 19 RCTs were assessed, 2 of which involved intraosseous access.

Utkin EV. [Efficacy of intraosseous administration of antibiotics in the treatment of pelvic inflammatory disease in women]. *Antibiot Khimioter* 2007;52(7-8):37-40. Russian 404

Clinical study of intraosseous antibiotic administration in 87 women with acute pelvic inflammatory disease.

YEAR: 2006

Cataldi E, McGinni-Hainsworth D, Megargel R, Bollinger M, O'Connor R. A comparison of intraosseous and intravenous access in adults and children in the prehospital setting. *Prehosp Emerg Care* 2006;10(1):124 633

An abstract describing a prehospital study comparing peripheral IV to tibial IO access for placement success, time to access and time to drug delivery. The authors concluded that using IO access on the first attempt results in faster drug administration than if IO access were used as a rescue line after failed IV.

Intraosseous Vascular Access Bibliography

Clinical, Observational and Other Studies

- Frascone RJ, Jensen J, Salzman J, Kaye K. EZ-IO: A field trial. *Prehosp Emerg Care* 2006;10(1):123-4** 354
In this study, presented at the NAEMSP 2006 annual meeting, investigators reported the results of a study that evaluated the performance of the EZ-IO® compared to an earlier evaluation of the Pyng F.A.S.T.1 system. There was a statistically significant higher success rate using the EZ-IO® compared to Pyng system, and investigators concluded that the EZ-IO® appears to be a superior device with regard to insertion success.
- Guyette FX, Rittenberger JC, Platt T, Suffoletto B, Hostler D, Wang HE. Feasibility of basic emergency medical technicians to perform selected advanced life support interventions. *Prehosp Emerg Care* 2006;10(4):518-21** 353
Prospective observational study evaluating EMT-B ability to provide care in out-of-hospital cardiac arrests. Found that EMT-Bs were able to place the EZ-IO with a 94% success rate. Median time to placement was 72 seconds.
- YEAR: 2005**
- Curran A, Sen A. Bone injection gun placement of intraosseous needles. *Emerg Med J* 2005;22(5):366** 335
A review of 129 cases comparing the BIG to standard IO needles. Concludes that the BIG is equivalent to manually driven IO needles in effectiveness and likely faster than manual needles in achieving IO access.
- Davidoff J, Fowler R, Gordon D, Klein G, Kovar J, Lozano M, Potkya J, Racht E, Saussy J, Swanson E, Yamada R, Miller L. Clinical evaluation of a novel intraosseous device for adults: prospective, 250-patient, multi-center trial. *JEMS* 2005;30(10):s20-3** 352
Observational study evaluating use of the EZ-IO®. Found 97% success rate for insertion and infusion into the IO space by paramedics, nurses, physicians and other EMS personnel in using the device for emergency vascular access. No serious complications reported. This study was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.
- Fiorito BA, Mirza F, Doran TM, et al. Intraosseous access in the setting of pediatric critical care transport. *Ann Emerg Med* 2005;46(5):475-6. doi:10.1016/j.annemergmed.2005.09.011** 858
This abstract describes a retrospective study evaluating use of IO access during pediatric critical care transport. From January 1, 2000 to March 31, 2002, 1,792 transports were performed and 47 patients received 58 IO catheter insertions. Insertion took a mean 1.2 attempts for placement and first attempt success was 78%. Most frequently accessed site as the proximal humerus (95%) and access was maintained for a mean 5.2 hours. The authors concluded EMT/paramedics, emergency physicians, and pediatric critical care transport teams should be familiar with IO placement.
- Fiorito BA, Mirza F, Doran TM, Oberle AN, Cruz EC, Wendtland CL, Abd-Allah SA. Intraosseous access in the setting of pediatric critical care transport. *Pediatr Crit Care Med* 2005;6(1):50-3** 344
Retrospective chart review demonstrating safe and effective IO placement on pediatric patients by EMT-Ps, ED physicians, and members of the transport team in the pediatric critical care transport environment.
- Gillum L, Kovar J. Powered intraosseous access in the prehospital setting: MCHD EMS puts the EZ-IO to the test. *JEMS* 2005;30(10):s24-6** 327
Observational study of initial use of the EZ-IO® in 125 patients by EMS providers. Found 94% success rate for insertion and infusion into the IO space. No complications reported. This study was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.
- Johnson DL, Findlay J, Macnab AJ, Susak L. Cadaver testing to validate design criteria of an adult intraosseous infusion system. *Mil Med* 2005;170(3):251-7** 342
Preclinical study of one IO device (FAST-1) in cadavers. Design criteria were validated in that 75 out of 77 attempts were successful.
- Miller DD, Guimond G, Hostler DP, Platt T, Wang HE. Feasibility of sternal intraosseous access by emergency medical technician students. *Prehosp Emerg Care* 2005;9(1):73-8** 351
Experimental study of the FAST-1 sternal IO device, with 29 EMT-B's with minimal training placing the device on mannequins. Authors reported 16 of 29 EMT-B's placed the device successfully on the first attempt and 27 of 29 on the fourth attempt.
- Rodriguez Nunez A, Garcia C, Lopez-Herce Cid J; Grupo de Estudio de la Parada Cardiorrespiratoria en Pediatria. [Is high-dose epinephrine justified in cardiorespiratory arrest in children?]. *An Pediatr (Barc)* 2005;62(2):113-6. Spanish** 343
Multicenter, prospective study of cardiopulmonary resuscitation data over 18 months. The study was design to evaluate the impact of survival of IV or IO high-dose epinephrine compared to standard doses in children with cardiorespiratory arrest. Limited conclusions showed that there is no significant difference between the two treatments.

Intraosseous Vascular Access Bibliography

Clinical, Observational and Other Studies

- Smith R, Davis N, Bouamra O, Lecky F. The utilisation of intraosseous infusion in the resuscitation of paediatric major trauma patients. *Injury* 2005;36(9):1034-8** 341
Retrospective study over a 14-year period examining 129 IO insertions among 23,489 pediatric trauma patients. Patients receiving IO fluids and medications tended to be younger and sicker. Concludes that IO is an essential skill for anyone involved in pediatric trauma resuscitation.
- YEAR: 2004**
- Miller LJ, Morissette C. VidaPort-an advanced easy IO device. *Prehosp Emerg Care* 2004;8(1):110-1** 326
Study compared the VidaPort (now EZ-IO®) and the Bone Injection Gun (B.I.G.). Of 32 cases for each device, insertion rates were 100% for the VidaPort and 88% for the B.I.G. Average insertion times were 16 seconds for the VidaPort and 21 seconds for the B.I.G.
- Vardi A, Berkenstadt H, Levin I, Bentencur A, Ziv A. Intraosseous vascular access in the treatment of chemical warfare casualties assessed by advanced simulation: proposed alteration of treatment protocol. *Anesth Analg* 2004;98(6):1753-8** 325
Evaluation of the BIG in a chemical warfare mass casualty scenario. Found 73.4% simulated survival in the IO group and 3.3% in the control group (no IO). Average treatment goals obtained in 3.5 minutes for IO group and 10 minutes for control group. Concludes that IO has great potential for early treatment of chemical.
- YEAR: 2003**
- Claudet I, Baunin C, Laporte-Turpin E, Marcoux MO, Grouteau E, Cahuzac JP. Long-term effects on tibial growth after intraosseous infusion: a prospective, radiographic analysis. *Pediatr Emerg Care* 2003;19(6):397-401** 313
Prospective radiographic study of 23 children who had received intraosseous infusion via trocar. Found no long-term effect on tibial growth with properly placed trocar.
- Nusstein J, Kennedy S, Reader A, Beck M, Weaver J. Anesthetic efficacy of the supplemental x-tip intraosseous injection in patients with irreversible pulpitis. *J Endo* 2003;29(11):724-8** 299
Dental study finding successful injections of 2% lidocaine with epinephrine in 27 of 33 (82%) X-tip IO injections (82%) for anesthesia in mandibular teeth.
- Ota FS, Yee LL, Garcia FJ, Grisham JE, Yamamoto LG. Which IO model best simulates the real thing? *Pediatr Emerg Care* 2003;19(6):393-6** 311
Evaluation of IO models by 40 emergency and critical care physicians. Chicken, turkey bones and plastic IO models received similar scores, pork rib was rated poorly. Emphasizes that bone models should be age appropriate to the expected patient population when using for IO research and training purposes.
- YEAR: 2000**
- Abe KK, Blum GT, Yamamoto LG. Intraosseous is faster and easier than umbilical venous catheterization in newborn emergency vascular access models. *Am J Emerg Med* 2000;18(2):126-9** 256
Study comparing practitioner experience with IO and umbilical vein catheterization with 42 medical students inexperienced in both techniques. IO was twice as fast as umbilical vein catheterization. Concludes that IO provides easy and rapid vascular access for clinicians who do not regularly perform newborn resuscitation.
- Foex BA. Discovery of the intraosseous route for fluid administration. *J Accid Emerg Med* 2000;17:136-7** 270
Brief review of the discovery and evolution of IO access in emergency care.
- Lavis M, Vaghela A, Tozer C. Adult intraosseous infusion in accident and emergency departments in the UK. *J Accid Emerg Med* 2000; 17: 29-32** 260
Survey on current opinion and practice regarding IO among 332 Accident and Emergency Departments. Found that 75% of respondents were aware of IO use in adult resuscitation.
- Nijssen-Jordan C. Emergency department utilization and success rates for intraosseous infusion in pediatric resuscitations. *Canadian J Emerg Med* 2000;2(1):10-4** 679
A retrospective chart review that evaluated use of IO access in pediatric patient resuscitation in a tertiary emergency department between 1989 and 1995. Results showed IO access was successfully established in 86% of patients. Median time to placement was 8 minutes; two complications of bone fracture were reported in one 10-day-old neonate patient.
Canada

Intraosseous Vascular Access Bibliography

Clinical, Observational and Other Studies

Spriggs NM, White LJ, Martin SW, Brawley D, Chambers RM. Comparison of two intraosseous infusion techniques in an EMT training program. Acad Emerg Med 2000;7:1168 266

Study comparing B.I.G. and Jamshidi IO needle in an EMS training program. 38 EMT trainees performed the insertion. Time to placement was 12 seconds for the B.I.G. and 17 seconds for the Jamshidi needle. There were no statistical differences in ease-of-use ratings between the devices.

YEAR: 1999

Claudet I, Alberge C, Bloom MC, Fries F, Lelong-Tissier MC. [Intraosseous infusion in children]. Ann Fr Anesth Reanim 1999;18:313-8. French 239

A retrospective non-comparative study of IO infusion in 41 children. Concludes that IO insertion is an easy technique. Recommends IO for emergency cases when other vascular access techniques have failed in the first 5 minutes of treatment.

Abstract

Claudet I, Fries F, Bloom MC, Lelong-Tissier MC. [Retrospective study of 32 cases of intraosseous perfusion]. Arch Pediatr 1999; 6: 516-9. French 238

Retrospective study of 32 cases of IO infusion over a 3 year period. Concludes that IO is rapid, safe and effective and provides an essential alternative vascular route in pediatric resuscitation.

Abstract

Daga SR, Gosavi DV, Verma B. Intraosseous access using butterfly needle. Trop Doct 1999;29(3):142-4 236

Evaluation of the utility of 18-gauge butterfly needles for IO administration of fluids and drugs in 23 children presenting in shock. 22 of 23 children were successfully stabilized after IO infusion.

Abstract

Ellemunter H, Simma B, Trawoger R, Maurer H. Intraosseous lines in preterm and full term neonates. Arch Dis Child Fetal Neonatal Ed 1999; 80: F74-5 241

Observational study in 27 newborns, describing 30 intraosseous lines placed after failed IV access. Reports that all patients survived the resuscitation procedures with no long-term side effects.

YEAR: 1998

Nusstein J, Reader A, Nist R, Beck M, Meyers WJ. Anesthetic efficacy of the supplemental intraosseous injection of 2% lidocaine with 1:100,000 epinephrine in irreversible pulpitis. J Endod 1998;24(7):487-91 1004

This article describes a study to determine the anesthetic efficacy of a supplemental intraosseous injection of 2% lidocaine with 1:100,000 epinephrine in teeth diagnosed with irreversible pulpitis. Patients who did not achieve anesthesia with traditional nerve blocks were given supplemental lidocaine using a Stabident IO injection. This technique was found to be 88% effective in gaining total pulpal anesthesia.

YEAR: 1997

Fiallos M, Kisson N, Abdelmoneim T, et al. Fat embolism with the use of intraosseous infusion during cardiopulmonary resuscitation. Am J Med Sci 1997;314(2):73-9 224

Preclinical study in 33 piglets of IO infusion during CPR. Found no increase in fat embolism in IO group compared to controls group.

Fiser RT, Walker WM, Seibert JJ, McCarthy R, Fiser DH. Tibial length following intraosseous infusion: a prospective, radiographic analysis. Pediatr Emerg Care 1997;13(3):186-8 223

Prospective blinded observational study in 10 subjects finding no difference in tibia length after IO infusion compared to opposite tibia at > 1 year post IO infusion.

Reisman D, Reader A, Nist R, Beack M, Weaver J. Anesthetic efficacy of the supplemental intraosseous injection of 3% mepivacaine in irreversible pulpitis. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 1997;84(6):676-82 856

A dental study evaluating use of supplemental intraosseous injection of 3% mepivacaine in mandibular posterior teeth following application of an alveolar nerve block. Results showed supplemental injections increased anesthetic effect and a second injection was sometimes necessary.

Intraosseous Vascular Access Bibliography

Clinical, Observational and Other Studies

Replogle K, Reader A, Nist R, Beck M, Weaver J, Meyers WJ. Anesthetic efficacy of the intraosseous injection of 2% lidocaine (1:100,000 epinephrine) and 3% mepivacaine in mandibular first molars. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 1997;83(1):30-7 855

A dental study comparing the anesthetic effect of 2% lidocaine (1:100,000 epinephrine) and 3% mepivacaine when injected in the mandibular first molars. The results showed the lidocaine to be more successful with a longer duration of pupal anesthesia than mepivacaine.

Waisman M, Waisman D. Bone marrow infusion in adults. J Trauma 1997;42(2):288-93 221

Seminal study on the use of the B.I.G. in elective and emergency situations in 50 adult patients. Success rate for IO insertion was 100%. No complications were observed.

YEAR: 1996

Coggins R, Reader A, Nist R, Beck M, Meyers W.. Anesthetic efficacy of the intraosseous injection in maxillary and mandibular teeth. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 1996;81(6):634-641. doi:10.1016/s1079-2104(96)80067-9 908

This study's objective was to determine the anesthetic efficacy of the intraosseous injection as a primary technique in human maxillary and mandibular teeth. Forty subjects were enrolled and received 2 sets of intraosseous injections with 1.8ml of 2% lidocaine with 1:100,000 epinephrine on two different occasions. Authors concluded that in 75%-93% of non-inflamed teeth subjects, an intraosseous injection may provide pupal anesthesia. Authors cautioned that the duration of the anesthesia declines over an hour.

Helm M, Breschinski W, Lampl L, Frey W, Bock KH. Intraosseous puncture in preclinical emergency medicine: Experiences of an air rescue service. Anaesthesist 1996;45(12):1196-202 545

This abstract describes the retrospective study of a German rescue helicopter service and initial experience using intraosseous access in their system. Ten cases presented in which IO puncture of the proximal tibia was required. In all attempts access was established within 60 seconds without complication; in 2 cases general anesthesia was administered via IO access. Authors concluded that IO infusion is simple, fast, and a safe alternative for emergent access.

Article in German

Shoemaker WC, Peitzman AB, Bellamy R, et al. Resuscitation from severe hemorrhage. Crit Care Med 1996;24(2S):12S-23S 215

Discusses research directions for resuscitation from trauma-induced acute hemorrhagic shock, particularly uncontrolled hemorrhagic shock, with emphasis on fluid resuscitation.

YEAR: 1995

Strausbaugh SD, Manley LK, Hickey RW, Dietrich AM. Circumferential pressure as a rapid method to assess intraosseous needle placement. Pediatr Emerg Care 1995;11:274-6 196

Preclinical study in dog tibias demonstrating that circumferential pressure about an IO infusion site is a rapid method to detect incorrect placement of the IO needle.

YEAR: 1994

Anderson TE, Arthur K, Kleinman M, Drawbaugh R, Eitel DR, Ogden CS, Baker D. Intraosseous infusion: success of a standardized regional training program for prehospital advanced life support providers. Ann Emerg Med 1994;23(1):52-5 165

Study of IO training for advanced life support providers. Providers were able to establish IO access in 13 of 15 (87%) of pediatric patients (age range 1-24 months) following completion of an 1-hour training course and supervised hands-on simulation. All procedures were performed in less than 10 minutes.

Banerjee S, Singhi SC, Singh S, Singh M. The intraosseous route is a suitable alternative to intravenous route for fluid resuscitation in severely dehydrated children. Indian Pediatr 1994;31:1511-20 188

Study of IO vs. IV for administering fluids for resuscitation in 60 children (age range 3-24 months) with severe dehydration. The IO route was successful in all cases within the first 5 minutes of attempt. The IV line could not be secured in 33% of patients within 5 minutes. Time for successful IV access was 129 seconds, significantly longer than time t for IO cannulation. Fluid infusion through either route was equally effective in stabilizing vital signs and normalizing laboratory values. No significant complications of IO route were noted on short-term follow-up.

Losek JD, Szewczuga D, Glaeser PW. Improved prehospital pediatric ALS care after an EMT-paramedic clinical training course. Am J Emerg Med 1994;12:429-32 176

Study demonstrating improved performance of pre-hospital endotracheal intubation and vascular access of younger children after introduction of an EMT-P PALS clinical course.

Intraosseous Vascular Access Bibliography

Clinical, Observational and Other Studies

YEAR: 1993

Glaeser PW, Hellmich TR, Szewczuga D, Losek JD, Smith DS. Five-year experience in prehospital intraosseous infusions in children and adults. *Ann Emerg Med* 1993;22(7):1119-24 158

Retrospective analysis of prehospital IO infusion covering 165 attempts on 152 patients over a 5-year period, found a success rate of 73%, with success rates significantly higher in younger children (<2 years old). EMT-Ps maintained proficiency in the technique over time despite infrequent use.

Guy J, Haley K, Zuspan SJ. Use of intraosseous infusion in the pediatric trauma patient. *J Pediatr Surg* 1993;28:158-6.1 144

Observational study finding 7 of 27 critically injured patients (ages 3mo-10y) successfully resuscitated using IO. Concluded that IO is a rapid, safe and simple method of obtaining short term vascular access in critically ill and injured children.

Kiaer T, Dahl B, Lausten GS. The relationship between inert gas wash-out and radioactive tracer microspheres in measurement of bone blood flow: effect of decreased arterial supply venous congestion on bone blood flow in an animal model. *J Orthop Res* 1993;11(1):28-35 149

Preclinical study of bone perfusion in pigs demonstrating feasibility of inert gas wash-out procedure to study local perfusion rates.

Neufeld JD, Marx JA, Moore EE, Light AI. Comparison of intraosseous, central, and peripheral routes of crystalloid infusion for resuscitation of hemorrhagic shock in a swine model. *J Trauma* 1993;34(3):422-8 148

Preclinical study finding IO infusion to be as effective as central and peripheral venous access for resuscitation with crystalloid infusion in an animal model of hemorrhagic shock.

Ronning G, Busund R, Revhaug A. Resuscitation of pigs with haemorrhagic shock by an intraosseous hyperosmotic solution and transfusion of autologous whole blood. *Eur J Surg* 1993;159(9):133-9 145

Preclinical study in 18 piglets finding significant improvement in hemodynamic variables after IO infusion of hyperosmotic saline and IO transfusion of whole blood in an animal model of hemorrhagic shock. Concludes that IO infusion is easy to establish and holds utility for treatment of shock victims.

Tighe SQ, Rudland SV, Kemp PM, Kershaw CR. Paediatric resuscitation in adverse circumstances: a comparison of three routes of systemic access. *J R Nav Med Ser* 1993;79:75-9 156

Study comparing 3 vascular access routes for fluid administration: intravenous (6 patients), intraosseous (6 patients) and/or intraperitoneal routes (4 patients). Concluded that IO and intraperitoneal routes allowed for severely dehydrated children to be resuscitated without significant complications when IV access is difficult to establish.

abstract only

Warren DW, Kissoon N, Sommerauer JF, Rieder MJ. Comparison of fluid infusion rates among peripheral intravenous and humerus, femur, malleolus, and tibial intraosseous sites in normovolemic and hypovolemic piglets. *Ann Emerg Med* 1993;22(2):183-6 147

Preclinical study comparing infusion rates of IO access sites with IV access under normo- and hypovolemia. Found IV access was most effective for acute volume replacement. IO sites differed in maximum flow rates achievable. The humerus had the greatest flow rate, followed by the femur, malleolus and tibia. Concludes each IO access site is a viable site for short term vascular access.

Welch RD, Johnston CE, Waldron MJ, Poteet B. Bone changes associated with intraosseous hypertension in the caprine tibia. *J Bone Joint Surg Am* 1993;75(1):53-60 151

Preclinical study in goats finding that intraosseous hypertension was associated with a significant increase in periosteal, endocortical, and cancellous new bone formation compared to controls.

Welch RD, Johnston CE, Waldron MJ, Poteet B. Intraosseous infusion of prostaglandin E2 in the caprine tibia. *J Orthop Res* 1993;11(1):110-21 150

Preclinical study in goats examining IO administration of prostaglandin E2 into the proximal metaphysis of the tibia under normotensive and hypertensive conditions within the intraosseous space. Hypertensive PGE2 infusion resulted in significantly more new bone formation.

YEAR: 1992

Dedrick DK, Mase C, Ranger W, Burney RE. The effects of intraosseous infusion on the growth plate in a nestling rabbit model. *Ann Emerg Med* 1992;21(5):494-7 135

Preclinical study in nestling rabbits finding that IO infusion of saline and bicarbonate intraosseous infusions did not damage the metaphyseal growth plate but did cause loss of bone trabeculae that support the growth plate.

Intraosseous Vascular Access Bibliography

Clinical, Observational and Other Studies

Dubick MA, Pfeiffer JW, Clifford CB, Runyon DE, Kramer GC. Comparison of intraosseous and intravenous delivery of hypertonic saline/dextran in anesthetized, euvoletic pigs. *Ann Emerg Med* 1992;21(5):498-503 134

Preclinical study in pigs comparing IO and IV infusion of hypertonic saline/dextran. Found equivalence in entry of sodium and dextran to the blood stream, plasma volume expansion, and increased cardiac output.

Jennings RW, Adzick NS, Longaker MT, Lorenz HP, Estes JM, Harrison MR. New techniques in fetal surgery. *J Pediatr Surg* 1992;27(10):1329-33 137

Preclinical study in sheep fetuses and human fetal cadavers finding that IO-derived blood gas parameters (pH, pCO₂, and pO₂) accurately reflected peripheral venous values and that resuscitation drugs (sodium bicarbonate, glucose, calcium chloride, epinephrine) rapidly entered the fetal circulation.

McClure SR, Welch RD, Johnson TL. Use of an implant for intraosseous infusion as supportive therapy for a Vietnamese pot-bellied pig with urethral obstruction caused by a polyp. *J Am Vet Med Assoc* 1992;201(10):1587-90 122

Veterinary case study finding that an IO implant facilitated vascular access for hyperalimentation and drug therapy over a 72-hour period.

Okrasinski EB, Krahwinkel DJ, Sanders WL. Treatment of dogs in hemorrhagic shock by intraosseous infusion of hypertonic saline and dextran. *Vet Surg* 1992;21(1):20-4 136

Preclinical study of hemorrhagic shock in dogs treated with IO infusion of hypertonic saline/dextran finding that IO infusion efficacious in the treatment of hemorrhagic shock.

Spivey WH, Crespo SG, Fuhs LR, Schoffstall JM. Plasma catecholamine levels after intraosseous epinephrine administration in a cardiac arrest model. *Ann Emerg Med* 1992;21(2):127-31 124

Preclinical study of cardiac arrest in 18 pigs finding IO epinephrine is rapidly transported to the central circulation. Recommends larger doses to produce a significant change in blood pressure.

YEAR: 1991

Chavez-Negrete A, Majluf Cruz S, Frati Munari A, Perches A, Arguero R. Treatment of hemorrhagic shock with intraosseous or intravenous infusion of hypertonic saline dextran solution. *Eur Surg Res* 1991;23(2):123-9 112

Clinical study comparing efficacy of IV or IO infusion of 7.5% NaCl/6% dextran compared to Ringer's lactate in 49 shock patients finding either that sternal IO or IV infusion of 7.5% NaCl/6% dextran is an effective initial treatment of hemorrhagic shock.

Fuchs S, LaCovey D, Paris P. A prehospital model of intraosseous infusion. *Ann Emerg Med* 1991;20(4):371-4 106

Comparison of IO administration in 3 simulated EMS settings: at the scene, in ambulance in steady traffic on curvy road, in ambulance at fast speed in stop and go traffic. Found that 12 EMS participants were successful in establishing IO infusions, with 84.8% of infusions achieved in less than one minute in all settings.

Pollack CV Jr, Pender ES. Intraosseous administration of digoxin: same-dose comparison with intravenous administration in the dog model. *J Miss State Med Assoc* 1991;32(9):335-8 120

Preclinical study in dogs finding that IO infusion of digoxin results in similar plasma concentrations of the drug as IV infusion.

Abstract only

Pollack CV, Pender ES, Woodall BN, Parks, BR. Intraosseous administration of antibiotics: Same-dose comparison with intravenous administration in the weanling pig. *Ann Emerg Med* 1991;20(7):772-6 683

A pre-clinical study comparing IV and IO blood serum levels of antibiotics: ceftriaxone, cefotaxime, ampicillin and gentamicin in weanling pigs. Blood levels were compared at 15, 30, 45, 60 and 90 minutes and each animal served as their own control. Results showed that IO levels were initially lower than IV levels though the difference became indistinguishable after 30 minutes. Ceftriaxone levels however remained lower throughout the 90 minute sample period. The authors concluded that standard IV doses may be administered intraosseously though further study may suggest higher doses of ceftriaxone may be more beneficial.

YEAR: 1990

Brickman K, Rega P, Choo M, Guinness M. Comparison of serum phenobarbital levels after single versus multiple attempts at intraosseous infusion. *Ann Emerg Med* 1990;19(1):31-3 86

Preclinical study in 24 dogs finding that a single IO attempt is preferable to multiple attempts to maintain adequate serum levels of Phenobarbital following IO infusion.

Intraosseous Vascular Access Bibliography

Clinical, Observational and Other Studies

- Orlowski JP, Gallagher JM, Porembka DT. Endotracheal epinephrine is unreliable. *Resuscitation* 1990;19(2):103-13** 99
Preclinical study of the pharmacokinetics of emergency medications in a canine model of shock. Found that endotracheal administration was unreliable, while IO administration was comparable to central and peripheral venous administration.
- Orlowski JP, Porembka DT, Gallagher JM, Lockrem JD, VanLente F. Comparison study of intraosseous, central intravenous, and peripheral intravenous infusions of emergency drugs. *Am J Dis Child* 1990;144(1):112-7** 92
Preclinical study comparing the pharmacokinetics of 6 emergency medications in dogs. Found that IO administration resulted in similar physiologic effect and/or serum drug levels as central and peripheral venous administration.
- YEAR: 1989**
- Cameron JL, Fontanarosa PB, Passalaqua AM. A comparative study of peripheral to central circulation delivery times between intraosseous and intravenous injection using a radionuclide technique in normovolemic and hypovolemic canines. *J Emerg Med* 1989;7(2):123-7** 77
Preclinical study demonstrating comparable central circulation transit times with IO and IV infusion of a radionuclide tracer.
- Jaimovich DG, Shabino CL, Ringer TV, Peters GR. Comparison of intraosseous and intravenous routes of anticonvulsant administration in a porcine model. *Ann Emerg Med* 1989;18(8):842-6** 592
A pre-clinical study evaluating resultant serum levels when administering phenobarbital and phenytoin via intraosseous infusion as compared to IV administration in domestic swine. Results showed that current IV dosing of phenobarbital 20 mg/kg obtains and maintains therapeutic serum levels when given IO; Phenytoin 15 mg/kg does not maintain therapeutic levels and cannot be recommended for IO administration.
- Kramer GC, Walsh JC, Hands RD, Perron PR, Gunther RA, Mertens S, Holcroft JW, Blaisdell FW. Resuscitation of hemorrhage with intraosseous infusion of hypertonic saline/dextran. *Braz J Med Biol Res* 1989;22(2):283-6** 80
Preclinical study in sheep finding no significant differences between IO and IV infusion of hypertonic saline/Dextran.
- Lathers CM, Jim KF, Spivey WH. A comparison of intraosseous and intravenous routes of administration for antiseizure agents. *Epilepsia* 1989;30(4):472-9** 81
Preclinical study in pigs finding equivalence in physiologic response between IO and IV administration of antiepileptic drugs.
- Orlowski JP, Porembka DT, Gallagher JM, Van Lente F. The bone marrow as a source of laboratory studies. *Ann Emerg Med* 1989;18(12):1348-51** 640
This article describes a pre-clinical study comparing bone marrow, venous blood, and arterial blood specimen results when used for blood electrolytes, blood chemistries, blood gases and hemoglobin; and a clinical evaluation of bone marrow and venous blood used for cultures.
- Seigler RS, Tecklenburg FW, Shealy R. Prehospital intraosseous infusion by emergency medical services personnel: a prospective study. *Pediatrics* 1989;84:173-7** 84
Prospective study finding EMS personnel able to successfully establish IO access in 16 of 17 pediatric patients with cardiopulmonary arrest. Observed 13 successful infusions within 1 minute on first attempts at IO access. No significant complications.
- Zimmerman JJ, Coyne M, Logsdon M. Implementation of intraosseous infusion technique by aero medical transport programs. *J Trauma* 1989;29:687-9** 79
Observational study finding nearly 70% of aeromedical transport programs do not use IO infusion. Concludes IO to be grossly under-utilized. Calls for further consideration.
- YEAR: 1988**
- Brunette DD, Fischer R. Intravascular access in pediatric cardiac arrest. *Am J Emerg Med* 1988;6(6):577-9** 63
Retrospective chart review of 33 pediatric patients finding 83% success in establishing IO infusion. IO and percutaneous peripheral catheterization were the quickest methods for vascular access. Observed no major and minimal delayed complications.
- Glaeser PW, Losek JD, Nelson DB, Bonadio WA, Smith DS, Walsh-Kelly C, Hennes H. Pediatric intraosseous infusions: impact on vascular access time. *Am J Emerg Med* 1988;6:330-2** 48
Retrospective chart review over a 1-year period finding IO reduced vascular access time in patients with cardiac arrest when standard techniques failed.

Intraosseous Vascular Access Bibliography

Clinical, Observational and Other Studies

- Jim KF, Lathers CM, Spivey WH, Matthews WD, Kahn C, Dolce K. Suppression of pentylenetetrazol-elicited seizure activity by intraosseous propranolol in pigs. J Clin Pharmacol 1988;28(12):1106-11** 71
Preclinical study in pigs demonstrating suppression of seizures with both IO and IV administered propranolol. Both IO and IV propranolol reduced basal heart rate by a 32-38% and reduced the transient increase in mean arterial pressure (MAP) elicited by pentylenetetrazol with no effect on the basal MAP.
- Neish SR, Macon MG, Moore JW, Graeber GM. Intraosseous infusion of hypertonic glucose and dopamine. Am J Dis Child 1988;142(8):878-80** 69
Preclinical study finding IO infusion of hypertonic glucose and dopamine to be as effective as IV administration.
- Saavedra J, Patterson H, Kramer G. Intraosseous injection of hypertonic saline dextran: anatomic considerations in man and sheep. Circ Shock 1988;24:283** 60
Anatomical study. Found that IO infusion into the sternum provides direct vascular access via the thoracic veins. Concludes that IO infusion of hypertonic saline dextran may provide paramedics and emergency room physicians with a more rapid and effective method of vascular access and volume expansion than conventional resuscitation regimens.
- YEAR: 1987**
- Brickman KR, Rega P, Guinness M. A comparative study of intraosseous versus peripheral intravenous infusion of diazepam and phenobarbital in dogs. Ann Emerg Med 1987;16(10):1141-4** 57
Preclinical study finding comparable serum drug levels with IO and IV administration.
- YEAR: 1985**
- Spivey WH, Lathers CM, Malone DR, et al.. Comparison of intraosseous, central, and peripheral routes of sodium bicarbonate administration during CPR in pigs. Ann Emerg Med 1985;14(12):1135-40** 43
Preclinical study in pigs examining blood pH during CPR with sodium bicarbonate administered via different vascular access routes. Found that pH of blood obtained via central venous access and intraosseous access were significantly different from the peripheral group, and that all three groups were significantly different from the control. Pathology studies showed only minor damage to bone with IO sodium bicarbonate administration.
- YEAR: 1982**
- Hedley DW, Joshua DE, Tattersall MH, Taylor IW. Fine-needle aspiration of bone marrow from sternum. Lancet 1982;2:415-16** 35
Study finding that 23-gauge needle is less painful and yields purer bone marrow sample from the sternum.
- YEAR: 1977**
- Valdes MM. Intraosseous fluid administration in emergencies. Lancet 1977;1(8024):1235-6** 29
Observational study of 15 patients needing emergency fluids and in whom IV's were difficult to establish. Patients received drugs and fluids via IO. Concludes that IO therapy is effective with no serious complications.
- YEAR: 1956**
- Bennike T, Gormsen H, Moller B. Comparative studies of bone marrow punctures of the sternum, the iliac crest, and the spinous process. Acta Med Scand 1956;155(5):377-96** 28
Study finding sternal puncture superior to iliac crest and spinous process punctures for bone marrow sampling. Cautions that inexperienced practitioners should use iliac crest or spinal process in the absence of training in sternal puncture.
- YEAR: 1950**
- Massey LW. Bone-marrow infusions: intratibial and intravenous routes compared. Br Med J 1950;2(4672):197-8** 22
Early review of IO infusion citing complication rate of osteomyelitis (approximately 1 in 150 cases).
- YEAR: 1947**
- Elston JT, Jaynes RV, Kaump DH, Irwin WA. Intraosseous infusions in infants. Am J of Clinical Path 1947;17(2):143-50** 20
Early article on IO puncture and infusion, emphasizing technique. Concludes their technique is safer and more effective than previously described techniques.

Intraosseous Vascular Access Bibliography

Clinical, Observational and Other Studies

Heinild S, Sondergaard T, Tudvad F. Bone marrow infusion in childhood: Experiences from a thousand infusions. *J of Pediatrics* 1947; 30: 400-11

21

Early study on IO. Makes strong distinction between ordinary blood transfusion or infusion of isotonic solutions (generally safe) and continuous infusion or the infusion of hypertonic solutions. The latter carries considerable risk of osteomyelitis and subsequent disturbance in growth of the bone.

YEAR: 1945

Gunz FW, Dean RFA. Tibial bone-marrow transfusions in infants. *Br Med J* 1945;1(4389):220-1

800

Abstract describes experience in one institution using tibial IO access to replace fluids, mostly due to dehydration.

Intraosseous Vascular Access Bibliography

Competitor

YEAR: 2019

Sørgjerd R, Sunde GA, Heltne JK. Comparison of two different intraosseous access methods in a physician-staffed helicopter emergency medical service - A quality assurance study. Scand J Trauma Resusc Emerg Med 2019;27(1):15 doi: 10.1186/s13049-019-0594-6 1062

This study compared IO insertions with the EZ-IO device (tibial/humeral insertions) to the FAST-R device (sternal insertions only) in a physician-staffed helicopter emergency medical service. Insertion time, insertion site, flow, indication for IO access, and complications were compared. Median insertion time was 15 seconds for EZ-IO and 20 seconds for FAST-R. Overall, 35.1% of EZ-IO insertions resulted in poor flow and required a pressure bag while 85.7% of FAST-R insertions had good or very good flow. EZ-IO complications included extravasation (2.4%), aspiration failure (11.9%), and insertion time >30 seconds (4.8%). Complications associated with FAST-R included user failure (12.5%) and insertion time >30 seconds (12.5%). The authors suggest that although EZ-IO is faster the FAST-R device may be more useful when high-flow infusion rates are required. The authors indicate that a low number of insertions were made with the FAST-R device and many outliers were observed in the data. However, the article does not present the total number of insertions per device.

YEAR: 2018

Wagner M, Olischar M, O'Reilly M, et al. Review of routes to administer medication during prolonged neonatal resuscitation. Pediatr Crit Care Med 2018;19(4):332-8. doi: 10.1097/PCC0000000000001493 1029

This article presents a review of current evidence regarding different routes for the administration of medications during neonatal resuscitation, of which the intraosseous route is included. A table comparing four different intraosseous devices, including EZ-IO, is presented in the document.

YEAR: 2017

Bielski K, Szarpak L, Smereka J, Ladny J, Leung S, Ruetzler K. Comparison of four different intraosseous access devices during simulated pediatric resuscitation. A randomized crossover manikin trial. Eur J Pediatr 2017;176(7):865-71. doi:10.1007/s00431-017-2922-z 899

This study compared success rate, procedure time and user satisfaction of pediatric NIO vs. Pediatric BIG, EZ-IO and Jamshidi intraosseous access devices in pediatric manikins. Study was randomized, crossover trial with 87 paramedics participating. The study evaluated each device on the ease of use in performing their procedures. Results of this study found that paramedics favored the NIO in ease of use in the pediatric manikins.

Clemency B, Tanaka K, May P, et al. Intravenous vs. intraosseous access and return of spontaneous circulation during out of hospital cardiac arrest. Am J Emerg Med 2017;35:222-6. doi:10.1016/j.ajem.2016.10.052 943

A retrospective chart review was done to analyze data of three EMS agencies over an 18 month timespan. Analysis was done on charts from adults who suffered OOHCA and received epinephrine through EMS established IV or IO access. An IO first approach was found non-inferior to an IV first approach based on the end point ROSC at time of emergency department arrival.

Iskrzycki L, Smereka J, Szarpak L. Knowledge, skills, and attitudes concerning intraosseous access among hospital physicians. Crit Care Med 2017;45(1):e117 876

This letter to the editor describes a manikin study that compared use of the Teleflex EZ-IO to the Persys Medical NIO intraosseous vascular access devices. Insertion times were statistically different, favoring the NIO but not considered clinically relevant. The authors concluded that, while hospital physicians' knowledge of intraosseous access was limited, with simple training they could learn the procedure and place IO needles safely in less than 30 seconds.

Shina A, Baruch EN, Shlaifer A, et al. Comparison of two intraosseous devices: The NIO versus the EZ-IO by novice users- a randomized cross over trial. Prehosp Emerg Care 2017;21(3):315-21. doi:10.1080/10903127.2016.1247201 817

Using a porcine hind leg model authors compared the success rate and ease-of-use ratings of an IO device, the NIO® in comparison to the Arrow® EZ-IO by novice users. NIO success rates were comparable to those of EZ-IO; 54% of the participants preferred using the EZ-IO over the NIO.

YEAR: 2016

Bramlett E, Fales W, West B, LaBond V. Rate of return of spontaneous circulation in relation to primary vascular access during out-of-hospital adult cardiac arrest. Ann Emerg Med 2016;68(4S):S120 812

Investigators conducted a retrospective prehospital study over a 3 month time period comparing IV vs. IO access for return of spontaneous circulation (ROSC). With approximately 800 cases of out-of-hospital cardiac arrest (OOHCA) they found a significantly greater success rate for IO access but no difference between IO and IV for ROSC or time to first epinephrine.

Chin YX, Kiat Tan KB, Koh ZX, et al. Comparing intraosseous and intravenous access for out-of-hospital cardiac arrest in Singapore. Resuscitation 2016;106(S1):e25 813

The objective of this study was to determine if there would be a difference in rates of vascular access and ROSC if paramedics were able to use IO access after two initial IV attempts failed. Investigators found higher vascular access success and prehospital epinephrine administration rates with the addition of IO access but no significant difference for ROSC.

Singapore

Intraosseous Vascular Access Bibliography

Competitor

- Ramirez JG, Truszewski Z, Drozd A. Comparison of two intraosseous access devices employed during simulated cardiopulmonary resuscitation. Disaster Emerg Med J 2016;1(1):24-9. doi:10.5603/DEMJ.2016.0004** 857

A study comparing use of the Bone Injection Gun (B.I.G.) and the NIO by paramedics in a manikin model simulation of CPR. Following training, 40 paramedics performed device insertion in the manikin using both devices; and completed a questionnaire regarding their knowledge of indications and contraindications of IO access and experience with each device. Successful insertion was achieved 100% with the NIO and 95% with the B.I.G. Authors concluded that after a short training program, paramedics can perform intraosseous injection with a high degree of efficacy.

- Singh S, Aggarwal P, Lodha R, et al. Feasibility study of a novel intraosseous device in adult human cadavers. Indian J Med Res 2016;143:275-80. doi:10.4103/0971-5916.182616** 861

A cadaveric study evaluating the function and safety of a manual, screw IO device designed to gain access to the medullary space. Twelve insertions were performed by the same device operator, of which 10 were successful. The 2 failed insertions were due to overshooting of the needle. The authors concluded the new device could successfully penetrate the bone cortex in adult cadaver bones, and that further testing and comparison to commercially available devices is needed.

India

- Smereka J, Madziala M, Szarpak L. Are firefighters able to perform intraosseous access and start fluid resuscitation in an anaphylactic patient. Am J Emerg Med 2016;34(8):1707-8. doi: 10.1016/j.ajem.2016.05.068** 851

This letter to the editor describes a simulation study evaluating use of the NIO device by 47 firefighters in a simulated anaphylactic shock model. The firefighters were trained on use of the device and standard anaphylactic shock management. An improvement in knowledge of intraosseous vascular access and anaphylactic shock protocol was demonstrated by the group.

- Szarpak L, Czyzewski L, Woloszczuk-Gebicka B, Krajewski P, Fudalej M, Truszewski Z. Comparison of NIO and EZ-IO intraosseous access devices in adult patients under resuscitation performed by paramedics: A randomized crossover manikin trial. Am J Emerg Med 2016;34(6):1166-7. doi:10.1016/j.ajem.2016.03.017.** 774

This randomized crossover manikin trial compared the NIO and EZ-IO devices for time to placement and ease of use. For both parameters the NIO performed better.

Poland

- Szarpak L, Ramirez JG, Buljan D, Drozd A, Madziala M, Czyzewski L. Comparison of Bone Injection Gun and Jamshidi intraosseous access devices by paramedics with and without CBRN person protective equipment. A randomized, crossover, manikin trial. Am J Emerg Med 2016;34(7):1307-8. doi:10.1016/j.ajem.2016.04.032** 843

A manikin study in which 40 paramedics dressed with and without CBRN PPE attempted to establish tibial intraosseous (IO) access using the jamshidi and BIG devices, time to placement was measured. Results showed that in participants with and without CBRN PPE, BIG access was faster than Jamshidi.

- Szarpak L, Truszewski Z, Smereka J, et al. A randomized cadaver study comparing first-attempt success between tibial and humeral intraosseous insertions using NIO device by paramedics. Medicine 2016;95(20):e3724. doi:10.1097/MD.00000000000003724** 845

A prospective study comparing use of the NIO device by 84 paramedics to establish proximal humerus and proximal tibia intraosseous (IO) access for first attempt success rate, time to access, and user feedback on ease of use and preference. IO access was established in fresh (within 72 hours of expiration) cadavers. The first attempt success rate with tibial IO access was 89.3% vs 73.8% humeral; procedure time was significantly faster for the tibial IO site; and participants found IO access in the proximal tibia as easier to obtain than the proximal humerus IO site.

- Szarpak L, Truszewski Z, Smereka J, Krajewski P, Fudalej M. Ability of paramedics to perform intraosseous access. A randomized cadaver study comparing EZ-IO and NIO devices. Resuscitation 2016;104:e5-e6. doi:10.1016/j.resuscitation.2016.04.011** 795

This letter to the editor describes a prospective, randomized, cross-over cadaveric study that evaluated use of the EZ-IO and NIO devices by novice paramedic device users. Following a brief in-service on use of both devices and practice insertions using a leg-trainer manikin, each participant attempted to establish IO access using each device in a resuscitation simulation with in an adult cadaver with CPR in progress. Results showed first attempt success rates of 97.4% with the NIO and 100% with the EZ-IO; and mean time to insertion was 16.8 seconds with the NIO and 42 seconds with the EZ-IO.

- Zasko P, Szarpak L, Kurowski A, Truszewski Z, Czyzewski L. Success of intraosseous access procedure in simulated adult resuscitation. Crit Care Resusc 2016;18(2):134** 834

A simulation study comparing use of peripheral IV access and tibial intraosseous access via the NIO device, by internal medicine specialists. Forty-three participants attempted to establish access using the two methods in a manikin; first attempt success, time to access and ease of procedure were measured. The NIO device was superior to IV access with regard to all endpoints.

YEAR: 2015

- Hammer N, Möbius R, Gries A, Hossfeld B, Bechmann I, Bernhard M. Comparison of the fluid resuscitation rate with and without external pressure using two intraosseous infusion systems for adult emergencies, the CITRIN (comparison of intraosseous infusion systems in emergency medicine)- study. PLoS ONE 2015;10(12):e0143726. doi:10.1371/journal.pone.0143726** 791

A cadaveric study performed by twenty-seven medical students, inexperienced with IO vascular access, that compared use of the EZ-IO for access in the proximal humerus and proximal tibia insertion sites and the FASTR for access in the sternum. First pass insertion success, insertion times, and one minute flow rates using external pressures from 0 to 300 mmHg were evaluated. The authors concluded that both the EZ-IO and FASTR devices may be effective IO devices and are likely suitable for fluid resuscitation using a pressure bag.

Intraosseous Vascular Access Bibliography

Competitor

Ohchi F, Komasa N, Mihara R, Minami T. Comparison of mechanical and manual bone marrow puncture needle for intraosseous access; a randomized simulation trial. Springer Plus 2015;doi:10.1186/s40064-015-0982-y

766

A simulation study comparing use of manual (Cook Medical) and mechanical (Arrow EZ-IO) intraosseous (IO) devices to establish IO access in mannequin bones representing infant, pediatric and adult tibias. Twenty-two anesthesiologists with no prior experience with IO devices participated in the study. The outcome measures were success rate, insertion time and operator reported difficulty of use. Results were in favor of the mechanical device for insertion time in each category, and success rate in the adult tibia group; there was no statistical difference in the difficulty of use evaluation.

Pasley J, Miller CHT, DuBose J, et al. Intraosseous infusion rates under high pressure: a cadaveric comparison of anatomic sites. J Trauma Acute Care Surg 2015;78(2):295-9. DOI: 10.1097/TA.0000000000000516

750

A cadaveric study evaluating intraosseous (IO) vascular access insertion sites for attainable flow rates under 300 mmHg. The EZ-IO was used to establish IO access at the proximal humerus and proximal tibia sites; the FAST1 was used to establish sternal IO access. The total volume of fluid infused at the three IO access sites was 469 ± 190 mL for the sternum; 286 ± 218 mL for the humerus; and 154 ± 94 mL for the tibia. The mean flow rate infused at each site was as follows: 93.7 ± 37.9 mL/min for the sternum; 57.1 ± 43.5 mL/min for the humerus; and 30.7 ± 18.7 mL/min for the tibia. First attempt placement success was 100% for the sternum and proximal humerus and 81% for the tibia.

YEAR: 2014

Demir OF, Aydin K, Akay H, Erbil B, Karcioğlu O, Gulalp B. Comparison of two intraosseous devices in adult patients in the emergency setting: a pilot study. Eur J Emerg Med 2014;DOI:10.1097/MEJ.0000000000000187

735

This was a prospective, randomized controlled clinical pilot study comparing the BIG and EZ-IO intraosseous (IO) vascular access devices in 52 adult patients admitted to an emergency department with difficult peripheral venous access. Twenty-six patients were randomized to each device; results were first attempt insertion success BIG 92.3%, EZ-IO 84.6% (P=0.668); procedure time: BIG 2.8 ± 1.2 seconds, EZ-IO 5.2 ± 2.2 seconds (P<0.001), significant; difficulty of use (with visual analogue scale): BIG 8.6 ± 6.4 mm, EZ-IO 25.4 ± 12.6 mm (P<0.001), significant. Authors concluded both EZ-IO and BIG are shown to be reliable and safe methods for insertion of intravascular access in emergency conditions. There were no adverse events or complications reported.

Turkey

Nadler R, Gendler S, Chen J, Lending G, Abramovitch A, Glassberg E. The Israeli Defense Force experience with intraosseous access. Military Medicine 2014;179(11):1254-7

740

Retrospective study of the Israeli Defense Force (IDF) registry from January 1999 through October 2012 to identify all cases in which IO access was attempted. The Bone Injection Gun (B.I.G.) was the device used for IO access. A total 37 attempts were made in 30 patients. First attempt success was 53% with an overall success rate 49% when factoring subsequent attempts. Most frequent cause for failure related to providers skill level, and due to the device design allowing little room for error. This study prompted the IDF to seek an alternative for the B.I.G.

Israel

Vassallo J, Horne S, Smith JE. Intraosseous access in the military operational setting. J R Nav Med Serv 2014;100(1):36-9

794

This article describes a prospective, observational study conducted March – July 2011 at the emergency department, Camp Bastion, Afghanistan evaluating use of IO access in 117 patients established using the EZ-IO and the FAST1 devices (76% EZ-IO).

Zielinski M, Skitek-Adamczak I, Sip M, Witt M. Ready-to-use devices for intraosseous injections (BIG) in the practice of emergency medical teams in the city and county of Poznan - Primary survey. Polish Annals of Medicine 2014;21:126-30. http://dx.doi.org/10.1016/j.poamed.2014.07.011

833

A survey study assessing the knowledge of members of emergency medical teams in Poznan about the BIG intraosseous device.

YEAR: 2012

Helm M, Goller R, Hackenbroch C, Hossfeld B. A complication of the use of an intra-osseous needle. Emerg Med J 2012;29:923. doi: 10.1136/emered-2011-200139

1054

This is a case report of needle sheering associated with the use of the FAST-1 intraosseous infusion system. A soldier successfully placed a FAST-1 needle in the sternum of a healthy volunteer soldier during a training session. Upon completion of the training session, the soldier was unable to remove the needle. The retained needle was later removed surgically at a field hospital.

Isayama K, Nakatani T, Tsuda M, Hirakawa A. Current status of establishing a venous line in CPA patients by emergency life-saving technicians in the prehospital setting in Japan and a proposal for intraosseous infusion. Int J Emerg Med 2012;5(1):2. doi:10.1186/1865-1380-5-2

527

This article discusses a retrospective review of Japanese prehospital system for intravenous infusion success rates in cardiopulmonary arrest (CPA) patients and a prospective simulation study. A nationwide database was reviewed for CPA records from 1 January 2005 to 31 December 2008 yielding 431,968 cases. Results showed the IV infusion success rate in adults increased annually, however the rate in pediatrics did not; and while the administration of adrenaline increased the 1-month survival rate did not. In the simulation study, 100 EMS technicians used the Bone Injection Gun (BIG) in simulator adult, pediatric and infant legs. There was no difference in the time to establish IO access between the simulation models. The authors concluded that IO access should be considered when IV access is difficult or impossible.

Intraosseous Vascular Access Bibliography

Competitor

YEAR: 2010

Hartholt KA, van Lieshout EM, Theis WC, Patka P, Schipper IB. Intraosseous devices: a randomized controlled trial comparing three intraosseous devices. *Prehosp Emerg Care* 2010;14(1):6-13. doi: 10.3109/10903120903349861

443

This article describes a randomized, single-blind, controlled trial to determine which IO needle can be used best for gaining IO access in patients requiring acute administration of fluids or medication in a prehospital setting. The study was performed at a level 1 trauma center in the Netherlands with a Helicopter Emergency Medical Service (HEMS). Adult and pediatric patients meeting inclusion criteria were randomized between Jamshidi 15G, B.I.G. 15G/18G and F.A.S.T.1. Insertion time, success, aspiration of bone marrow, side effects, medication given, trauma mechanism, and user satisfaction were recorded. In the adult group Jamshidi was placed fastest, significantly faster than the F.A.S.T.1. ($p=0.002$). Time to insert the B.I.G. 15G did not differ statistically from other devices. In the pediatric group insertion time of the Jamshidi did not differ statistically from the B.I.G. 18G. On average, the devices (adult and pediatric) did not differ significantly with respect to success rate, complication rates, and user satisfaction. EZ-IO was not included in this study as it was not approved for use in the Netherlands at the time the trial began. Authors recommend comparison with EZ-IO in future research.

YEAR: 2009

Fortin JL, Capellier G, Manzon C, Giocanti J, Gall O. Intraosseous administration of hydroxocobalamin in the acute treatment of cyanide poisoning. *Burns* 2009;35(S1):S15-6. doi: 10.1016/j.burns.2009.06.061. France

801

Case study of a 9-month old treated with IO hydroxocobalamin for suspected smoke inhalation cyanide poisoning. The patient was discharged from the ICU without neurological sequelae. Authors stated the IO route for hydroxocobalamin warrants further exploration to improve ease and speed of treatment.

YEAR: 2007

Stone MN, Teismann NA, Wang R. Ultrasonographic confirmation of intraosseous needle placement in an adult unembalmed cadaver model. *Ann Emerg Med* 2007;49(4):515-9. doi:10.1016/j.annemergmed.2006.11.009

832

A cadaveric study evaluating the use of ultrasonography visualization of flow within the intraosseous space to confirm proper needle placement. In a sample of 4 freshly frozen, unembalmed cadavers with bilateral distal tibia IO access, ultrasonography accurately detected the flow of crystalloids through the IO space 100%.

YEAR: 1998

Nusstein J, Reader A, Nist R, Beck M, Meyers WJ. Anesthetic efficacy of the supplemental intraosseous injection of 2% lidocaine with 1:100,000 epinephrine in irreversible pulpitis. *J Endod* 1998;24(7):487-91

1004

This article describes a study to determine the anesthetic efficacy of a supplemental intraosseous injection of 2% lidocaine with 1:100,000 epinephrine in teeth diagnosed with irreversible pulpitis. Patients who did not achieve anesthesia with traditional nerve blocks were given supplemental lidocaine using a Stabident IO injection. This technique was found to be 88% effective in gaining total pulpal anesthesia.

Intraosseous Vascular Access Bibliography

Complications

YEAR: 2019

Sampson CS. Extravasation from a misplaced intraosseous catheter. Clin Pract Cases Emerg Med 2019;3(3):303-4

1068

A 75-year old female presented by EMS to the Emergency Department (ED) after a ventricular fibrillation cardiac arrest. EMS defibrillated the patient and placed a right proximal tibial EZIO intraosseous (IO) catheter which multiple medications (epinephrine, magnesium, amiodarone, and calcium chloride) were administered; and she had return of spontaneous circulation prior to ED arrival. The IO catheter wasn't patent upon arrival in the ED and was removed. The patient was discharged on day four with ecchymosis near the insertion site. Three weeks post discharge the patient presented with tissue necrosis in an area surrounding the initial proximal tibial IO insertion site. The patient's leg was debrided and grafting was performed; the author reported "good healing" three months post-event.

Sørgjerd R, Sunde GA, Heltne JK. Comparison of two different intraosseous access methods in a physician-staffed helicopter emergency medical service - A quality assurance study. Scand J Trauma Resusc Emerg Med 2019;27(1):15 doi: 10.1186/s13049-019-0594-6

1062

This study compared IO insertions with the EZ-IO device (tibial/humeral insertions) to the FAST-R device (sternal insertions only) in a physician-staffed helicopter emergency medical service. Insertion time, insertion site, flow, indication for IO access, and complications were compared. Median insertion time was 15 seconds for EZ-IO and 20 seconds for FAST-R. Overall, 35.1% of EZ-IO insertions resulted in poor flow and required a pressure bag while 85.7% of FAST-R insertions had good or very good flow. EZ-IO complications included extravasation (2.4%), aspiration failure (11.9%), and insertion time >30 seconds (4.8%). Complications associated with FAST-R included user failure (12.5%) and insertion time >30 seconds (12.5%). The authors suggest that although EZ-IO is faster the FAST-R device may be more useful when high-flow infusion rates are required. The authors indicate that a low number of insertions were made with the FAST-R device and many outliers were observed in the data. However, the article does not present the total number of insertions per device.

YEAR: 2018

Abramson TM, Alreshaid L, Kang T, Mailhot T, Omer T. Fasciotomy: Ultrasound evaluation of an intraosseous needle causing compartment syndrome. Clin Pract Cases Emerg Med 2018;2(4):323-25

1041

This case review describes a complication of compartment syndrome post IO placement in a 64 year old male initially unresponsive and hypoglycemic. Approximately 15 minutes post-ED arrival compartment syndrome signs were noted and confirmed with compartment pressures. An ultrasound confirmed lack of flow from the IO needle and x-ray showed the needle set to be inserted 2 mm beyond the posterior tibial cortex. Patient was taken to surgery for fasciotomy and four compartment release with subsequent return of pulses.

*(Correspondence by the manufacturer 12-2018 with lead author confirmed the tibial placement was lateral and the patient had a full functional recovery).

Chalopin T, Lemaignan A, Guillon A, et al. Acute tibial osteomyelitis caused by intraosseous access during initial resuscitation: a case report and literature review. BMC Infectious Diseases 2018;18(1):665. doi: 10.1186/s12879-018-3577-8

1047

This report from France reports a case of tibial osteomyelitis in a 40 year old male that was diagnosed by MRI and biopsy three months post-intraosseous (IO) catheter removal. The patient was given parenteral as well as oral antibiotics and had a good outcome. The initial IO catheter placement was for treatment of overdose after failed IV attempts. The catheter was removed on the first day and the patient was treated with oral antibiotics due to local inflammation at the insertion site. He left against medical advice before a full treatment course was completed.

Molacek J, Houdek K, Opatrný V, et al. Serious complications of intraosseous access during infant resuscitation. Eur J Pediatr Surg Rep 2018;6:e59-e62

1057

This case reports a serious compartment syndrome in a 2.5 year old infant which resulted in a left leg partial amputation. The IO device was placed to administer treatment following a respiratory arrest and extravasated.

Reic C, Fogg T, Healy G. Deformation of a humeral intraosseous catheter due to positioning for thoracostomy. Clin Exp Emerg Med 2018;5(3):208-9

1013

This article describes a complication of a deformed EZ-IO catheter which was noted following removal of the catheter in an adult patient. The catheter had been placed by a helicopter emergency medical service team following a motor vehicle accident. The cause of the catheter bending was most likely the result of arm positioning for thoracostomy. No difficulties in removing the catheter were noted and it appeared to have been functioning effectively.

Simsek P, Bayram SB, Gursoy A. İlaç uygulamaları için farklı bir yol: İntraosseöz ulaşım ve infüzyon [A different route for drug administration: Intraosseous access and infusion]. HEAD 2018;15(1):40-44. doi: 10.5222/HEAD2018.040. Turkish

1061

This is an article published in a Turkish nursing journal and written in Turkish. From the abstract, the IO route is described as an alternative approach to vascular access when venous access via a peripheral catheter cannot be obtained quickly. Complications of IO access and how to prevent them using nursing interventions are discussed. EZ-IO is discussed in the article.

Intraosseous Vascular Access Bibliography

Complications

Winkler M, Issa M, Lowry C, Chornenkyy Y, Sorrell V. Intraarticular extravasation, an unusual complication of computed tomographic angiography performed with intraosseous needle intravenous access. Cardiovasc Diagn Ther 2018;8(4):516-9. doi:10.21037/cdt.2018.06.04

1033

This paper describes a case study of a 66 year-old female who presented to an emergency department with symptoms of an acute stroke. After failure of intravenous (IV) placement, humeral intraosseous (IO) access was obtained using the EZ-IO device. Contrast media (CM) for computed tomographic angiography (CTA) was later infused, off label, through the IO line. At the time of the CT scan 20 mL of CM was seen within the glenohumeral joint. The patient did not experience any ill effects from the extravasation following the procedure nor at her 1 week follow-up.

YEAR: 2017

Bromberg R, Dave K, Mankodi D, Danckers M. Soft tissue laceration caused by lower extremity intraosseous access insertion in an obese patient. BMJ Case Rep 2017;doi:10.1136/bcr-2017-220069. (United Kingdom)

938

This case report describes a complication of a laceration that occurred in an 85 year old morbidly obese female that presented in septic shock and received a proximal tibial IO placement. A 45 mm needle set was used for the initial insertion, which was completed without any initial problems; no stabilizer was placed. The patient had fluid resuscitation via the IO site with rapidly improved hemodynamics. During transport she developed a 7 cm laceration across the IO insertion site. The catheter was removed and laceration sutured. Authors opined that the lack of use of the EZ-Stabilizer dressing, the amount of soft tissue and thin skin and traction forces on the IO site applied during transport contributed to this complication.

Hodgetts JM, Johnston A, Kendrew J. Long-term follow-up of two patients with retained intraosseous sternal needles. J R Army Med Corps 2017;163(3):221-2. doi: 10.1136/jramc-2016-000699

872

This article describes two cases in which FAST1 intraosseous needle tips were retained in the sternal manubrium of patients following device removal. In each case, there were no long-term complications.

Meyers BL, Kramer SA, Field AE, et al. Unexpected procedural complications during intraosseous infusions. J Am Assoc Lab Anim Sci 2017;56(5):P98, pg. 598

994

This poster presents a complication and unexpected ultrasound findings associated with IO infusions attributed to fat embolization. At necropsy, lung histology of 35 female swine revealed numerous large fat emboli consisting of bone marrow cellular elements and adipose cells within medium-sized arteries. High IO infusion rates also contributed to fat embolism in the femoral vein. Providers should be aware of the potential for pulmonary embolism.

Santos AP, Conkin R, Dowd K. Needle break: Complication and management of intraosseous vascular access. Am Surg 2017;83(1):e18-20

1016

This report describes a case study of a 19 year-old male who had an IO catheter placement in the left proximal tibia with EZ-IO after sustaining injuries in a motorcycle accident. Upon removal of the IO access, the needle broke at the hub with the retained needle no longer exposed above the skin. Removal at the bedside using Hemostat forceps failed, as well as the use of a sternal needle holder and a wire twister. Under fluoroscopic guidance, a 4 mm Stryker Crown drill bit was used to remove the retained needle by coring it out of the bone. The site was irrigated, bone graft substitute was placed into the defect, and the surgical site was closed. The patient healed well and was discharged with no complications 3 days later.

Takei H, Nomura O, Yasuda M, Inoue N. Dermal abrasion due to semi-automatic intraosseous device. Pediatr Int 2017;59(5):641-2

1027

This paper describes a complication of dermal abrasion with the EZ-IO device in a 1 year old female in Japan who was treated in the emergency department for severe dehydration due to acute gastroenteritis.

Thadikonda KM, Egro FM, Ma I, Spiess AM. Deltoid compartment syndrome: A rare complication after humeral intraosseous access. Plast Reconstr Surg Glob Open 2017;5(1):e1208. doi: 10.1097/GOX.0000000000001208

807

Case report of a 64 year old female in critical condition that had bilateral humeral intraosseous (IO) access sites placed for resuscitation. Past medical history included a clotting disorder. IO access was removed within 24 hours after CVC placement. Eight days post-IO catheter removal the patient developed pain, swelling, decreased motion and firmness in the area near the IO site. Conservative management failed and clinicians confirmed elevated deltoid compartment pressures and diagnosed compartment syndrome. She was taken to the operating room for a fasciotomy. Post-operatively the patient had pain relief, improved range of motion and last check-up had no pain and full range of motion.

Yee D, Deolankar R, Marcantoni J, et al. Tibial osteomyelitis following prehospital intraosseous access. Clin Pract Cases Emerg Med 2017;1(4):391-4

936

Case report of a 29 year old that was diagnosed with osteomyelitis in his left tibia after a prehospital IO placement for resuscitation of cardiac arrest. Medications infused included naloxone, epinephrine, and amiodarone. The patient had ROSC and his IO catheter was removed within one hour of ED arrival due to infiltration. Diagnosis of tibial osteomyelitis occurred approximately 8 weeks post-initial placement.

Intraosseous Vascular Access Bibliography

Complications

YEAR: 2016

- Azan B, Teran F, Nelson BP, Andrus P. Point-of-care ultrasound diagnosis of intravascular air after lower extremity intraosseous access. J Emerg Med 2016;51(6):680-3. <http://dx.doi.org/10.1016/j.jemermed.2016.05.064>** 808
- This case reports one patient in which they found a vascular air embolism via ultrasound when they were assessing the patient's femoral vessels prior to arterial line placement on the same side as a limb that had an IO device placed. The authors noted that it was possible air was introduced when the patient injected IV heroin to that same leg; but believe it was more likely the IO line or tubing was not flushed or left open for a period of time.
- Bustamante S, Cheruku S. Ultrasound to improve target site identification for proximal humerus intraosseous vascular access. Anesth & Analg 2016;123(5):1335-7. doi:10.1213/ane.0000000000001543** 904
- In this letter to the editor authors discuss intraosseous access (IO) via proximal anterior tibia and proximal humerus. Per authors, the tibial site was used more frequently due to ease of identifying the landmarks for insertion and accessibility to this area while proximal humerus intraosseous access (PHIO) site can be more difficult to identify landmarks for insertion. The authors discuss the use of ultrasound to identify structures for PHIO access has the potential to increase the success rate of proper site insertion.
- Ginsberg-Peltz J. Time to bone healing after intraosseous placement in children is ill defined. Pediatr Emerg Care 2016;32(11):799-800. doi:10.1097/PEC.0000000000000652** 944
- This article discusses the difficulty in defining the time to bone healing after IO access insertion in children. A case study is presented of a 23 month old male with multiple comorbidities that had a tibial and proximal humerus IO placed then 3 weeks post IO placement had tibial swelling. Upon follow-up he was diagnosed with a tibial fracture and incomplete healing of the tibial bone accessed for IO use. Repeated IO access to a limb previously accessed is advised regardless of time after access. Authors emphasize that IO access is a "critically important tool" in pediatric emergency medicine and IO access should be used early and often.
- Greenstein YY, Koenig SJ, Mayo PH, Narasimhan M. A serious adult intraosseous catheter complication and review of the literature. Crit Care Med 2016;44(9):e904-9. doi: 10.1097/CCM.0000000000001714** 775
- This article includes a case study of an adult patient who received an intraosseous (IO) catheter, that may have extravasated, resulting in vascular compromise. The patient was treated with pharmacologic intervention and the status was reversed. A review of the literature on adult IO complications is also described.
- Johnson M, Inaba K, Byerly S, et al. Intraosseous infusion as a bridge to definitive access. Am Surg 2016;82(10):876-80** 826
- This retrospective study examined indications and outcomes associated with IO use at a Level 1 trauma center from 2008-2015. All 68 IO placements were with the EZ-IO device; most patients had trauma diagnoses. Most IO placements were successful on first attempt within 3 minutes of arrival. Non-serious extravasation was the most common complication. Authors concluded IO access "should be considered as a rapid, low risk, high yield aid to long-term IV access in both adults and children, and is an important bridge to definitive access in resuscitation".
- Krishnan M, Lester K, Johnson A, Bardeloza K, Edemekong P, Berim I. Case report: Bent metal in a bone: A rare complication of an emergent procedure or a deficiency in skill set? Case Reports in Critical Care 2016;doi:10.1155/2016/4382481** 806
- This article describes a case in which an EZ-IO catheter inserted into the proximal humerus required surgical intervention for removal after traditional removal efforts failed. Authors noted the patient refused an attempt to stabilize the insertion site. Discussion and a brief review of the literature discusses available IO devices and complications. In conclusions authors opined that with education and training, EZ-IO may become the preferred method of achieving rapid vascular access for emergent resuscitation with a low risk for complications.
- Malhotra R, Chua WL, O'Neill G. Calf compartment syndrome associated with the use of an intra-osseous line in an adult patient: A case report. Malays Orthop J 2016;10(3):49-51. doi:10.5704/MOJ.1611.014.** 868
- This reports a case of left lower extremity compartment syndrome in a multi-trauma patient that received bilateral proximal tibia IO catheters. The patient had 1L crystalloid and 2 units of packed red blood cells infused into his left IO tibial site. While in the operating room the team noticed the left leg was tense and swollen. He was diagnosed with compartment syndrome and fasciotomies were done. A left fibula fracture was also discovered but authors do not believe that or the soft tissue injuries present were enough to cause the compartment syndrome.
- Singapore
- Puga T, Montez D, Philbeck T, Davlantes C. Adequacy of intraosseous vascular access insertion sites for high-volume fluid infusion. Crit Care Med 2016;44(12 Suppl):143** 821
- This study was completed on 30 healthy subjects to evaluate infusion rates via the sternum (SIO) and proximal humerus (PH) sites under 300 mmHg via pressure bag. The mean SIO infusion rate was 9,587±2,706mL/hr (n=27); mean PH infusion rate was 6,292 ±3,277mL/hr (n=52). There were no serious complications; minor complications were 5 cases of excess pain, 2 cases vagal response, and mammary tissue engorgement. The mean PH flow rate was significantly lower than that of SIO, but placing IO catheters in each humeri with simultaneous infusion could result in fluid delivery of 13,000mL/hr, surpassing that of the sternum. This study was sponsored by Teleflex Incorporated.

Intraosseous Vascular Access Bibliography

Complications

YEAR: 2015

- Grabel Z, DePasse JM, Lareau CR, Born CT, Daniels AH. Intra-articular placement of an intraosseous catheter. Prehosp Disaster Med 2015;30(1):1-4. doi:10.1017/S1049023X14001290** 741
- Case report of a prehospital misplacement of an IO catheter into the intra-articular space of the knee joint when access was attempted in the field. Upon ED arrival IO placement was noted to be high and intra-articular placement was confirmed by xray. A sterile NS lavage was done and patient recovered without complication. Authors note this as a previously unidentified complication of IO placement and advise xray confirmation of affected sites with follow-up of intra-articular placements for the septic arthritis. (Picture of site appears to be an EZ-IO).
- Lee PMJ, Lee C, Rattner P, Wu X, Gershengorn H, Acquah S. Intraosseous versus central venous catheter utilization and performance during inpatient medical emergencies. Crit Care Med 2015;doi: 10.1097/CCM.0000000000000942** 762
- This single center, prospective, observational clinical study compared use of intraosseous (IO) access to central venous catheter (CVC) access for inpatient medical emergencies, managed by the medical emergency team (MET), within an urban teaching hospital. CVC access training included percutaneous, landmark-guided CVC placement without ultrasound guidance, using the femoral vein as the primary site. For IO access, the proximal tibia was the primary site and proximal humerus was secondary. Results showed IO access was significantly superior to CVC access with regard to first pass success rates, overall success rates, time to placement, and number of attempts for proper placement. On average more CVC kits were used per patient; complications were greater with CVC. There was one serious complication of tissue necrosis secondary to extravasation in the IO group.
- Overbey JK, Kon AA. Dermal abrasion experienced as an adverse effect of the EZ-IO. J Emerg Med 2016;50(1):e7-10. doi: 10.1016/j.jemermed.2015.09.003.** 753
- This article presents a case report of a 7 month old female who received intraosseous vascular access via the EZ-IO in the distal femur that resulted in a dermal abrasion where the needle hub contacted the skin. The wound healed without significant complication however the scar at the IO site persisted at 11 months post the event. The authors recommend that providers use the minimal force necessary when operating the EZ-IO to avoid similar adverse events.
- Pifko EL, Busch C, Price A, et al. An observational review of pediatric intraosseous needle placement in the pediatric emergency department. Ann Emerg Med 2015;66(4s):S87** 754
- A retrospective study evaluating attempts to establish intraosseous vascular access in pediatric patients using a manual device and the EZ-IO, in a tertiary care pediatric emergency department. Results showed 35 patients had IO access attempted using manual and EZ-IO devices. In patients greater than and less than 8kg the EZ-IO had a higher success rate but time to placement was longer. Overall success rate including both devices was 64%. There were 2 complications of transient leg swelling after EZ-IO placement in 2 patients.
- Reuter-Rice K, Patrick D, Kantor E, Nolin C, Foley J. Characteristics of children who undergo intraosseous needle placement. Adv Emerg Nurs J 2015;37(4):301-7. doi:10.1097/TME.0000000000000077** 854
- A retrospective study evaluating the use of pre-hospital and emergency department placed IO access in children before transport to a children's hospital. Data were extracted from a Level 1 trauma, tertiary care children's hospital transport database from 1993-2009. There were 143 eligible patients with an average transport distance of 33 miles; all but 8 catheters were placed by the ED. The most common reasons for IO placement were no IV access (53%) and no perfusion (33.6%); the most commonly reported complication was infiltration (27.3%); 46.9% of patients experienced no complication. The authors concluded IO access plays a significant role in promoting life-saving efforts when IV access is unachievable or no perfusion is determined.
- Rubal BJ, Meyers BL, Kramer SA, Hanson MA, Andrews JM, DeLorenzo RA. Fat intravasation from intraosseous flush and infusion procedures. Prehosp Emerg Care 2015;19(3):376-90. doi: 10.3109/10903127.2014.980475** 748
- This preclinical study evaluated the occurrence of fat intravasation resulting from intraosseous (IO) flush and infusion in anesthetized swine. Intravasated fat was assessed using a lipophilic fluoroprobe (Nile red) and by vascular ultrasound imaging. Fat intravasation was observed during all IO infusion regimens, with subclinical pulmonary fat emboli persisting 24 hours post infusion. It was noted that initial flush was a significant factor in fat intravasation, low levels of intravasation occurred with infusions ≤ 300 mmHg, fat intravasation and bone marrow shear-strain increased with IO infusion rates, and intravasation was influenced by cannula insertion site.
- Suominen P, Nurmi E, Lauerma K. Intraosseous access in neonates and infants: Increased risk of compartment syndrome and leg amputation. Resuscitation 2015;96(Suppl 1):S131-2. http://dx.doi.org/10.1016/j.resuscitation.2015.09.313** 1024
- This is an abstract of a study that analyzed possible technical and anatomical factors leading to the complication of amputation as a result of IO placement. The study was prompted by a case report of amputation in a neonate after IO access using the EZ-IO device. The study measured medullary diameter of the proximal tibia at the recommended IO access site in three groups: 1-28 day old full term neonates, 1-12 month old infants, and 3-4 year old children. The mean diameter in each group was 7.7 mm, 9.9 mm, and 12.4 mm, respectively. The small size of the IO space, especially in neonates and infants, makes correct placement difficult. As such, complications should be taken into consideration in this patient population.

Intraosseous Vascular Access Bibliography

Complications

Suominen PK, Nurmi E, Lauerma K. Intraosseous access in neonates and infants: risk of severe complications- a case report. *Acta Anaesthesiologica Scandinavica* 2015;59(10):1389-93. doi: 10.1111/aas.12602

769

This case study describes a neonate who suffered a cardiac arrest, had return of spontaneous circulation (ROSC) and was treated with multiple medications and therapeutic hypothermia. The patient had received three IO needle insertions, one in the left tibia that was removed following swelling with bolus injection; one in the left distal femur that dislodged with movement of the patient's legs; and one in the right proximal tibia. Twenty-four hours after initial IO needle placement the child developed pallor and discoloration and was diagnosed with compartment syndrome to the right lower extremity. Five days post-IO insertion a below the knee amputation was performed. Medications infused via the IO access included epinephrine and norepinephrine infusions.

YEAR: 2014

Barlow B, Kuhn K. Orthopedic management of complications of using IO catheters. *Am J Orthop* 2014;43(4):186-90

694

Literature search for complications associated with IO access included 5759 patients with overall complication rate of 2.1 %. Two cases involving retained needle fragment discussed; one with a proximal tibial EZ-IO that required surgical removal. Authors concluded IO catheters are reliable tools for fluid and drug delivery to critically ill patients with low complication rates (which can be potentially serious but managed).

Danz M, Schulz G, Hinkelbein J, Braunecker S. Breaking the needle: A rare complication on EZ-IO removal. *Eur J Anaesthesiol* 2014;31:172-80

742

This letter to the editor describes a single case of a needle breaking off after a proximal tibial insertion of the EZ-IO into a volunteer (one of the letter's authors) during a training session. "Divergent from manufacturer instructions the sterile steel stylet was put back into place to achieve better grip for a manual pull-out. Under steady pull in strict axial alignment and gentle clockwise turn, the needle broke away from the plastic connector". The needle was extracted using combination pliers and there is no evidence of damage to the leg. Authors acknowledge this can be avoided by adherence to manufacturer's directions for use.

Germany

Fowler RL, Lippmann MJ. Benefits vs risks of intraosseous vascular access. *Patient Safety Network* <https://psnet.ahrq.gov/webmm/case/331> Published July-August 2014. Accessed August 6, 2018

977

This is a discussion of a case study involving a hospitalized woman who had an IO line placed during a code after becoming unresponsive. Several unsuccessful attempts at peripheral venous access were made prior to IO access. The patient was diagnosed 3 hours later with compartment syndrome due to extravasation that required complex ongoing care in the ICU for 2 months.

Oesterlie GE, Petersen KK, Knudsen L, Henriksen TB. Crural amputation of a newborn as a consequence of intraosseous needle insertion and calcium infusion. *Ped Emerg Care* 2014;30(6):413-4

699

Case study of newborn girl resuscitated with 15 mm EZ-IO catheter placed to her right proximal tibia. Medications given included antibiotics, "fluids" and calcium. Demarcation of the infants skin was noted immediately post-calcium administration; with progression to necrosis. Trans-tibial amputation was performed 1.5 months after initial IO access. Authors concluded calcium extravasation most likely caused the injury but were unable to identify extravasation cause; citing possible needle displacement. Cautionary steps to reduce risk emphasized by authors.

Denmark

Vassallo J, Horne S, Smith JE. Intraosseous access in the military operational setting. *J R Nav Med Serv* 2014;100(1):36-9

794

This article describes a prospective, observational study conducted March – July 2011 at the emergency department, Camp Bastion, Afghanistan evaluating use of IO access in 117 patients established using the EZ-IO and the FAST1 devices (76% EZ-IO).

YEAR: 2013

Cook LS. Infusion-related air embolism. *J Infus Nurs* 2013;36(1):26-36. Doi: 10.1097/NAN.0b013e318279a804

613

This article looks at various methods of vascular access including venous, arterial and intraosseous access and their potential to result in air embolism.

d'Heurle A, Archdeacon MT. Compartment syndrome after intraosseous infusion associated with a fracture of the tibia. *The Journal of Bone and Joint Surgery, Incorporated Case Connect* 2013;3(1):e20. <http://dx.doi.org/10.2106/JBJS.CC.L.00231>

651

Case study of adult multi-trauma patient that had an intraosseous device placed to a fractured left tibia and developed compartment syndrome. Authors concede it is unclear if the fluid infused through the IO device caused the compartment syndrome or if it was due to the multiple-fractures in the tibia. Authors advise against placing an IO line in an injured limb and mention the proximal humerus and sternum as alternative IO sites.

Intraosseous Vascular Access Bibliography

Complications

- Dolister M, Miller S, Borron S, et al. Intraosseous vascular access is safe, effective and costs less than central venous catheters for patients in the hospital setting. J Vasc Access 2013;14(3):216-24. doi:10.5301/jva.5000130** 583
- An observational clinical study evaluating use of the EZ-IO in patients requiring urgent vascular access that would have otherwise received a central venous catheter due to a lack of other options. One hundred five (105) patients were enrolled across five hospitals. The authors concluded that use of IO access in place of CVCs provides time savings, safety, ease of use, and is effective at significant cost savings; IO access may be used as a bridge to CVC placement under optimal conditions; and IO access may be used to replace use of CVCs all together in selective patients. This study was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.
- Fetissov H, Nadaud J, Landy C, Millot I, Paris R, Plancade D. Amines on intraosseous vascular access: A case of skin necrosis. Ann Fr Anesth Reanim 2013;32(5):e89-90.http://dx.doi.org/10.1016/j.annfar.2013.02.022** 644
- A letter to the editor reporting a case study of skin necrosis after IO administration of norepinephrine following resuscitation of a 74 years old in septic shock. The EZ-IO was placed to the proximal tibia; approximately 45 minutes post- norepinephrine administration symptoms of necrosis were evident. Authors cite 3 hypotheses for the cause of necrosis and consider that amines' high level concentration could induce local toxicity in the bone matrix and artery spasm; suggesting it is necessary to define an upper limit of amines' concentration that should be administered through IO vascular access.
- Hallas P, Brabrand M, Folkestad L. Complication with intraosseous access: Scandinavian users' experience. West J Emerg Med 2013;14(5):440-3. doi:10.5811/westjem.2013.1.1200** 669
- A questionnaire study in which Scandinavian emergency physicians, anesthesiologist and pediatricians reported complications they have experienced with IO vascular access based on recollection alone. Complications were reported related to establishing IO access and using established IO access. Out of 1,802 IO cases reported by 386 responders, the most frequently reported complications included difficulty with periosteum penetration and bone marrow aspiration when establishing IO access; and slow infusion and needle displacement with established IO access. Osteomyelitis and compartment syndrome were reported with an occurrence of 0.4% and 0.6%. Researchers concluded that potential complications following IO insertion should be addressed during training. Devices discussed included the EZ-IO, BIG, Cook-Surfast, and other unidentified IO devices
- Denmar
- Lewis GC, Crapo SA, William JG. Critical skills and procedures in emergency medicine- vascular access skills and procedures. Emerg Med Clin N Am 2013;31(1):59-86. doi: 10.1016/j.emc.2012.09.006** 631
- This article provides an overview of various vascular access modalities in emergency medicine including peripheral IV, venous cut-down, central venous catheter, intraosseous access, umbilical vessel access, and arterial access. The anatomy and physiology, indications and contraindications, procedure steps and special considerations are outlined for each access methods discussed.
- Oksan D, Ayfer K. Powered intraosseous device (EZ-IO) for critically ill patients. Indian Pediatr 2013;50(7):689-91** 685
- A retrospective chart review evaluating use of the EZ-IO in 25 pediatric patients between July 2008 and August 2010 at a Turkish university affiliated hospital. All attempts were made in the proximal tibia and IO access was attempted following failed PIV access within 60 seconds. First attempt success was 80%; the most reported complication was simple extravasation (3 cases) and needle dislodgement (1 case).
- Turkey
- Plancade D, Millot I, Fetissov H, et al.. Sternal perforation with an intraosseous device and hemomediastinum infusion Ann Fr Anesth Reanim 2013;http://dx.doi.org/10.1016/j.annfar.2013.01.009** 616
- A 45-year-old woman in hemorrhagic shock with multiple injuries to the limbs, secondary to a war wound, received sternal IO access using the Jamshidi trocar (not specifically intended for sternal use). After initiating a blood transfusion through the IO line a contrast CT scan revealed sternal perforation and hemomediastinum, secondary to the transfusion, as well as drainage into the left pleural cavity. The catheter was removed, right thoracic drainage was performed, and the patient was released from ICU 48 hours later. The authors conclude this case report demonstrates the difficulty in selecting emergency insertion sites and the necessity of choosing an appropriate IO catheter.
- Plancade D, Ruttimann M, Wagnon G, et al.. La perfusion intraosseuse chez l'adulte. Annales Francaises d'Anesthesie et de Reanimation 2013;http://dx.doi.org/10/1016/j.annfar.2013.02.024. French** 617
- This article in French gives an overview of intraosseous vascular access including the physiology of IO infusion, insertion sites, indications, and complications. Available IO devices on the market are described including, time to insertion, success rate and cost.
- Torres A, Banister N, Fernandez M, Cox K, Fletcher J. Appropriateness and complications of intraosseous needle placements during pediatric transports. Crit Care Med 2013;41(12):abstract 215** 792
- A quality initiative study conducted evaluating use of the EZ-IO needles in pediatric patients and their associated complications rates when placed by EMS/ED staff compared Air Evac Lifeteam placement in 2012. The authors concluded that the powered IO device was appropriately utilized by ED/EMS staff as well as Air Evac staff and that there was no difference in the complication rate when the device was used by the two groups.

Intraosseous Vascular Access Bibliography

Complications

YEAR: 2012

- Cote C, Dumont M, Gagnon JA. Abnormal bone scanning following intraosseous access. *Medecine Nucleaire* 2012; doi:10.1016/j.mednuc.2012.02.175** 537
- This case study describes a 12 month boy who received IO access for administration of anticonvulsant therapy. Three days post IO infusion sensitivity to the leg was noted and the child returned to the ED. Blood work showed elevated white blood counts and C-reactive protein. A bone scan showed a small round lucency at the site of IO access. Two weeks later, x-rays were normal. The authors suggest that IO access may cause an increased uptake on bone scan in absence of osteomyelitis.
- Helm M, Goller R, Hackenbroch C, Hossfeld B. A complication of the use of an intra-osseous needle. *Emerg Med J* 2012;29:923. doi: 10.1136/emermed-2011-200139** 1054
- This is a case report of needle sheering associated with the use of the FAST-1 intraosseous infusion system. A soldier successfully placed a FAST-1 needle in the sternum of a healthy volunteer soldier during a training session. Upon completion of the training session, the soldier was unable to remove the needle. The retained needle was later removed surgically at a field hospital.
- Lairet JR, Bebarta V, Mathis D, et al. Comparison of intraosseous infusion rates of blood under high pressure in an adult hypovolemic swine model in three different limb sites. *Ann Emerg Med* 2012;60(4S):S75** 600
- This pre-clinical study sought to compare the flow rates of blood administered through an IO needle in the proximal tibia, distal femur and the proximal humerus in an adult hypovolemic swine at an infusion pressure greater than 300 mmHg. Investigators also evaluated the presence of fat emboli in the lungs. Results showed that the mean rate of IO infusion of blood through the swine humerus (103 mL/min) was greater than the femur (49 mL/min) and tibia (78 mL/min); fat emboli were detected in the lungs of most animals (tibia: 14.14; humerus: 10/11; femur: 8/14).
- Lammers R, Byrwa M, Fales W. Root causes of errors in a simulated prehospital pediatric emergency. *Acad Emerg Med* 2012;19(1):37-47. doi: 10.1111/j.1553-2712.2011.01252.x** 590
- This simulation study evaluated the ability of 2 person EMS crews to manage a pediatric emergency and sought to determine root causes of errors made. Participating EMS crews used the BIG for IO access. The authors concluded that cognitive, procedural, affective, teamwork errors and error-producing conditions were identified as root causes for the errors made in the simulation. Authors also concluded that simulation followed by facilitated debriefing is an effective tool for identifying underlying causes of active and latent errors.
- Landy C, Plancade D, Gagnon N, Schaeffer E, Nadaud J, Favier JC. Complication of intraosseous administration of systemic fibrinolysis for a massive pulmonary embolism with cardiac arrest. *Resuscitation* 2012;83(6):e149-50. doi: 10.1016/j.resuscitation.2012.01.044** 547
- This letter to the editor describes a case in which a 53-year-old male in ventricular fibrillation received IO access via the EZ-IO in the ED with suspected massive pulmonary embolism. The patient was successfully resuscitated. Necrosis of the anteromedial side of the leg, at the IO site, presented 48 hrs post IO use. After 18 weeks the patient underwent surgical grafting. The authors linked the necrosis to adrenaline extravasation and local ischaemia. While the authors conclude that thrombolysis or repeated high doses of adrenaline should be given via the IO route when needed, it is not without the risk of complication.
- Miller LJ, Montez DF, Puga TA, Philbeck TE. Intraosseous vascular access in the 21st century: improvements further reduce complication rates. *Ann Emerg Med* 2012;60(4S):S112** 597
- This abstract presented at the 2012 ACEP Research Forum discusses a literature review of intraosseous access publications since 1985 providing an updated safety profile for IO access. The search resulted in 192 articles describing IO access with 6 cases of osteomyelitis and 6 cases of compartment syndrome secondary to extravasation reported. Of the 192 articles identified, 140 described the EZ-IO. This study was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.
- Paxton JH. Intraosseous vascular access: A review. *Trauma* 2012;14(3):195-232. DOI:10.1177/1460408611430175** 690
- An overview of IO vascular access including a review of currently available literature. The author discusses various IO devices available and their performance metrics, IO access sites, flow rates, advantages and disadvantages of IO access compared to conventional access methods, complications and recommendations on use of the approach. The author concludes that while IO access may not be appropriate for all patients, it deserves a place in the modern provider's armamentarium.
- Rogers J, Fox M. The safety of intraosseous vascular access. *Emergency Medicine Patient Safety Foundation Forum. Fall* 2012:18-21** 606
- An article discussing the technique and safety profile of intraosseous access using the EZ-IO device. Needle selection, contraindications, insertion sites and techniques, catheter stabilization and removal are all discussed along with the safety profile of the EZ-IO against other IO devices and central venous catheters. The authors concluded that IO access should be considered whenever immediate vascular access is required. This article was co-written by an employee of Vidacare Corporation, acquired by Teleflex Incorporated.

Intraosseous Vascular Access Bibliography

Complications

- Rogers JJ, Fox M, Miller LJ, Philbeck TE. Safety of intraosseous vascular access in the 21st century. J Vasc Access 2012;13:19A** 579
This abstract presented at the 2nd World Congress on Vascular Access 2012 describes the results of an analysis of published IO complications since 1985. The safety profile of the EZ-IO is also discussed in this abstract. The authors conclude that new devices and techniques have resulted in an approved IO safety profile. This study was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.
- Rose EC. The evidence-based use of intraosseous lines in pediatric patients. Pediatr Emerg Med Pract 2012;9(6):1-12. www.edmedicine.net** 585
This article presents a general overview of intraosseous (IO) vascular access in the pediatric population through an IO literature review. Available IO devices were discussed.
- Severyn FA. Complication after intraosseous needle removal following successful systemic thrombolysis for a massive pulmonary embolism. Resuscitation 2012;83(11):e207. doi:10.1016/j.resuscitation.2012.07.014** 575
This letter to the editor is written in response to the case report by Landy titled, Complication of intraosseous administration of systemic thrombolysis for a massive pulmonary embolism with cardiac arrest. The author suggests that the tissue necrosis described by Landy may have been due to the removal of the IO needle while there was still significant fibrinolytic activity at the needle insertion site. The author suggests a change in medical care after return of spontaneous circulation (ROSC) in patients following thrombolytic administration through IO access to convert the functioning IO line to a non-flowing saline lock. The EZ-IO was used to provide IO access in the case report by Landy.
- YEAR: 2011**
- Auerhammer J. [Lebensbedrohliche arterielle blutung aus der a. carotis communis: Fallstricke bei der intraossaren punktion]. Notfall Rettungsmedizin 2011;14(2):147-150;doi 10.1007/s10049-010-1380-1. German** 490
This article in German presents a case of a 67-year-old female patient with an arterial bleed and venous access difficulties in whom IO access was attempted unsuccessfully two times using two different IO systems. The author concluded that IO success is dependent upon IO anatomy and physiology knowledge as well as knowledge of the device being used.
- Byars DV, Tsuchitani SN, Erwin E, Anglemeyer B, Eastman J. Evaluation of success rate and access time for an adult sternal intraosseous device deployed in the prehospital setting. Prehosp Disaster Med 2011;26(2):127-9** 655
A prospective study evaluating use of the FAST-1 sternal IO device in critically ill or injured patients in cardiac arrest in the pre-hospital setting. In one year, 41 insertion attempts were performed using the FAST-1. Thirty (73%) of attempts were successful and the mean time to placement was 67 seconds from time of opening the packaging to ability to aspirate/infuse without infiltration. Of the 11 insertion failures, 7 were due to failure of the device to deploy; 2 infiltrations after insertion; 1 inability to aspirate; and 1 failure of the catheter to deploy though the needles were inserted.
- Carreras-Gonzalez E, Brio-Sanagustin S, Guimera I, Crespo C. [Complicacion de la via intraosea en un neonate]. Med Intensiva 2011;doi:10.1016/j.medin.2011.05.004. Spanish** 487
This article in Spanish describes an IO complication case in which a newborn infant developed tissue necrosis as a result of extravasation during IO infusion.
- Cotte J, Prunet B, d'Aranda E, Asencio Y, Kaiser E. [A compartment syndrome secondary to intraosseous infusion]. Ann Fr Anesth Reanim 2011;30(1):90-1. doi: 10.1016/j.annfar.2010.05.038. French** 691
A case study report in French describing compartment syndrome secondary to intraosseous infusion in a 57-year-old burn patient. IO access was established in the proximal tibia on second attempt; both attempts were made in the same limb though it was noted that the first attempt did not penetrate the cortex. Drug and fluid infusion was initiated; ten hours later the limb was found to appear ischemic. The IO catheter was removed and compartment release was performed. The author concluded that IO access remains an important mode of vascular access and that adherence to contraindications and careful clinical monitoring should decrease risk of complications.
France
- Cullen PM. Intraosseous cannulation in children. Paediatric Critical Care 2011;13(1):28-30** 523
This article presented a general overview of IO use in pediatrics. The history, techniques, anatomy and physiology, complications and a short discussion of most devices on the market, including the EZ-IO, were discussed.
UK

Intraosseous Vascular Access Bibliography

Complications

- Dolister M, Miller ST, Borron S, Truemper E, Shah MR. Intraosseous vascular access can be used safely and effectively, and at a lower cost than central venous catheters, for pediatric and adult patients in the hospital setting. *Ann Emerg Med* 2011;58(4S):S311** 453
- This abstract describes the interim results of an observational clinical trial evaluating use of the EZ-IO to establish venous access in patients that would typically receive a central line due to lack of other options. At interim analysis, 50 patients had been enrolled in the study. First attempt IO access success rate was 96%; mean time to IO access was 95.1 seconds. The authors concluded that IO access in place of or as a bridge to central venous catheters is safe, fast, and effective for adult and pediatric patients in the hospital setting with substantial cost savings potential. This research was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.
- Hansen M, Meckler G, Spiro D, Newgard C. Intraosseous line use, complications, and outcomes among a population-based cohort of children presenting to California hospitals. *Pediatr Emerg Care* 2011;27(10):928-32** 710
- This retrospective cohort study evaluated data from 450 California hospitals and emergency departments to determine the rate of IO access use and related complications in the pediatric population from 2005-2007. Results showed 291 children had IO access placed in 90 hospitals out of 6.6 million pediatric ED visits and 2.2 million pediatric admissions; no complications were identified. The most frequent diagnosis related to IO use was cardiac arrest (34%).
- Harcke T, Crawley G, Ritter B, Mazuchowski E. Feedback to the field: an assessment of sternal intraosseous (IO) infusion. *J Spec Oper Med* 2011;11(1):23-6** 544
- This article summarizes the case-based observations made by the Armed Forces Medical Examiner System on soldiers killed in action/died of wounds who had evidence of sternal intraosseous access. The Pyng Fast-1 is noted in the article as the sternal IO device most widely distributed by the department of defense (DOD); the EZ-IO is listed as another device that may be seen in emergency care facilities within the DOD. Of 98 cases, 78 (80%) showed proper placement; 20% were unsuccessful. It should be noted that the article incorrectly states that the EZ-IO using the powered driver is indicated for sternal placement.
- Henson NL, Payan JM, Terk MR. Tibial subacute osteomyelitis with intraosseous abscess: an unusual complication of intraosseous infusion. *Skeletal Radiol* 2010;40(2):239-42. doi:10.1007/s00256-010-1027-9** 462
- This report describes the case of a 62-year-old man who received emergency tibial IO infusion without complication in the pre-hospital setting and presented to the ED 6 months later complaining of shin pain. MRI and culture findings were diagnostic of subacute osteomyelitis with IO abscess. The patient had a history of multiple chronic health problems including diabetes type II, MGUS, and positive MRSA colonization dating back two years prior. The authors concluded that the occurrence of osteomyelitis with IO abscess may increase as a result of increased pre-hospital use of IO infusion in adult patients with multiple comorbidities.
- Khan LAK, Anakwe RE, Murray A, Godwin Y. A severe complication following intraosseous infusion used during resuscitation of a child. *Inj Extra* 2011;doi:10.1016/j.injury.2011.05.015** 485
- This article describes the case of an 11-year-old boy who suffered compartment syndrome of the lower leg following use of the EZ-IO for resuscitation and 24 hours of intraosseous infusion of adrenaline, calcium and potassium. The author concluded that further work is needed to develop recommendations for maximum duration, dose, volume and rates for intraosseous infusion.
- Nagler J, Krauss B. Intraosseous catheter placement in children. *NEJM* 2011;364(8):e14-8** 491
- This article provides an overview of intraosseous vascular access for pediatrics and discusses general indications, contraindications, complications, and intraosseous devices.
- Reades R, Studneck J, Garrett J, Vandeventer S, Blackwell T. Comparison of first-attempt success between tibial and humeral intraosseous insertions during out-of-hospital cardiac arrest. *Prehosp Emerg Care* 2011;15(2):278-81. doi:10.3109/10903127.2010.545479** 464
- This article describes a pre-hospital clinical study comparing IO first-attempt success between humeral and tibial sites. Of 88 cardiac arrest patients analyzed, 58 and 30 IO access attempts were made in the tibia and humerus, respectively. Of those, there was a 90% first attempt success rate for the tibia, compared to 60% for the humerus. Of successful insertions, 6% of tibial insertions became displaced during transport, compared to 33% of humeral insertions. Investigators concluded that proximal tibial IO needle placement was associated with a significantly higher frequency of first-attempt success and lower incidence of needle dislodgements compared to humeral placements.
- Reece A, Cohn A. Safety of power driven devices for intraosseous access in infants. *BMJ* 2011;343:d4362.doi:10.1136/bmj.d4362** 435
- This letter to the editor is regarding the relative safety of using power driven IO devices in infants. Three cases of amputation secondary to compartment syndrome in children under 2 years of age are referenced. The author expressed concern with the weight designations for IO needles stating some of the needles intended for pediatric patients may actually be too long for smaller children and that manually inserted devices may be safer in younger children.
- Schexnayder SM, Storm EA, Stroud MD, et al. Chapter 15-Pediatric vascular access and centeses. *Pediatric Critical Care* 2011;4th ed:139-63. ISBN: 978-0-323-07307-3** 680
- This document addresses pediatric vascular access and includes an overview of intraosseous vascular access. Indications, contraindications, supplies and equipment, technique, complications and maintenance are discussed.

Intraosseous Vascular Access Bibliography

Complications

- Taylor CC. Amputation and intraosseous access in infants. *BMJ* 2011;342:d2778. doi:10.1136/bmj.d2778** 484
This article describes two cases of leg amputation after intraosseous infusion in a 5-month-old girl and a 17-month-old boy. The author concluded that fluid extravasation, exacerbated by tibial fracture and needle dislodgement during transportation, caused limb ischemia in these two patients, and that adherence to the principles of careful needle placement, splinting/securing the catheter and limb, limited length of infusion and repeated monitoring of the limb will help avoid this devastating complication.
- Waltzman ML. Amputation and intraosseous access in infants-Intraosseous access: It's the operator and not the device. *BMJ* 2011; <http://www.bmj.com/rapid-response/2011/11/03/intraosseous-access-its-operator-and-not-device>** 563
This article is a response to the Taylor and Clarke 2011 report of two amputations required following development of compartment syndrome after IO infusion. The author notes that complications are possible with all methods of establishing IO access including manual, spring loaded and power driven needles and that it is not accurate to directly relate the adverse events to the power driven device only.
- Wechselberger G, Radauer W, Schimpl G, et al. Lower limb salvage in a 7-month-old infant using free tissue transfer. *J Ped Surg.* 2011;46:1852-4. Doi:10.1016/j.jpedsurg.2011.06.037** 625
A 7-month-old male infant in septic shock from *Neisseria meningitidis* experienced a complication of bilateral extravasation of noradrenalin at the proximal tibia intraosseous infusion site resulting in severe soft tissue necrosis. Necrosectomy was performed bilaterally and surgical interventions were successfully performed to salvage both limbs. At 19 months the patient was able to crawl without extension deficit.
- YEAR: 2010**
- Bukoski A, Winter M, Bandt C, Wilson M, Shih A. Comparison of three intraosseous access techniques in cats. *J Vet Emerg Crit Care* 2010;20(4):393-7.doi:10.1111/j.1476-4431.2010.00558.x** 437
This veterinary study evaluated 3 IO access devices, impact driven, automatic rotary, and manual, to compare the placement feasibility and amount of bone trauma induced when used in adult feline cadavers. Seventy-two IO insertion locations were used, the 3 devices were equally randomized to the insertion site. The rotary device was found to have shorter time to insertion and better ease of insertion. No statistically significant differences between number of bone fragments, defect diameter, or success rate were found between devices.
- Dasgupta S, Playfor S. Intraosseous fluid resuscitation in meningococcal disease and lower limb injury. *Pediatr Rep* 2010;2(1):e5:18-9** 426
Authors reviewed two complications (extravasation and compartment syndrome) associated with IO access in children with meningococcal disease. Authors concluded that IO systems need formal evaluation to assess safety and complication profiles.
- Fenwick R. Intraosseous approach to vascular access in adult resuscitation. *Emerg Nurse* 2010;18(4):22-5** 456
This article reviews intraosseous vascular access and its increased use in adult resuscitation. The IO route is described, including indications, contraindications, insertion sites and devices.
- Larson SD, Hebra A, Raju R, Lee S. Vascular access, surgical treatment. <http://emedicine.medscape.com/article/1018395>. Updated January 25, 2010** 446
This article describes the vascular access options available to physicians caring for children, including details about each method, placement technique, indication, and complications.
- LeMaster CH, Schuur JD, Pandya D, et al. Infection and natural history of emergency department-placed central venous catheters. *Ann Emerg Med* 2010;56(5):492-7.doi:10.1016/j.annemergmed.2010.05.033** 457
A retrospective chart review in an urban emergency department (ED) was performed to identify central venous catheters placed in the ED and determine the bloodstream infection and duration of catheterization within a one year period. A total of 656 patients (3,622 catheter-days) with CVCs placed in the ED were identified, with 7 bloodstream infections. The mean duration of catheterization was 5.5 days. Within the infected CVC group, the mean duration of catheterization was 8.6 days
- Lima R, Navarro L, Cesani F, et al. Repeated doses of adriamycin may be safely delivered through the intraosseous route in different bones in swine. *Blood* 2010;116(21):4344. Accessed May 25, 2017. Retrieved from <http://www.bloodjournal.org/content/116/21/4344>** 949
This abstract describes a follow-up swine study to an earlier study done using concentrated doses of Adriamycin over 72 days in which bone complications occurred. Investigators studied different drug administration regimens that might be used to prevent complications. After the study was completed authors concluded that IO delivery of lower dose and diluted concentrations of Adriamycin was determined to be safer and resulted in less tissue abnormality when compared with higher dose/higher concentration; and use of the IO route with rotation of sites may be a feasible option for Adriamycin or other vesicant delivery.

Intraosseous Vascular Access Bibliography

Complications

Luck RP, Haines C, Mull CC. Intraosseous access. J Emerg Med 2010;39(4):468-75. doi:10.1016/j.jemermed.2009.04.054 492

This article provides an overview of intraosseous vascular access and discusses general indications, contraindications, complications, and intraosseous devices.

Miller L, Philbeck T, Montez D, Puga T. Volunteer studies of pain management during intraosseous infusion. Ann Emerg Med 2010;56(3):S141 499

This abstract presented at the 2010 ACEP Research Forum describes a study designed to compare Lidocaine's effect on pain during fluid infusion through the tibial and humeral IO routes. Authors concluded that, for adequate IO infusion rates with minimal and tolerable pain, 40mg of preservative-free Lidocaine may be needed; followed by a rapid normal saline syringe flush of at least 10mL and another 20mg of Lidocaine. Additional dosing and flushing may be required. For less overall pain due to IO infusion, and greater infusion flow rates, the proximal humerus should be strongly considered, using a longer IO needleset. This research was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.

Navarro K. Intraosseous infusion. Texas EMS Magazine 2010;Nov/Dec:34-9 447

This article provides a brief history of IO infusion and further discusses this vascular access technique in terms of anatomy and physiology, indications and contraindications, performing the manual procedure, and possible complications. A case study is discussed in which a 7-month-old male was treated under emergency circumstances with IO infusion in the lower limb and developed compartment syndrome, resulting in a below the knee amputation.

Phillips L, Brown L, Campbell T, Miller J, Proehl J, Youngberg B. Recommendations for the use of intraosseous vascular access for emergent and nonemergent situations in various healthcare settings: a consensus paper. J Emerg Nurs 2010;36(6):551-6. doi:10.1016/j.jen.2010.09.001 458

This article discusses use of IO access within the hospital setting in the emergent and non-emergent patient populations. The history of IO access, clinical situations in which IO access may be considered, devices, contraindications, and complications are discussed. Additionally, pain management, economics, education and training and risk management are explored. This article is co-published in Journal of Infusion Nursing, the Journal of Pediatric Nursing, and Critical Care Nurse and was produced by the Consortium on Intraosseous Vascular Access in Healthcare Practice.

YEAR: 2009

Fenton P, Bali N, Sargeant I, Jeffrey SLA. A complication of the use of an intra-osseous needle. J R Army Med Corps 2010;155(2):110-1 450

This case report describes a complication of use of a sternal IO device (FAST-1, Pyng Medical Corporation, Richmond, Canada) in a 21-year-old soldier who suffered multiple soft tissue fragmentation injuries, in which the needle tip broke in situ. The author concluded the complication resulted from the IO needle being placed when the patient was lying in a lateral position with the skin over the manubrium displaced from the midline.

Nutbeam T, Fergusson A. Intraosseous access in osteogenesis imperfecta (IO in OI). Resuscitation 2009;80(12):1442-3. doi:10.1016/j.resuscitation.2009.08.016 408

This article describes a case in which IO access, using the EZ-IO, was attempted in a patient with osteogenesis imperfecta. In each of 3 attempts, the needle became loose immediately after IO insertion. The author acknowledged that during emergencies it is difficult to assess and consider every possible contraindication for every intervention; and that IO access using the EZ-IO is the author's choice for emergency vascular access when peripheral access is difficult or has failed.

YEAR: 2008

Atanda A Jr, Statter MB. Compartment syndrome of the leg after intraosseous infusion: guidelines for prevention, early detection, and treatment. Am J Orthop 2008;37:E198-200 413

This article discusses the importance of proper technique, attention to detail, and serial monitoring of limb involved when using IO vascular access to avoid potential compartment syndrome and other complications. The author reports the case of a 2-year-old boy who suffered compartment syndrome of the lower limb following use of IO infusion for resuscitation. Early detection of and response to changes in the affected limb resulted in the patient's successful recovery

Fowler RL, Pierce A, Nazeer S, Philbeck TE, Miller LJ. 1,199 case series: Powered intraosseous insertion provides safe and effective vascular access for emergency patients. Ann Emerg Med 2008;52(4):S152 418

Large retrospective study of patients for whom emergency vascular access was obtained using the Vidacare EZ-IO intraosseous system. Insertion success was 92% and within 10 seconds for 84% of the one-attempt successful cases. Complication rate was low (4.8%), none were serious, and extravasation was the most frequent (0.8%). The device was rated easy to use 72% of the time, and researchers concluded that the powered IO device is safe and effective for achieving vascular access in the resuscitation and stabilization of emergency patients. This study was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.

Intraosseous Vascular Access Bibliography

Complications

- Langley DM, Moran M. Intraosseous needles: They're not just for kids anymore. J Emerg Nurs 2008; 34:318-9** 370
Case reports in which intraosseous (IO) vascular access was successfully used on adults. Summarizes indications for use, complications, and precautions/considerations.
- Moen TC, Sarwark JF. Compartment syndrome following intraosseous infusion. Orthopedics 2008; 31: 815** 411
Case report of compartment syndrome in a 6-year old girl after IO infusion during cardiac arrest.
- van Rijn RR, Knoester H, Maes A, van der Wal AC, Kubat B. Cerebral arterial air embolism in a child after intraosseous infusion. Emerg Radiol 2008;15:259-62. doi:10.1007/s10140-007-0681-2** 410
In this case study a 7-month-old female with comorbidities was taken to the ED in cardiopulmonary arrest. IO access was the only vascular access method available for resuscitation. Post mortem CT of the head showed a considerable amount of air within the arterial circulation; the cause of death was listed as undetermined. The authors conclude that considering the details of the patient, the only logical explanation for the cerebral arterial air embolism is that air was introduced into the bloodstream via the IO route.
- YEAR: 2007**
- Hillewig E, Aghayev E, Jackowski C, Christe A, Plattner T, Thali MJ. Gas embolism following intraosseous medication application proven by post-mortem multislice computed tomography and autopsy. Resuscitation 2007;72:149-53** 530
This case study describes a 4-month-old boy that was found unresponsive. Resuscitation was started and continued through arrival to the ED; IO access at the proximal tibia was established using a 15 gauge aspiration needle as the only vascular access. Post mortem multislice CT examination showed gas in the hepatic veins, the right atrium, right ventricle, the upper pole of the right kidney and the cerebral vessels. Though air embolism was ruled out as the cause this death, it could have caused death in another case. The authors conclude that gas may have entered the body during resuscitation due to IO needle disconnections and that resuscitation with an inserted, disconnected IO needle should be avoided.
- YEAR: 2006**
- Buck ML. Intraosseous administration of drugs in infants and children. Pediatr Pharm 2006;12(12)** 367
Overview article of IO vascular access describes technique, efficacy in medication delivery, utility in pediatric emergencies, use in neonates, complications, and commonly-infused medications.
- YEAR: 2005**
- Helm M, Gries A, Fischer S, Hauke J, Lampl L. Invasive techniques in emergency medicine. III. Intraosseous puncture--an alternative vascular access in paediatric emergencies. Anaesthesist 2005;54(1):49-56** 330
Review article on IO vascular access in the pediatric patient. Advises that it is not necessary to adjust doses from IV doses, except for hypertonic solutions. Recommends that IO needle be replaced by an IV within 2 hours to avoid complications.
Abstract only. Article in German
- YEAR: 2004**
- Dogan A, Irmak H, Harman M, Ceylan A, Akpinar F, Tosun N. Tibial osteomyelitis following intraosseous infusion: a case report. Acta Orthop Traumatol Turc 2004; 38:357-60** 324
Case report of acute osteomyelitis developing 10 days after IO infusion in a 5-month-old infant admitted for sepsis.
- Farrow A, Morrison R, Pickersgill T, Currie R, Hammersley N. Transient femoral neuropathy after harvest of bone from the iliac crest. Br J Oral Maxillofac Surg 2004; 42: 572-4** 319
Case report of a 31-year old developing left femoral mononeuropathy after bupivacaine is infused for postoperative analgesia into the iliac wound.
- Schwartz SB, Kleid DM. Fictitious fracture after infusion of intravenous contrast material via an intraosseous needle. Pediatr Emerg Care 2004;20:829-31** 388
Case report of misdiagnosis of a bone fracture as a result of IO infusion of radiographic contrast material in the involved extremity.

Intraosseous Vascular Access Bibliography

Complications

YEAR: 2003

Bowley DM, Loveland J, Pitcher GJ. Tibial fracture as a complication of intraosseous infusion during pediatric resuscitation. J Trauma 2003; 55: 786-7 298

Case report of IO infusion complicated by iatrogenic fracture at the IO insertion site. Concludes that multiple attempts to achieve IO access weakened the bone cortex and that "considerable force" applied by an anxious 100-kg emergency room doctor led to the fracture.

Carillo A, Lopez-Herce J. [Canalización intraósea]. An Pediatr Contin 2003;1(1):38-41. Spanish 653

This article in Spanish discusses general IO principles.

Claudet I, Baunin C, Laporte-Turpin E, Marcoux MO, Grouteau E, Cahuzac JP. Long-term effects on tibial growth after intraosseous infusion: a prospective, radiographic analysis. Pediatr Emerg Care 2003;19(6):397-401 313

Prospective radiographic study of 23 children who had received intraosseous infusion via trocar. Found no long-term effect on tibial growth with properly placed trocar.

Gluckman, W, Forti RJ. Intraosseous cannulation. www.emedicine.com/ped/topic2557.htm Last Updated: Jan 14, 2003 301

Web article discusses IO cannulation procedure insertion sites, pathophysiology, risks, contraindications and complications.

Launay F, Paut O, Katchburian M, Bourelle S, Jouve JL, Bollini G. Leg amputation after intraosseous infusion in a 7-month-old infant: a case report. J Trauma 2003; 55(4):788-90 306

Case report of a 7-month-old infant who developed severe compartment syndrome associated with popliteal arterial thrombosis following IO fluid infusion resulting in limb amputation.

YEAR: 2002

Alam HB, Punzalan CM, Koustova E, Bowyer MW, Rhee P. Hypertonic saline: intraosseous infusion causes myonecrosis in a dehydrated swine model of uncontrolled hemorrhagic shock. J Trauma 2002;52(1):18-25 285

IO infusion of 7.5% hypertonic saline in this model was associated with a high rate of local complications (soft tissue or bone marrow necrosis).

Harty MP, Kao SC. Intraosseous vascular access defect: fracture mimic in the skeletal survey for child abuse. Pediatr Radiol 2002;32(3):188-90 294

Case report emphasizing that a cortical lesion in the proximal tibia corresponding to the site of IO insertion should not be mistaken for a radiographic sign of child abuse.

Stoll E, Golej J, Burda G, Hermon M, Boigner H, Trittenwein G. Osteomyelitis at the injection site of adrenalin through an intraosseous needle in a 3-month-old infant. Resuscitation 2002;53(3):315-8 287

Case report of a 3-month-old infant developing osteomyelitis after IO administration of high-dose epinephrine. Speculates that administration of adrenalin in high concentrations may promote the development of osteomyelitis.

YEAR: 2001

Byrick RJ. Pulmonary fat embolism and intraosseous infusion. Pediatr Crit Care Med 2001;2(2):184-5 282

Review advocating that pathological evidence of a few pulmonary fat emboli should not deter clinicians from using IO because of the many advantages of the technique.

Hasan MY, Kissoon N, Khan TM, Saldajeno V, Goldstein J, Murphy SP. Intraosseous infusion and pulmonary fat embolism. Pediatr Crit Care Med 2001;2(2):133-8 278

Article implying that the risk of fat emboli is common with IO, but its clinical relevance is unclear.

Hubble MW, Trigg DC. Training prehospital personnel in saphenous vein cutdown and adult intraosseous access techniques. Prehosp Emerg Care 2001;5(2):181-9 276

Study in EMS personnel comparing saphenous vein cutdown to IO access (B.I.G.) in the adult patient. Times to fluid flow were 7.6 minutes for saphenous cutdown and 3.9 minutes for IO. Investigators conclude that use of the B.I.G. was more rapid and successful with fewer complications than saphenous vein cutdown.

Intraosseous Vascular Access Bibliography

Complications

Orgiler Uranga PE, Navarro Arnedo JM, De Haro Marin S. [The intraosseal route. When the veins have disappeared]. *Enferm Intensiva* 2001;12(1):31-40. Spanish 275

Literature review on intraosseous administration of drugs during pediatric emergencies. Concludes that IO is a valid alternative route for infusion of drugs and other substances into the blood stream with a low complication rate.

YEAR: 2000

Nijssen-Jordan C. Emergency department utilization and success rates for intraosseous infusion in pediatric resuscitations. *Canadian J Emerg Med* 2000;2(1):10-4 679

A retrospective chart review that evaluated use of IO access in pediatric patient resuscitation in a tertiary emergency department between 1989 and 1995. Results showed IO access was successfully established in 86% of patients. Median time to placement was 8 minutes; two complications of bone fracture were reported in one 10-day-old neonate patient.

Canada

Vreede E, Bulatovic A, Rosseel P, Lassalle X. Intraosseous infusion. *Update in Anesthesia* 2000;12 (Article 10):1. <http://rcpals.com/downloads/2007files/may/pals/IntraosseousInfusion.html> 263

Brief overview of IO infusion for an anesthesiology audience. Discusses technique, indications, contraindications, equipment, anatomical target sites and potential complications.

YEAR: 1997

Fiallos M, Kissoon N, Abdelmoneim T, et al. Fat embolism with the use of intraosseous infusion during cardiopulmonary resuscitation. *Am J Med Sci* 1997;314(2):73-9 224

Preclinical study in 33 piglets of IO infusion during CPR. Found no increase in fat embolism in IO group compared to controls group.

YEAR: 1996

Brickman KR, Rega P, Schoolfield L, Harkins K, Weisbrode SE, Reynolds G. Investigation of bone developmental and histopathologic changes from intraosseous infusion. *Ann Emerg Med* 1996;28(4):430-5 216

Preclinical study in pigs examining developmental and histopathologic changes in bone following IO infusion and effect of osmolality and infusion speed. Found that infusion osmolality and speed was not related to physiologic or histologic changes in the bone marrow or in complication.

Gunal I, Kose N, Gurer D. Compartment syndrome after intraosseous infusion: an experimental study in dogs. *J Pediatr Surg* 1996;31(11):1491-3 208

Preclinical study finding no compartment syndrome with up to 350 ml of IO fluid infusion; however, radio-opaque dye was detected in the soft tissues with compartment pressures increasing to more than 35 mmHg. Calls for a dose and time independent scale for safe intraosseous infusion.

Moller JC, Tegtmeyer FK, Schaible TF, Sussmane JB. [Intraosseous puncture as vascular access in pediatric emergency and intensive care medicine]. *Anaesthesiol Reanim* 1996;21(4):103-7. German. Abstract 209

Article describing IO infusion 18 pediatric resuscitative situations. Authors conclude that 11 patients would not have survived without IO access. Complications included a minor fracture, 1 case of compartment syndrome that did not require surgical intervention and a minor fat embolism that was of no clinical significance.

Wolff AA. Trial of an intraosseous infusion case. *Trial Diplomacy Journal* 1996;19:113-7 639

This article describes a malpractice case from the perspective of the prosecution regarding permanent drop foot suffered by a pediatric patient following extravasation from an IO line in the proximal tibia.

YEAR: 1995

Erb T, Hampl KF, Frei FJ. An unusual complication of intra-osseous infusion during paediatric resuscitation. *Anaesthesia* 1995;50(5):471 192

Case report describing extravasation of fluids through a previous IO puncture site in the same tibia.

Moller JC, Reiss I, Schaible T. Vascular access in neonates and infants--indications, routes, techniques and devices, complications. *Intensive Care World* 1995;12(2):48-53 197

Suggests that intraosseous infusion is reliable alternative to peripheral vein access for rapid infusion of fluids in neonates and infants when venous access is impossible.

Abstract only

Intraosseous Vascular Access Bibliography

Complications

- Plewa MC, King RW, Fenn-Buderer N, Gretzinger K, Renuart D, Cruz R. Hematologic safety of intraosseous blood transfusion in a swine model of pediatric hemorrhagic hypovolemia. Acad Emerg Med 1995;2(9):799-809** 205
Preclinical study examining hematologic parameters (hemoglobin, schistocytes, free hemoglobin in plasma, bilirubin, lactate dehydrogenase, platelets, fibrinogen, and alveolar-arteriolar O2 gradient) with IO and IV autologous blood transfusions. Found that all hematologic parameters remained within normal limits in both IO and IV groups. Concludes IO blood transfusions to be hematologically safe, i.e. without risk of appreciable hemolysis, DIC or fat embolism syndrome.
- Strausbaugh SD, Manley LK, Hickey RW, Dietrich AM. Circumferential pressure as a rapid method to assess intraosseous needle placement. Pediatr Emerg Care 1995;11:274-6** 196
Preclinical study in dog tibias demonstrating that circumferential pressure about an IO infusion site is a rapid method to detect incorrect placement of the IO needle.
- YEAR: 1994**
- Barron BJ, Tran HD, Lamki LM. Scintigraphic findings of osteomyelitis after intraosseous infusion in a child. Clin Nucl Med 1994; 19: 307-8** 186
Case report of unilateral tibial osteomyelitis in a 20-month-old child following bilateral IO infusion. Reviews clinical indications, potential complications, and scan findings.
- Gayle M, Kissoon N. A case of compartment syndrome following intraosseous infusions. Pediatr Emerg Care 1994;10:378** 185
Case report of compartment systems following improper intraosseous infusion technique.
- Katz DS, Wojtowycz AR. Tibial fracture: a complication of intraosseous infusion. Am J Emerg Med 1994; 12: 258-9** 160
Long bone fractures should be considered a potential, although rare, complication of intraosseous infusion in children.
- Melker RJ, Miller GJ, Gearen PH, Molliter L. A novel intraosseous needle. Ann Emerg Med 1994;23(4):923** 548
This abstract describes clinical use of the SurFast Cook Critical Care IO needle. Thirty-two IO insertion attempts were made, 87.5% were successful on first attempt. Average time to insertion was less than one minute; flow rate for infants and children was 1-2 mL/kg/min; flow rate for adults was 150-200 mL/min. There were two reports of minimal extravasation
- Orlowski JP. Emergency alternatives to intravenous access. Intraosseous, intratracheal, sublingual, and other-site drug administration. Pediatr Clin North Am 1994;41(6):1183-99** 164
Seminal article describing alternatives to intravenous cannulation including intraosseous access, intratracheal drug administration, sublingual and intralingual injection, intra-penile administration, and intracardiac injection. Concludes that the intraosseous method is an effective alternative to intravenous access in emergency situations.
Review
- Rosovsky M, FitzPatrick M, Goldfarb CR, Finestone H. Bilateral osteomyelitis due to intraosseous infusion: case report and review of the English-language literature. Pediatr Radiol 1994;24:72-3** 171
Case report of bilateral osteomyelitis secondary to intraosseous infusion.
Review
- Sheridan RL, Tompkins RG, McManus WF, Pruitt BA Jr. Intracompartmental sepsis in burn patients. J Trauma 1994; 36: 301-5** 179
Retrospective multi-center review of 1171 burned patients identifying 5 patients developing intracompartmental sepsis presenting with fever and swelling on clinical examination. Contributing factors may have included high volume resuscitation, delayed escharotomy, extravasated intraosseous infusion, cannulation related arterial injury, and splinting or positioning difficulties.
- Simmons CM, Johnson NE, Perkin RM, van Stralen D. Intraosseous extravasation complication reports. Ann Emerg Med 1994;23(2):363-6** 178
Case reports of 2 children with severe complications of IO infusions. One child developed severe tissue necrosis after IO placement. A second child developed compartment syndrome requiring fasciotomy.
- Wright R, Reynolds SL, Nachtsheim B. Compartment syndrome secondary to prolonged intraosseous infusion. Pediatr Emerg Care 1994;10:157-9** 172
Case report of compartment syndrome after prolonged intraosseous infusion (53 hours). Recommends that IO lines be used only temporarily until more permanent vascular access is established.
Review

Intraosseous Vascular Access Bibliography

Complications

YEAR: 1993

Bielski RJ, Bassett GS, Fideler B, Tolo VT. Intraosseous infusions: effects on the immature physis--an experimental model in rabbits. J Pediatr Orthop 1993;13:511-5 143

Preclinical study in 20 immature rabbits receiving IO infusion of saline, bicarbonate, or dopamine solutions into the tibia. Found no changes in bone growth or epiphyseal injury related to IO infusion.

Burke T, Kehl DK. Intraosseous infusion in infants. Case report of a complication. J Bone Joint Surg Am 1993; 75: 428-9 153

Case report of a 4-month-old infant developing compartment syndrome after IO infusion. The patient underwent a fasciotomy and had full and normal use of the leg at the 6 month follow up visit.

Golenz MR, Carlson GP, Madigan JE, Craychee T. Preliminary report: the development of an intraosseous infusion technique for neonatal foals. J Vet Intern Med 1993; 7:377-82 142

Preclinical study of IO infusion in 6 foals. Local soft tissue swelling and periosteal reactions observed immediately following the procedure resolved by 2 months.

Platt SL, Notterman DA, Winchester P. Fungal osteomyelitis and sepsis from intraosseous infusion. Pediatr Emerg Care 1993;9:149-50 141

Case report of fungal osteomyelitis following IO infusion in a child. Cautions that physicians consider both bacterial and fungal sources for infection.

Ribeiro JA, Price CT, Knapp DR Jr. Compartment syndrome of the lower extremity after intraosseous infusion of fluid. A report of two cases. J Bone Joint Surg Am 1993;75A(3):430-3 155

This article presented two case studies in which pediatric patients received emergency IO infusions that ultimately resulted in compartment syndrome. In both cases the patients underwent a four-compartment fasciotomy and recovered without deficit. The authors conclude that though compartment syndrome is a risk of IO infusion, insertion of an IO line in emergency situations is a valuable technique.

Vidal R, Kissoon N, Gayle M. Compartment syndrome following intraosseous infusion. Pediatrics 1993;91:1201-2 152

Case report outlining precautions to prevent compartment syndrome following IO infusion. Advocates early recognition and aggressive treatment to preserve function in the affected limb.

YEAR: 1991

Christensen DW, Vernon DD, Banner W Jr, Dean JM. Skin necrosis complicating intraosseous infusion. Pediatr Emerg Care 1991;7:289-90 114

Case reports of 2 patients with local skin necrosis complicating IO infusion.

Galpin RD, Kronick JB, Willis RB, Frewen TC. Bilateral lower extremity compartment syndromes secondary to intraosseous fluid resuscitation. J Pediatr Orthop 1991;11:773-6 109

Case report of a child with severe compartment syndrome of both lower extremities following IO fluid resuscitation.

Von Hoff DD. Intraosseous infusions: an important but forgotten method of vascular access. Cancer Invest 1991;9(5):521-8 116

Review of intraosseous vascular access targeted for an oncology audience. Describes an implantable IO device with potential to make intraosseous access more convenient for the patient.

YEAR: 1990

Crane RG. Where are the fractures and needles? Ann Emerg Med 1990;19(6):731 87

Letter to the editor regarding a previous article, "Iatrogenic Bilateral Tibial Fracture After Intraosseous Infusion Attempts in a 3-Month-Old Infant." Inquires if fractures were caused by questionable technique or an unexplainable complication of a proximally placed needle.

Fiser DH. Intraosseous infusion. N Engl J Med 1990;322(22):1579-81 98

Review of the use of intraosseous infusion in children in the prehospital setting and in the emergency department. Outlines anatomy, indications and contraindications, technique, complications and role of intraosseous infusion in pediatrics.

Intraosseous Vascular Access Bibliography

Complications

- Melker RJ, Miller G, Gearen P, Molliter L. Complications of intraosseous infusion. *Ann Emerg Med* 1990;19(6):731-2** 97
This series of 3 letters to the editor are in response to the case report of bilateral fracture of the mid-tibial shaft in a 3-month old child following tibial IO insertion. It is noted that the insertions were made in the mid-tibial shaft rather than at the proximal or distal tibial insertion sites.
- Moscato R, Moore GP. Compartment syndrome with resultant amputation following intraosseous infusion. *Am J Emerg Med* 1990; 8: 470-1** 91
Case report of compartment syndrome following IO infusion. Emphasizes IO to be useful for temporary vascular access. Advises that that IV lines be placed as soon as possible after IO infusion. Recommends that radiograph be performed after the procedure in very young children to check for bone abnormalities.
- Spivey WN. Intraosseous infusion: Current concepts : The medical college of Pennsylvania, Department of Emergency Medicine, Philadelphia, PA. *J Emerg Med* 1990;8(3):382** 743
This abstract describes a review of the literature on intraosseous pathways and reaches the conclusion that the rate of fluid administered is limited by the size of the marrow cavity and the complication is extravasation of fluids and/or drugs into the soft tissue.
- YEAR: 1989**
- La Fleche FR, Slepian MJ, Vargas J, Milzman DP. Iatrogenic bilateral tibial fractures after intraosseous infusions attempts in a 3-month-old infant. *Ann Emerg Med* 1989;18(10):1099-101** 82
Case report of bone fracture following IO access in an infant.
- Orlowski JP, Julius CJ, Petras RE, Porembka DT, Gallagher JM. The safety of intraosseous infusions: risks of fat and bone marrow emboli to the lungs. *Ann Emerg Med* 1989;18(10):1062-7** 78
Preclinical study in dogs examining lung samples for fat and bone marrow emboli following IO infusion. Found no significance difference in embolism formation or density between dogs receiving IO infusion of emergency drugs and control group.
- YEAR: 1988**
- Brickman KR, Rega P, Koltz M, Guinness M. Analysis of growth plate abnormalities following intraosseous infusion through the proximal tibial epiphysis in pigs. *Ann Emerg Med* 1988;17(2):121-3** 65
Preclinical study in pigs examining the epiphyseal plate after intentional penetration with IO needle and subsequent fluid infusion. Found no significant growth defects despite injury to the developing growth plate.
- Brillman JC. Intraosseous infusion for emergency intravascular access. *Top Emerg Med* 1988;10(1):75-80** 73
Description of IO infusion technique, site selection, procedure, anatomy, physiology, historical perspectives, contemporary research, indications, contraindications, complications, and future direction.
- Manley L, Haley K, Dick M. Intraosseous infusion: rapid vascular access for critically ill or injured infants and children. *J Emerg Nurs* 1988;14(2):63-9** 66
Article for emergency nursing audience describing IO technique, anatomy, absorption rates, clinical indications and contraindications, technique, complications and training in critically ill or injured infants and children.
- Peck KR, Altieri M. Intraosseous infusions: an old technique with modern applications. *Pediatr Nurs* 1988;14(4):296-8** 70
Nursing article recommending IO early in the treatment of critically ill or injured children with difficult venous access. Highlights speed and ease of IO technique.
- YEAR: 1987**
- Spivey WH. Intraosseous infusions. *J Pediatr* 1987;111(5):639-43** 56
Review article on IO infusion, includes historical background, physiology, method, clinical applications and complications of the IO procedure.
- YEAR: 1986**
- Hoelzer MF. Recent advances in intravenous therapy. *Emerg Med Clin North Am* 1986;4(3):487-500** 55
Review of medical literature and research on the problem of difficult intravenous access.

Intraosseous Vascular Access Bibliography

Complications

YEAR: 1985

Hodge D. Intraosseous infusions: a review. *Pediatr Emerg Care* 1985;1(4):215-8 44
Review of IO insertion techniques of insertion, clinical indications, contraindications, and complications.

YEAR: 1984

Rosetti V, Thompson BM, Aprahamian C, Darin JC, Mateer JR. Difficulty and delay in intravascular access in pediatric arrests. *Ann Emerg Med* 1984;13(5):406 39
Outlines problems with conventional vascular access in emergency medicine. Discusses possible resurgence of the "old" technique of intraosseous infusion.

YEAR: 1977

Valdes MM. Intraosseous fluid administration in emergencies. *Lancet* 1977;1(8024):1235-6 29
Observational study of 15 patients needing emergency fluids and in whom IV's were difficult to establish. Patients received drugs and fluids via IO. Concludes that IO therapy is effective with no serious complications.

YEAR: 1956

Bennike T, Gormsen H, Moller B. Comparative studies of bone marrow punctures of the sternum, the iliac crest, and the spinous process. *Acta Med Scand* 1956;155(5):377-96 28
Study finding sternal puncture superior to iliac crest and spinous process punctures for bone marrow sampling. Cautions that inexperienced practitioners should use iliac crest or spinal process in the absence of training in sternal puncture.

YEAR: 1954

Marill F. Death from sternal puncture. *JAMA* 1954;155:1276 25
Case report of death following pericardial rupture with hemorrhage, associated shock, and peripheral circulatory collapse.

YEAR: 1951

Fortner JG, Moss ES. Death following sternal puncture: report of two cases. *Annals of Internal Medicine* 1951;34:809-15 23
Case reports of 2 deaths from sternal puncture. Discusses 4 additional cases from the medical literature. Comments of the mechanism of death.

YEAR: 1950

Massey LW. Bone-marrow infusions: intratibial and intravenous routes compared. *Br Med J* 1950;2(4672):197-8 22
Early review of IO infusion citing complication rate of osteomyelitis (approximately 1 in 150 cases).

YEAR: 1947

Heinild S, Sondergaard T, Tudvad F. Bone marrow infusion in childhood: Experiences from a thousand infusions. *J of Pediatrics* 1947; 30: 400-11 21
Early study on IO. Makes strong distinction between ordinary blood transfusion or infusion of isotonic solutions (generally safe) and continuous infusion or the infusion of hypertonic solutions. The latter carries considerable risk of osteomyelitis and subsequent disturbance in growth of the bone.

YEAR: 1946

Quilligan JJ, Turkel H. Bone marrow infusion and its complications. *Am J Dis Child* 1946; 71: 457-65 18
Historical article discussing refinements in IO technique and analysis of IO complications. Includes case report of an infant who developed osteomyelitis subsequent to IO infusion.

Intraosseous Vascular Access Bibliography

Complications

YEAR: 1945

Tocantins L, O'Neill J. Complications of intraosseous therapy. *Ann Surg* 1945;122:266-77

16

Early article on IO with caveats on use. Includes case report of complication following IO infusion via the sternal marrow of a diabetic. Reviews relevant anatomy, actual and possible technical complications.

YEAR: 1944

Arbeiter H I, Greengard J. Tibial bone marrow infusion in infancy. *J Pediatr* 1944; 25:(1):1-12

12

Early article describes technique for tibial bone marrow infusion. Reports 6 failures and 2 partial failures in 43 attempts on 34 young children. X-ray studies post IO infusion showed small bone defects and periosteal elevation with new bone formation.

YEAR: 1943

Ravitch MM. Suppurative anterior mediastinitis in an infant following intrasternal blood transfusion. *Arch Surg* 1943;47(3):250-7

1012

This article provides a brief history of intraosseous infusion beginning in 1903 with supportive literature through the writing of this article in 1943. An overview of mediastinitis, a complication of intrasternal blood transfusion, is also provided followed by a case report of anterior mediastinitis in an infant.

YEAR: 1922

Drinker C, Drinker K, Lund C. The circulation in the mammalian bone marrow. *Am J Physiol* 1922;62(1):1-92

1

Seminal article on blood circulation in the IO space. Demonstrates movement of red blood cells from the bone marrow into the circulating blood by perfusion of the tibia of the dog and by injections into the bone marrow in the rabbit and cat.

Intraosseous Vascular Access Bibliography

Emergency Care

YEAR: 2019

Sørgjerd R, Sunde GA, Heltne JK. Comparison of two different intraosseous access methods in a physician-staffed helicopter emergency medical service - A quality assurance study. *Scand J Trauma Resusc Emerg Med* 2019;27(1):15 doi: 10.1186/s13049-019-0594-6

1062

This study compared IO insertions with the EZ-IO device (tibial/humeral insertions) to the FAST-R device (sternal insertions only) in a physician-staffed helicopter emergency medical service. Insertion time, insertion site, flow, indication for IO access, and complications were compared. Median insertion time was 15 seconds for EZ-IO and 20 seconds for FAST-R. Overall, 35.1% of EZ-IO insertions resulted in poor flow and required a pressure bag while 85.7% of FAST-R insertions had good or very good flow. EZ-IO complications included extravasation (2.4%), aspiration failure (11.9%), and insertion time >30 seconds (4.8%). Complications associated with FAST-R included user failure (12.5%) and insertion time >30 seconds (12.5%). The authors suggest that although EZ-IO is faster the FAST-R device may be more useful when high-flow infusion rates are required. The authors indicate that a low number of insertions were made with the FAST-R device and many outliers were observed in the data. However, the article does not present the total number of insertions per device.

YEAR: 2018

Abramson TM, Alreshaid L, Kang T, Mailhot T, Omer T. FasciOotomy: Ultrasound evaluation of an intraosseous needle causing compartment syndrome. *Clin Pract Cases Emerg Med* 2018;2(4):323-25

1041

This case review describes a complication of compartment syndrome post IO placement in a 64 year old male initially unresponsive and hypoglycemic. Approximately 15 minutes post-ED arrival compartment syndrome signs were noted and confirmed with compartment pressures. An ultrasound confirmed lack of flow from the IO needle and x-ray showed the needle set to be inserted 2 mm beyond the posterior tibial cortex. Patient was taken to surgery for fasciotomy and four compartment release with subsequent return of pulses.

*(Correspondence by the manufacturer 12-2018 with lead author confirmed the tibial placement was lateral and the patient had a full functional recovery).

Backman S, Angerman-Haasman S, Jousi M, et al. ABO and D typing and alloantibody screening in marrow samples: Relevance to intraosseous blood transfusion. *Transfusion* 2018;58(6):1372-75. doi: 10.1111/trf.14557

957

This article describes a study using prospective sampling of bone marrow (BM) to assess the feasibility of using bone marrow samples for blood group serotype analyses. Peripheral blood (PB) from each subject was used as that subject's control. 71 pairs of BM and PB samples were tested for ABO type, D type, and RBC alloantibody screening. All BM samples were successfully analyzed with no inconclusive results. The study concluded that BM samples collected from IO devices can be utilized for blood group serologic analyses.

Bowry R, Nour M, Kus T, et al. Intraosseous administration of tissue plasminogen activator on a mobile stroke unit. *Prehosp Emerg Care* 2018;25:1-6. doi:10.1080/10903127.2018.1526355

963

This study describes 3 cases in which tissue plasminogen activator (tPA) was administered via intraosseous (IO) access on a mobile stroke unit as part of the BEST-MSU study. IO access was obtained with the EZ-IO device as part of the study protocol.

Burgert J, Martinez A, O'Sullivan M, Blouin D, Long A, Johnson A. Sternal route more effective than tibial route for intraosseous amiodarone administration in a swine model of ventricular fibrillation. *Prehosp Emerg Care* 2018;22(2):266-75. doi:10.1080/10903127.2017.1358782

903

This study examined the measured mean plasma concentration, maximum plasma concentration (Cmax), and time to maximum concentration (Tmax) of amiodarone administered by 3 different routes, sternal IO (SIO), tibial IO (TIO), and IV over a time period of 5 minutes in 21 swine who were randomly assigned to one of the 3 routes. The swine were under general anesthesia and ventricular fibrillation was induced and CPR initiated. After 4 minutes in ventricular fibrillation the swine were administered 300 mg of amiodarone and blood samples were taken at 30 second intervals over 300 seconds. Authors concluded that the SIO and IV routes of amiodarone were comparable. The TIO group took almost 3 times longer to reach Tmax than the SIO and IV groups. In the swine model used in this study, the authors concluded that SIO route was more effective than the TIO route for the amiodarone delivery in a swine with VF and ongoing CPR.

Cho Y, You Y, Park JS, et al. Comparison of right and left ventricular enhancement times using a microbubble contrast agent between proximal humeral intraosseous access and brachial intravenous access during cardiopulmonary resuscitation in adults. *Resuscitation* 2018;129:90-3. doi:10.1016/j.resuscitation.2018.06.014

967

This study was a prospective, single-center, observational, cohort study of 10 patients comparing the ventricular enhancement time between humeral intraosseous (HIO) access and brachial intravenous (BIV) access during CPR in adult humans. HIO access was obtained with the EZ-IO device. Endpoints were right and left ventricular enhancement times after administration of a contrast agent. Results indicated that arrival times of medication at the right and left ventricles were significantly lower with HIO than BIV.

Intraosseous Vascular Access Bibliography

Emergency Care

Chreiman KM, Dumas RP, Seamon MJ, et al. The intraosseous have it: A prospective observational study of vascular access success rates in patients in extremis using video review. J Trauma Acute Care Surg 2018;84(4):558-63. doi:10.1097/TA.0000000000001795

890

Prospective cohort study done by review of video footage which was taken over a 15 month period as part of a quality improvement initiative for patients in extremis (the absence of a palpable pulse or measurable blood pressure) undergoing thoracotomies during trauma resuscitation. Data recorded for vascular access included types intraosseous (IO), peripheral intravenous (PIV), central venous (CVC) and intracardiac (IC)) and site of attempted access, number of attempts and success rates, procedure time, demographics, and mechanism of injury. 145 access attempts were made in 38 patients (median 3.8 (SD 1.4) attempts per patient). Time to access was similar for PIV and IO but longer for CVC and success rates for IO insertion were significantly higher than for PIVs or CVCs (95% vs. 42% vs. 46%, p<0.001). Authors "recommend placement of IO cannulae as a best practice to rapidly establish first line vascular access for resuscitation and as a bridge to additional access."

Durnford S, Bulstrode H, Durnford A, Chakraborty A, Tarmey NT. Temporising an extradural haematoma by intraosseous needle craniostomy in the District General Hospital by non-neurosurgical doctors-A case report. J Intensive Care Soc 2018;19(1):76-9. doi:10.1177/1751143717734997

971

This is a case report of a 69 year-old male admitted to an ED in the UK with an extradural hematoma following closed head injury. He was treated with decompression of the hematoma using a 25 mm long EZ-IO intraosseous needle. This is believed to be the first reported use of an EZ-IO device in this manner in the UK. The patient succumbed to his injuries two days later. However, the authors recommend consideration of this technique when transfer to a hospital with a neurosurgery unit for craniostomy is not a feasible option.

Durnford S, Bulstrode H, Durnford A, Chakraborty A, Tarney N. Reply from authors to letter on temporising an extradural haematoma by intraosseous needle craniostomy in the district general hospital by non-neurosurgical doctors - a case report. J Intensive Care Soc 2018;19(3):275. doi: 10.1177/1751143717746049

1050

This paper is a response to a letter to the editor (see Wiles 2018) responding to this author's original work where an IO needle was used (off-label) in an attempt to decompress an acute intracranial hematoma. The authors emphasize that patient safety is their primary concern and that their off-label use of an approved IO device was the best option at the time. They also reiterate that the technique used has not been studied in a clinical trial and they do not advocate its use as standard practice.

Feinstein BA, Stubbs BA, Rea T, Kudenchuk PJ. Intraosseous compared to intravenous drug resuscitation in out-of-hospital cardiac arrest [Letter to the Editor, Authors' Reply]. Resuscitation 2018;127:e2

974

This letter to the editor is the authors' response to another letter to the editor by Drs. Soar and Hormis for their review of the authors' study comparing initial access between IV and IO during out-of-hospital cardiac arrest (OHCA) resuscitation. Reference: Feinstein BA, Stubbs BA, Rea T, et al. Intraosseous compared to intravenous drug resuscitation in out-of-hospital cardiac arrest. (Initial publication: Resuscitation 2017;117:91-96)

Kawano T, Grunau B, Scheuermeyer FX, et al. Intraosseous vascular access is associated with lower survival and neurologic recovery among patients with out-of-hospital cardiac arrest. Ann Emerg Med 2017;71(5):588-96. doi:10.1016/j.annemergmed.2017.11.015

946

A retrospective analysis of data collected in the prehospital setting to evaluate the effect of either intravenous (IV) or intraosseous (IO) vascular access management of non-traumatic, adult, out-of-hospital cardiac arrest (OOHCA) cases on patient (pt) outcomes. Results: 23.9% IO patients achieved ROSC vs 38.3% IV; 3.8% IO subjects survived to hospital discharge vs 10.3% IV subjects. The authors concluded that in patients with non-traumatic OOHCA, use of IO access is associated with lower survival and poor neurologic outcomes as compared to IV access. Limitations: 660 pts received IO access (5%) and 12,495 received IV access (95%); selection bias by paramedics choosing the vascular access method based upon presenting conditions; and IO access had a higher proportion of non-shockable initial rhythms, fewer public location and witnessed arrests and shorter times from call to first ALS paramedics arrival.

Kawano T, Grunau B, Scheuermeyer FX. In reply: Effect of time to vascular access in out-of-hospital cardiac arrest. Ann Emerg Med 2018;72(2):229-31

987

This letter to the editor is in response to Nurii et al.'s letter to the editor regarding Kawano et al.'s article on the effect of time to vascular access in out-of-hospital cardiac arrest (OHCA). Kawano et al. performed Nurii et al.'s suggested sensitivity analysis by modifying their multivariable logistic regression model to include duration of out-of-hospital resuscitation among patients with return of spontaneous circulation (ROSC) or termination of resuscitation as measured from the 911 call to either ROSC or termination of resuscitation. The authors conclude that the model continued to demonstrate that IO access, when compared to IV access, was associated with a decreased probability of a favorable neurologic outcome.

Markic J, Polic B, Mestrovic J, Kovacevic T, Zanchi I. Successful intraosseous therapy using EZ-IO system in a preterm neonate below 2 kg. Minerva Pediatr 2018;70(1):104-5. doi:10.23736/S0026-4946.16.04707-1. (Croatia)

928

This paper is a letter to the editor describing successful insertion of EZ-IO in a neonate weighing less than 2 kg with respiratory failure, signs of sepsis, and shock. After successful insertion the patient was resuscitated and later stabilized. The authors advise that IO access is safe, effective, and attainable in all age groups despite FDA approval only in patients greater than 3 kg.

Intraosseous Vascular Access Bibliography

Emergency Care

- Norii T, Crandall C, Braude D. Effect of time to vascular access in out-of-hospital cardiac arrest [Letter to the Editor]. *Ann Emerg Med* 2018;72(2):228-9. <https://doi.org/10.1016/j.annemergmed.2018.03.031>** 1003
- This letter to the editor is in response to Kawano et al.'s article on the effect of time to vascular access in out-of-hospital cardiac arrest (OHCA). Kawano et al. found an association between intraosseous vascular access and lower survival and worse neurologic outcome in OHCA. Norii et al. express concern regarding selection bias and confounding factors not being accounted for in the original study. Norii et al. suggest accounting for time from call to vascular access or return of spontaneous circulation (ROSC). Norii et al. also suggest considering whether ROSC is an appropriate outcome. Reference: Kawano T, Grunau B, Scheuermeyer FX, et al. Intraosseous vascular access is associated with lower survival and neurologic recovery among patients with out-of-hospital cardiac arrest. (Initial article: *Ann Emerg Med*. 2018;71:588-596).
- Petrie A, Lubin J. Assessment of intraosseous needle placement by EMS providers. *Prehosp Emerg Care* 2018;22(1):28** 925
- Investigators assessed the ability of EMS providers with various skill levels to correctly identify the insertion sites for both the proximal tibia and proximal humerus. Participants were attending a state EMS conference. The distances from the sites identified to correct site was significant. The study concluded the accuracy of landmark identification was low and proper training is important.
- Redfield C, Suarez S, Daniels, Sanchez C, Siples H, Landry K. The effect of IV vs. IO access in prehospital cardiac arrest ROSC rates. *Prehosp Emerg Care* 2018;22(1):38** 926
- Retrospective study reviewing data from one EMS service that compared return of spontaneous circulation (ROSC) in cardiac arrests when intraosseous (IO) or intravenous (IV) access was obtained. An IV was placed in 361 patients with a ROSC in 148 (41.1%); and 360 patients had an IO placed with a ROSC in 80 (22.2%). The difference for greater ROSC rates with IV vs. IO use was significant.
- Rideout M, Raszka W. Hypovolemic shock in a child: A pediatric simulation case. *MedEdPORTAL* 2018;14:10694. doi: 10.15766/mep_2374-8265.10694** 1060
- This is a learning module for fourth year medical students to learn about fluid management and IO needle placement. The module simulates hypovolemic shock in a 3 year old patient using a child mannequin. An IO kit, including an EZ-IO driver, is supplied for obtaining IO access. A pilot study was conducted in 2017 with 16 subinterns on a pediatric service. Perceived competence in management of volume depletion and procedural skills were high following the training session and students felt the case was a beneficial learning experience.
- Sawyer T, Nishisaki A. Intraosseous access during newborn resuscitation: It may be fast, but is it safe? *Pediatr Crit Care Med* 2018;19(5):499-501. doi:10.1097/PCC.0000000000001513** 1017
- This article examines emergency vascular access during newborn resuscitation. It discusses the time needed to place an emergency umbilical vein catheter (eUVC) and intraosseous kits (EZ-IO) in a series of simulated newborn resuscitations across 4 studies. In all 4 studies IO placement was significantly faster than eUVC placement. An additional study found eUVC placement to be significantly faster with real human umbilical cords than with simulated umbilical cords as used in the aforementioned studies. While IO access in newborns appears faster than eUVC in simulated models, to date, no randomized trials or large case-cohort studies have systematically evaluated the short and long-term safety of IO placement during newborn resuscitation. Current guidelines still support eUVC as the preferred method of obtaining vascular access during newborn resuscitation. The authors suggest further studies are needed to determine short and long-term safety of IO access in newborns before widespread adoption of the process can be recommended.
- Sulava EF, Bianchi W, Krepela A, et al. Performance of single versus double site intraosseous blood transfusion strategies in a swine (sus scrofa) model of hemorrhagic shock. *Ann Emerg Med* 2018;72(4s):S3-4** 1023
- This abstract describes interim results of a study in a swine model that discusses the utility of intraosseous blood transfusions for treating hypovolemic battlefield injuries, compares advantages and complications of humeral versus sternal IO access for resuscitation, and identifies flow rates, degree of intravascular hemolysis, and occurrence of coagulopathy in single versus double site intraosseous blood transfusion. The study found that in an animal model of hemorrhagic shock, double site IO transfusion appears to confer a significant advantage in flow rates without significant complications
- Wagner M, Olischar M, O'Reilly M, et al. Review of routes to administer medication during prolonged neonatal resuscitation. *Pediatr Crit Care Med* 2018;19(4):332-8. doi: 10.1097/PCC0000000000001493** 1029
- This article presents a review of current evidence regarding different routes for the administration of medications during neonatal resuscitation, of which the intraosseous route is included. A table comparing four different intraosseous devices, including EZ-IO, is presented in the document.
- Wehbi NK, Wani R, Yang Y, et al. A needs assessment for simulation-based training of emergency medical providers in Nebraska, USA. *Adv Simul (Lond)*. 2018;3:22. doi: 10.1186/s41077-018-0081-6** 1063
- This paper describes a project where information was collected using a paper survey from EMS and ED providers in Nebraska. The purpose of the survey was to identify gaps in their skills, knowledge and abilities in order to aid curriculum development for a mobile training unit to be used in rural areas of the state. Intraosseous placement is a clinical skill in which the participants would like further training.
- Wiles M. Temporising an extradural haematoma by intraosseous needle craniostomy in the District General Hospital by non-neurosurgical doctors: A response. *J Intensive Care Soc* 2018;19(3):274. doi: 10.1177/1751143717743940** 1065
- This letter to the editor is a response to Durnford et al. (2018) regarding their off-label surgical procedure utilizing an IO needle in an attempt to decompress an acute intracranial hematoma. Wiles requests confirmation of the regulatory processes in place prior to the undertaking of the IO surgical technique.

Intraosseous Vascular Access Bibliography

Emergency Care

YEAR: 2017

- Battaloglu E, Porter K. Management of pregnancy and obstetric complications in prehospital trauma care: Faculty of prehospital care consensus guidelines. *Emerg Med J* 2017;34(5):318-25. doi: 10.1136/emered-2016-205978** 1043
- This paper is a consensus statement seeking to provide clear guidance for the management of pregnant trauma patients in the pre-hospital setting in the UK. IO access is recommended as an alternative to gain vascular access in pregnant trauma patients when IV access cannot be easily or quickly established. If possible, it is recommended that IO access be placed in the right humeral head in order to facilitate left tilt/left lateral positioning of the pregnant patient.
- Budach NM, Niehues SM. CT angiography of the chest and abdomen in an emergency patient via humeral intraosseous access. *Emerg Radiol* 2017;24(1):105-8. doi:10.1007/s10140-016-1438-6. (Germany)** 823
- This case report describes a CT angiography of the chest and abdomen done via an EZ-IO catheter placed in a critically ill patient's proximal humerus. The contrast media was infused at a rate of 4 mL/s and the infusion pressure never exceeded 300 mmHg. No immediate or short term complications were observed. The authors describe the overall image quality and vessel contrast observed as excellent.
- Butler F. Two decades of saving lives on the battlefield: Tactical combat casualty care turns 20. *Mil Med* 2017;182(3):1563-68. doi:10.7205/milmed-d-16-00214** 905
- The author discusses tactical combat casualty (TCCC), which has evolved over the past the past 20 years into a set of evidence-based, best practice prehospital trauma care guidelines for use in combat. TCCC has become a standard of trauma care in the US military and many other militaries of our allied nations. The Committee on TCCC and the Joint Trauma System are working with civilian trauma colleagues to advance prehospital trauma care into civilian trauma care in situations such as shooter events, terrorist bombings, motor vehicle accidents, household accidents and criminal violence.
- Clemency B, Tanaka K, May P, et al. Intravenous vs. intraosseous access and return of spontaneous circulation during out of hospital cardiac arrest. *Am J Emerg Med* 2017;35:222-6. doi:10.1016/j.ajem.2016.10.052** 943
- A retrospective chart review was done to analyze data of three EMS agencies over an 18 month timespan. Analysis was done on charts from adults who suffered OOHCA and received epinephrine through EMS established IV or IO access. An IO first approach was found non-inferior to an IV first approach based on the end point ROSC at time of emergency department arrival.
- Elliott A, Dubé P, Cossette-Côté A, et al. Intraosseous administration of antidotes-a systematic review. *Clin Toxicol* 2017; 55(10):1025-54. doi:10.1080/15563650.2017.1337122** 917
- This study reviews current IO administration of antidotes for patients that have presented to the emergency department with serious poisoning and IV access is not available. The study concluded that the evidence supporting the use of IO route for administering antidotes for poisoning patients is rare. Most evidence of IO access administration of antidotes has occurred in animal studies and case reports. Per author, despite lack of evidence, IO access is a potential option for antidotal treatments for resuscitation for patients where IV access is not available.
- Faudeux C, Tran A, Dupont A, et al. Development of reliable and validated tools to evaluate technical resuscitation skills in a pediatric simulation setting: resuscitation and emergency simulation checklist for assessment in pediatrics. *J Pediatr* 2017;188:252-57. doi:10.1016/j.jpeds.2017.03.055** 920
- This study addresses the need for the development of a reliable and validated tool to evaluate technical resuscitation skills in a pediatric simulation setting. The authors created four resuscitation and emergency simulation checklist and evaluation tools were created, (RESCAPE). Study found that use of the RESCAPE tools are reliable and validated tools for evaluation of resuscitation skills in pediatric simulation-based educational programs.
- Feinstein B, Stubbs B, Rea T, Kudenchuk P. Intraosseous compared to intravenous drug resuscitation in out-of-hospital cardiac arrest. *Resuscitation* 2017;117:91-6. doi:10.1016/j.resuscitation.2017.06.014** 922
- This retrospective cohort study evaluated emergency medical services (EMS) that treated adult patients with atraumatic out of hospital cardiac arrest (OHCA) in order to compare drug administration via intraosseous (IO) versus intravenous (IV) and the effectiveness. Study endpoints were survival to hospital discharge, return of spontaneous circulation (ROSC), and survival to hospital admission. The study included 1,800 patients, 1,525 of whom received IV access and 275 who received IO access. The practice for OHCA management in the EMS system from which the data was obtained was to attempt tibial IO access after failed IV attempts. The authors concluded that use of IO access was associated with a lower likelihood of ROSC and hospitalization; and acknowledged that further study of how vascular access routes affect OHCA patient outcomes is warranted.
- Leutscher SA, Gerritse BM, van der Meer NJ, Schuitemaker FJ, Scohy TV. Need of intraosseous access in advanced life support in the in-hospital setting: Evaluation of difficult vascular access in cardiac arrest. *Resuscitation* 2017;112:e7** 885
- This letter to the editor states the usefulness of intraosseous access devices in out-of-hospital-cardiac-arrest (OHCA) settings.
- Morrison G. Management of acute hypothermia. *Medicine* 2017;45(3):135-8. doi:10.1016/j.mpm.2016.12.009** 998
- This paper describes the management of acute hypothermia. In moderate hypothermia (28-32°C) intraosseous access should be considered in patients with difficult peripheral access.

Intraosseous Vascular Access Bibliography

Emergency Care

- Nassar BS, Kerber R. Improving CPR performance. CHEST 2017;152(5):1061-9. doi:10.1016/j.chest.2017.04.178** 1001
This manuscript provides an overview of CPR physiology, especially as it relates to compression and ventilation. The placement of peripheral and central venous catheters can interfere with compressions. As such, IO access is an alternative that allows drug administration with similar pharmacokinetics and absorption as peripherally administered medications and a higher insertion success rate (>80%).
- Tallman CI, Darracq M, Young M. Analysis of intraosseous blood samples using an EPOC point of care analyzer during resuscitation. Am J Emerg Med 2017;35(3):499-501. doi:10.1016/j.ajem.2016.12.005** 805
A prospective study comparing results of intravenous (IV) and intraosseous (IO) blood specimens when analyzed using an EPOC point of care analyzer during resuscitation of non-traumatic cardiac arrest and critically ill patients. Seventeen patients who had IO and IV specimens collected within 5 minutes of each other were included in the study; IO samples were collected before administration through the IO catheter in the proximal tibia or proximal humerus. Results showed that based upon Bland Altman plots, there was reasonable agreement between IV and IO values for PH, bicarbonate, sodium and base excess, and moderate agreement for lactic acid. The intraclass correlation co-efficient was excellent for sodium and reasonable for pH, pO₂, bicarbonate and glucose. The primary limitation noted was the small sample size (n=17) and the substantial impact of single outliers in the data.
- Walsh BM, Gangadharan S, Whitfill T, et al. Safety threats during the care of infants with hypoglycemic seizures in the emergency department: A multicenter, simulation-based prospective cohort study. J Emerg Med 2017;53(4):467-74. doi:10.1016/j.jemermed.2017.04.028** 1030
This article describes a prospective, multicenter, in situ, simulation-based cohort study to describe the frequency of different types of errors between general emergency departments (GEDs) and pediatric emergency department (PEDs) in a simulated pediatric patient case of hypoglycemic seizure. During the debriefing portion of the simulation providers and teams were asked about obtaining vascular access (IV/IO). Questions involved how to obtain vascular access, barriers to obtaining access, assessment of confidence in ability to obtain access, location of access, needle size, time to gain access, who to contact after failed attempts at access, and how to decide which medications or fluids to administer.
- Wolfson DL, Tandoh MA, Jindal M, Forgiione PM, Harder VS. Adult intraosseous access by advanced EMTs: A statewide non-inferiority study. Prehosp Emerg Care 2017;21(7):7-13. doi:10.1080/10903127.2016.1209262** 816
This retrospective non-inferiority study examined EMS data extracted from a statewide EMS data system over a two year period. IO insertions performed by advanced EMTs (AEMT) and Paramedics were compared for insertion success rates. The majority of IO placements were with the EZ-IO®. The investigators concluded successful IO access was not different among AEMTs and Paramedics lending evidence in support of expanding the scope of practice of AEMTs to include establishing IO access in adults.
- Yee D, Deolankar R, Marcantoni J, et al. Tibial osteomyelitis following prehospital intraosseous access. Clin Pract Cases Emerg Med 2017;1(4):391-4** 936
Case report of a 29 year old that was diagnosed with osteomyelitis in his left tibia after a prehospital IO placement for resuscitation of cardiac arrest. Medications infused included naloxone, epinephrine, and amiodarone. The patient had ROSC and his IO catheter was removed within one hour of ED arrival due to infiltration. Diagnosis of tibial osteomyelitis occurred approximately 8 weeks post-initial placement.
- YEAR: 2016**
- Bramlett E, Fales W, West B, LaBond V. Rate of return of spontaneous circulation in relation to primary vascular access during out-of-hospital adult cardiac arrest. Ann Emerg Med 2016;68(4S):S120** 812
Investigators conducted a retrospective prehospital study over a 3 month time period comparing IV vs. IO access for return of spontaneous circulation (ROSC). With approximately 800 cases of out-of-hospital cardiac arrest (OOHCA) they found a significantly greater success rate for IO access but no difference between IO and IV for ROSC or time to first epinephrine.
- Burgert J. A primer on intraosseous access: History, clinical considerations, and current devices. Am J Disaster Med 2016;11(3):167-73. doi:10.5055/ajdm.2016.0236** 901
This journal article literature review was written to provide information about the history, clinical considerations, and devices associated with intraosseous access to administer resuscitative drugs when IV access can't quickly or easily obtained.
- Burgert J. Intraosseous vascular access in disasters and mass casualty events: A review of the literature. Am J Disaster Med 2016;11(3):149-66. doi:10.5055/ajdm.2016.0235** 902
This literature review examined the increase in use of intraosseous access for administration of resuscitative fluids and drugs to patients where intravenous access could not quickly or easily obtained during disasters and mass casualty events. The review also included a comparison of IO route to other routes for establishing vascular access in patients that have been involved in mass casualty or disasters.

Intraosseous Vascular Access Bibliography

Emergency Care

- Chin YX, Kiat Tan KB, Koh ZX, et al. Comparing intraosseous and intravenous access for out-of-hospital cardiac arrest in Singapore. *Resuscitation* 2016;106(S1):e25** 813
- The objective of this study was to determine if there would be a difference in rates of vascular access and ROSC if paramedics were able to use IO access after two initial IV attempts failed. Investigators found higher vascular access success and prehospital epinephrine administration rates with the addition of IO access but no significant difference for ROSC.
- Singapore
- Davis J, Bates L. Rapid sequence induction via an intraosseous needle. *J Intensive Care Society* 2016;17(2):178-9** 788
- This article presents a case study of rapid sequence intubation via intraosseous (IO) access with a review of relevant literature. The authors describe a case of an adult male patient, peri-arrest with cardiogenic shock, cyanosed with un-recordable oxygen saturations and blood pressure. IO access was established in the proximal tibia and rapid sequence induction was performed using fentanyl, ketamine and suxamethonium. After 30 seconds direct laryngoscopy was attempted and intubation was secured on first attempt. The authors concluded that use of IO access for RSI can be useful in cases of difficult vascular access and rapid intubating conditions can be achieved which are comparable to using IV drug delivery.
- Davlatov C, Miller LJ, Montez DF, Puga TA, Philbeck TE. Intraosseous catheter dwell-time appears safe for up to 48 hours: A preliminary report. *The Journal of Vascular Access* 2016;17(4):e26** 782
- The abstract describes the interim results of an investigational device exemption study evaluating use of EZ-IO in volunteers for a 48 hour dwell time period. At the time of the report, 39 subjects completed the study with no serious adverse event reports. Subjects were randomized to receive IO insertion in the proximal tibia or proximal humerus insertion sites. Pain has been managed using oral hydrocodone/acetaminophen and/or intravenous/intramuscular ketorolac. This study is sponsored by Teleflex Incorporated.
- Drozdz A, Madziara M. Nurses' attitudes and beliefs concerning intraosseous access in pediatric patients. *Am J Disaster Med* 2016;34(9):1890. doi:10.1016/j.ajem.2016.06.064** 916
- This study examined the attitudes of nurses working with pediatric patients and intraosseous access in pediatric patients. The study was conducted with the use of a diagnostic survey distributed to 200 nurses, with 135 nurses returning the surveys. The study found that there is a need for more training with nurses to increase their level of knowledge of intraosseous access and improve nurses attitudes for use of intraosseous access in pediatric population in emergency situations.
- Drozdz A, Madziara M. Which vascular access technique should be chosen during hypovolemic shock? *Am J Emerg Med* 2016;34(9):1886-7. doi:10.1016/j.ajem.2016.06.070** 824
- In this letter to the editor authors discuss the difficulties of obtaining vascular access in patients in shock; and make a case for use of intraosseous access (IOA) in shock. Authors note IOA access as a safe, effective alternative to venous access with relatively rare complications.
- Poland
- Edwards S, Smith J. Advances in military resuscitation. *Emerg Nurse* 2016;24(6):25-9. doi:10.7748/en.2016.en1630** 818
- This journal article discusses lessons learned from treatment of severe traumatic injury in combat situations and how they can be applied in the civilian environments when treating the same type injuries.
- EMEDHOME.com. Clinical Pearl: Getting a CTA for PE if the IV is inadequate *Emerg Med News* 2016;38(12):19. doi:10.1097/01.EEM.0000511109.41978.1a** 931
- Online article that briefly discusses use of intraosseous access to obtain a CTA study for pulmonary vasculature imaging when intravenous access is difficult.
- Engels P, Erdogan M, Widder S, et al. Use of intraosseous devices in trauma: A survey of trauma practitioners in Canada, Australia and New Zealand. *Can J Surg* 2016;59(6):374-82 doi:10.1503/cjs.011215** 918
- This study was conducted to determine the level of experience as well as the beliefs and attitudes of trauma practitioners in Canada, Australia and New Zealand about using IO devices in adult trauma patients. The study used a web-based survey submitted to 1771 to all members of 4 national emergency and trauma organizations. Surveys were completed by 425 participants and most participants surveyed were comfortable using the IO device in resuscitation of adult trauma patients.
- Fulkerson J, Lowe R, Anderson T, Moore H, Craig W, Johnson D. Effects of intraosseous tibial vs. intravenous vasopressin in a hypovolemic cardiac arrest model. *West J Emerg Med* 2016;17(2):222-8. doi:10.5811/westjem.2015.12.28825** 777
- Randomized, prospective preclinical study that examined the differences in pharmacokinetics and pharmacodynamics of tibial IO (TIO) and IV-delivered vasopressin during cardiac arrest and CPR until ROSC was achieved. No difference was noted for ROSC between TIO and IV delivered vasopressin. Authors concluded the use of IO access could avoid the time delay associated with IV access, and that it is effective for treatment of hypovolemic cardiac arrest and should be first line for rapid vascular access.
- Hampton K, Wang E, Argame JI, Bateman T, Craig W, Johnson D. The effects of tibial intraosseous versus intravenous amiodarone administration in a hypovolemic cardiac arrest porcine model. *Am J Disaster Med* 2016;11(4):253-60** 829
- This study compared IV to tibial IO administration of amiodarone. Investigators found no significant differences for the endpoints of Cmax, Tmax and time to/ rate of ROSC between IO and IV.

Intraosseous Vascular Access Bibliography

Emergency Care

- Hess T, Böhmer R, Arndt F, et al. Bilateral intraossärer zugang am humerus bei reanimation eines 3-Jährigen [Case Report- Bilateral humeral intraosseous access for CPR in a 3-years-old child]. *Anästhesiol Intensivmed Notfallmed Schmerzther* 2016;51(07-08):468-74. doi:10.1055/s-0042-110237.** 819
- This article in German describes a case study of a 3 year old child with a serious heart defect (after total cavopulmonary anastomosis) in which bilateral humeral IO access sites were obtained to manage her condition and the patient was discharged after 30 days without neurological deficits. Key messages include that IO access in children should be a primary access route in emergent and urgent situations, unless a suitable venous access is already available; the humeral head insertion site is an accepted method in emergency situations in adults and children; and IO access is intended for regular emergency administration of drugs. The purely preventive use of an IO is not indicated. Article in German.
- Holloway MM, Jurina SL, Orszag JD, et al. Effects of humerus intraosseous versus intravenous amiodarone administration in a hypovolemic porcine model. *Am J Disaster Med* 2016;11(4):261-9** 828
- In a swine study comparison of the humeral IO and IV amiodarone administration routes investigators found no difference in time to ROSC or rate, time to maximum concentration (Tmax) $p = 0.501$ or in maximum plasma drug concentration (Cmax) ($p = 0.232$).
- Johnson M, Inaba K, Byerly S, et al. Intraosseous infusion as a bridge to definitive access. *Am Surg* 2016;82(10):876-80** 826
- This retrospective study examined indications and outcomes associated with IO use at a Level 1 trauma center from 2008-2015. All 68 IO placements were with the EZ-IO device; most patients had trauma diagnoses. Most IO placements were successful on first attempt within 3 minutes of arrival. Non-serious extravasation was the most common complication. Authors concluded IO access "should be considered as a rapid, low risk, high yield aid to long-term IV access in both adults and children, and is an important bridge to definitive access in resuscitation".
- Maddry JK, Savell S, Mora A, Perez C, Bebart V. En route intraosseous access performed in the combat setting. *Ann Emerg Med* 206;68(4):S106** 889
- This abstract describes a study designed to describe and compare the use of intraosseous (IO) catheters by military MEDEVAC providers during recent conflicts. There were 12 patients that receive IO catheters following failed intravenous cannulation with an 83% success rate, and 74 patients for whom IO access was the first access attempted with an 85% success rate. Researcher concluded that IO access can be used successfully in the combat setting and accounted for approximately 12% of vascular access in the MEDEVAC population they studied.
- Montez DF, Puga TA, Davlantes C, Higgins R, Miller LJ, Philbeck TE. Blood transfusion via intraosseous access: A pre-clinical study. *J Vasc Access* 2016;17(4):e5-6** 783
- A preclinical study evaluating blood transfusion via IO vascular access in anesthetized swine. Results showed pressurized blood transfusion through IO vascular access resulted in acceptable flow rates and did not result in appreciable hemolysis as indicated by free hemoglobin values. This study was sponsored by Teleflex Incorporated.
- O'Sullivan M, Martinez A, Long A, et al. Comparison of the effects of sternal and tibial intraosseous administered resuscitative drugs on return of spontaneous circulation in a swine model of cardiac arrest. *Am J Disaster Med* 2016;11(3):175-82. doi:10.5055/ajdm.2016.0237** 1006
- This study compared the effects of IO and IV administered resuscitative drugs (vasopressin, amiodarone, and epinephrine) on return of spontaneous circulation (ROSC) in a swine model of sudden cardiac arrest (SCA) with ongoing resuscitation. Swine were randomized to 1 of 5 groups; tibial IO, sternal IO, IV, CPR+defibrillation, and CPR-only. There was no significant difference in ROSC between SIO, TIO, and IV groups. However time to ROSC was significantly less for the SIO group compared to the TIO group ($p=0.003$). This is possibly related to higher fat content in tibial bone marrow relative to the sternum and the lipophilicity of amiodarone.
- Puga T, Montez D, Philbeck T, Davlantes C. Adequacy of intraosseous vascular access insertion sites for high-volume fluid infusion. *Crit Care Med* 2016;44(12 Suppl):143** 821
- This study was completed on 30 healthy subjects to evaluate infusion rates via the sternum (SIO) and proximal humerus (PH) sites under 300 mmHg via pressure bag. The mean SIO infusion rate was $9,587 \pm 2,706 \text{ mL/hr}$ ($n=27$); mean PH infusion rate was $6,292 \pm 3,277 \text{ mL/hr}$ ($n=52$). There were no serious complications; minor complications were 5 cases of excess pain, 2 cases vagal response, and mammary tissue engorgement. The mean PH flow rate was significantly lower than that of SIO, but placing IO catheters in each humeri with simultaneous infusion could result in fluid delivery of $13,000 \text{ mL/hr}$, surpassing that of the sternum. This study was sponsored by Teleflex Incorporated.
- Puga TA, Montez DF, Davlantes C, Miller LJ, Philbeck TE. Swine study shows no intramedullary effects of power-injected contrast media using intraosseous access. *J Vasc Access* 2016;17(4):e16** 785
- A preclinical study evaluating the immediate effects of power injected contrast media on the medullary space of anesthetized swine. Contrast media (150 mL) was administered at a rate of 5 mL/second. For each limb receiving power injection a control limb was submitted for evaluation. The pathologist was blinded to which limb received power injection. Results showed no histological difference in limbs receiving and not receiving power injection. This study was sponsored by Teleflex Incorporated.

Intraosseous Vascular Access Bibliography

Emergency Care

- Ramirez JG, Truszewski Z, Drozd A. Comparison of two intraosseous access devices employed during simulated cardiopulmonary resuscitation. *Disaster Emerg Med J* 2016;1(1):24-9. doi:10.5603/DEM.J.2016.0004** 857
- A study comparing use of the Bone Injection Gun (B.I.G.) and the NIO by paramedics in a manikin model simulation of CPR. Following training, 40 paramedics performed device insertion in the manikin using both devices; and completed a questionnaire regarding their knowledge of indications and contraindications of IO access and experience with each device. Successful insertion was achieved 100% with the NIO and 95% with the B.I.G. Authors concluded that after a short training program, paramedics can perform intraosseous injection with a high degree of efficacy.
- Riess ML. New developments in cardiac arrest management. *Adv Anesth* 2016;34(1):29-46.** 849
<http://dx.doi.org/10.1016/j.aan.2016.07.003>
- This article reviews the best practices for optimal cardiac arrest management, echoing the 2015 ACLS guidelines. Intraosseous vascular access is identified as an access route for delivery of pharmacological agents to aid in patient management.
- Ross EM, Mapp J, Kharod CU. Time to epinephrine in out-of-hospital cardiac arrest: A retrospective analysis of intraosseous versus intravenous access. *Ann Emerg Med* 2016;68(4S):S61** 811
- This retrospective study evaluated 3 years of data in an urban EMS system to determine if out-of-hospital intraosseous (IO) access results in shorter time to epinephrine than peripheral intravenous (PIV) access. The proximal humerus was the most common IO access site with a first pass IO success rate of 95.6%; and a significantly lower complication rate when compared to the tibia. Authors reported the time to epinephrine administration was faster in the IO access group; and concluded the out-of-hospital use of IO vascular access for time-dependent medical conditions is recommended.
- Savell S, Mora AG, Perez CA, Bebarta VS, Maddry JK. En route intraosseous access performed in the combat setting. *Am J Disaster Med* 2016;11(4):225-31. doi:10.5055/ajdm.2016.0243** 847
- A retrospective study evaluating vascular access routes used for US Military personnel injured in combat and transported by MEDEVAC. Medical records were reviewed for intravenous (IV) and intraosseous (IO) use including, number of attempts and rates of success; along with events occurring in transit, hospital and ICU stays and 30 day outcomes. Results showed IV and/or IO access was attempted in 832 patients. PIV was first line of attempt in 758 cases with 93% success; IO access was first line of attempt in 74 cases with 85% success. There were 25 attempts to establish IO as the second line of access with 100% successful placement. Success rates were 100% with tibia (29); 94% with humerus (21/22); and 89% with the sternum (41/46). The overall IO success rate was 88% for all attempts made.
- Schwindt J. Intraosseous access- Of no value in neonatal resuscitation? *Resuscitation* 2016;103:e1.** 853
<http://dx.doi.org/10.1016/j.resuscitation.2016.01.037>
- In this letter to the editor, the author calls into question the continued recommended use of the umbilical venous catheter in neonatal resuscitation by the European Resuscitation Council and the lack of intraosseous vascular access recommendation. The author makes the argument that accessing the umbilical vein is difficult for even the most experienced NICU clinicians and that time cannot be spared in these resuscitations; and intraosseous access can provide a viable option for drug delivery.
- Smereka J, Madziala M, Szarpak L. Are firefighters able to perform intraosseous access and start fluid resuscitation in an anaphylactic patient. *Am J Emerg Med* 2016;34(8):1707-8. doi: 10.1016/j.ajem.2016.05.068** 851
- This letter to the editor describes a simulation study evaluating use of the NIO device by 47 firefighters in a simulated anaphylactic shock model. The firefighters were trained on use of the device and standard anaphylactic shock management. An improvement in knowledge of intraosseous vascular access and anaphylactic shock protocol was demonstrated by the group.
- Smith S, Borgkvist B, Kist T, Annelin J, Johnson D, Long R. The effects of sternal intraosseous and intravenous administration of amiodarone in a hypovolemic swine cardiac arrest model. *Am J Disaster Med* 2016;11(4):271-7. doi:10.5055/ajdm.2016.0249** 830
- A pre-clinical study comparing the effects of IV and sternal IO administered amiodarone in a swine cardiac arrest model. Following 2 minutes of cardiac arrest, CPR was initiated and after an additional 2 minutes, amiodarone was administered via sternal IO or IV access. Blood samples were collected over 5 minutes. Results showed no statistical difference between routes for return of spontaneous circulation (ROSC), time to ROSC, T-max, or C-max. The authors concluded sternal IO route provides rapid and reliable access to administer life-saving medications during cardiac arrest.
- Strong D, Powell E, Tilney PVR. A 20-year-old-male with hemorrhagic shock. *Air Med J* 2016;35(1):8-11.** 803
<http://dx.doi.org/10.1016/j.amj.2015.10.003>
- This case study describes the medical management of a 20 year old male post high-speed motor vehicle crash with multitrauma and in shock upon air medical team arrival. Care entailed aggressive airway support, bilateral chest decompressions, management of potential pelvic bleeding with a pelvic binder, one peripheral IV through which packed red blood cells and plasma were given and one proximal humerus IO through which 1 g tranexamic acid (TXA) was given.
- Szarpak L, Ramirez JG, Buljan D, Drozd A, Madziala M, Czyzewski L. Comparison of Bone Injection Gun and Jamshidi intraosseous access devices by paramedics with and without CBRN person protective equipment. A randomized, crossover, manikin trial. *Am J Emerg Med* 2016;34(7):1307-8. doi:10.1016/j.ajem.2016.04.032** 843
- A manikin study in which 40 paramedics dressed with and without CBRN PPE attempted to establish tibial intraosseous (IO) access using the jamshidi and BIG devices, time to placement was measured. Results showed that in participants with and without CBRN PPE, BIG access was faster than Jamshidi.

Intraosseous Vascular Access Bibliography

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- Szarpak L, Truszcwski Z, Fudalej M, Krajewski P. The intraosseous access devices as a method of vascular access during cardiopulmonary resuscitation. *Am J Emerg Med* 2016;34(2):321-2. doi:10.1016/j.ajem.2015.11.013** 804
Letter to the editor supporting use of the proximal humerus for IO access during CPR.
- Szarpak L, Truszcwski Z, Smereka J, Krajewski P, Fudalej M. Ability of paramedics to perform intraosseous access. A randomized cadaver study comparing EZ-IO and NIO devices. *Resuscitation* 2016;104:e5-e6. doi:10.1016/j.resuscitation.2016.04.011** 795
This letter to the editor describes a prospective, randomized, cross-over cadaveric study that evaluated use of the EZ-IO and NIO devices by novice paramedic device users. Following a brief in-service on use of both devices and practice insertions using a leg-trainer manikin, each participant attempted to establish IO access using each device in a resuscitation simulation with in an adult cadaver with CPR in progress. Results showed first attempt success rates of 97.4% with the NIO and 100% with the EZ-IO; and mean time to insertion was 16.8 seconds with the NIO and 42 seconds with the EZ-IO.
- Uwaydah NI, Hoskins SL, Bruttig SP, et al. Intramuscular versus intraosseous delivery of nerve agent antidote pralidoxime chloride in swine. *Prehosp Emerg Care* 2016;20(4):485-92. doi:10.3109/10903127.2014.942479** 842
A preclinical study comparing delivery of nerve agent antidote when administered via intramuscular (IM) and proximal tibia intraosseous (IO) routes, in normovolemic and hypovolemic swine. IO and IV administration of the antidote achieved and surpassed therapeutic levels in normovolemic groups; time to therapeutic level with IM was 2 minutes versus 15 seconds with IO access. Combined administration via IO route initially, followed by IM injection 60 minutes post IO injection resulted in therapeutic levels for a prolonged time, most closely mimicking standard hospital care of poisoned patients. The authors concluded the rapid increase in plasma concentrations, coupled with the sustainability of the drug in plasma supported advantages of IO over IM delivery.
- Vallier DJ, Torrence AD, Stevens, III R, Arcinue PN, Johnson D. The effects of sternal and intravenous vasopressin administration on pharmacokinetics. *Am J Disaster Med* 2016;11(3):203-9. doi:10.5055/ajdm.2016.0240** 841
A preclinical study comparing the maximum concentration (Cmax), time to maximum concentration (Tmax) when administering vasopressin via intravenous (IV) and sternal intraosseous (SIO) access in a cardiac arrest swine model. Anesthetized swine were put into cardiac arrest, after 2 minutes CPR was initiated for 2 minutes, then 40 units of vasopressin was administered via IV or SIO route. Results showed no significant difference in SIO and IV groups for Cmax or Tmax.
- Wilson J, Passmore A, Leger S, Lannan J, Bentley M, Johnson D. Effects of tibial intraosseous and intravenous administration of Hextend on tiem of administration and hemodynamics in a hypovolemic swine model. *Am J Disaster Med* 2016;11(3):193:201. doi:10.5055/ajdm.2016.0239** 836
A preclinical study comparing administration of Hextend via IV and tibial intraosseous (IO) access routes for time for administration and hemodynamic measures in a hypovolemic swine model. Following exsanguination, 500 mL of Hextend was administered via both routes; a control group received no Hextend. Hemodynamic measures data were collected every 2 minutes for 8 minutes. The mean time for administration in the IV group was 10 minutes 16 seconds (\pm 2 minutes 47 seconds), and for the IO group it was 10 minutes 12 seconds (\pm 1 minutes 36 seconds). There was no significant difference in systolic blood pressure, diastolic blood pressure, mean arterial pressure, cardiac output, and stroke volume.
- Wimmer MH, Heffner K, Smithers M, et al. The comparison of humeral intraosseous and intravenous administration of vasopressin on return of spontaneous circulation and pharmacokinetics in a hypovolemic cardiac arrest swine model. *Am J Disaster Med* 2016;11(4):237-42. doi:10.5055/ajdm.2016.0245** 827
A preclinical study comparing IV and humeral intraosseous (IO) access administration of vasopressin in a hypovolemic swine model in cardiac arrest. Following exsanguination, the swine were placed in cardiac arrest for 2 minutes, then resuscitated for 2 minutes in accordance with ACLS guidelines. Vasopressin was administered. Blood samples were collected at various time points following vasopressin injection and analyzed for maximum concentration (Cmax) and time to maximum concentration (Tmax) between groups; return of spontaneous circulation was also captured. ROSC was achieved for all HIO subjects (n=7) and in seven out of eight IV subjects; mean time to ROSC was 9.8 minutes for HIO and 10.7 for the IV group. However, statistically there was no significant difference between HIO and IV administration of vasopressin for achievement of ROSC, time to ROSC, Cmax, Tmax, concentration over time, survivability, or odds ratio.
- Wong MR, Reggio MJ, Morocho FR, et al. Effects of intraosseous epinephrine in a cardiac arrest swine model. *J Surg Res* 2016;201(2):327-33. doi:10.1016/j.jss.2015.11.015** 776
Preclinical study that examined the differences in pharmacokinetics and pharmacodynamics of tibial IO (TIO) and IV-delivered epinephrine during cardiac arrest and CPR. There were no significant differences between IV versus TIO epinephrine in achieving ROSC, time to ROSC, and Cmax. In the context of ROSC, epinephrine delivered via TIO route was a clinically relevant alternative to IV administration. The authors concluded that when IV access cannot be immediately obtained in cardiac arrest patients, TIO access should be considered.
- Woodhart B, Shaw J. A study to determine the EZ-IO intraosseous infusion system success rate, including impact on return of spontaneous circulation. *Emerg Med J* 2016;33:e5. doi: 10.1136/emered-2016-206139.19** 1034
This is an abstract of a study conducted in the UK to determine the success rate of the EZ-IO Intraosseous Infusion System on return of spontaneous circulation (ROSC). Patient records were examined for 195 cardiac arrest patients who had an EZ-IO placement attempt. ROSC was achieved for 29% of patients. In patients who received IV administration of medications, 46% achieved ROSC. While IV access appears more favorable in this study, there may be other factors associated with achieving ROSC that were not taken into account.

Intraosseous Vascular Access Bibliography

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YEAR: 2015

- Anson JA, Sinz EH, Swick JT. The versatility of intraosseous vascular access in perioperative medicine: a case series. *J Clin Anesth* 2015;27(1):63-7. <http://dx.doi.org/10.1016/j.jclinane.2014.10.002>** 729
- This article presents a 5-case series describing use of IO vascular access by anesthesiologists in the perioperative and critical care settings. All insertions were made in the proximal tibia and there were no adverse events reported. The devices cited as being used were the EZ-IO and the Cook Surfast manual needle. A proposed perioperative vascular access algorithm incorporating IO access is presented. The authors address key topics around IO access including use of same drug dosing as IV administered drugs, frequent palpation and monitoring of the insertion site for extravasation, low complication rate and actual risks associated with fat emboli and bone injury, pain and anxiety management in the awake patient and clinician-perceived pain. Administration of blood products, ACLS drugs, Lactated Ringer's solution and anesthetics are noted without complication. Use of IO aspirate for laboratory testing is noted, however use of the initial aspirate is indicated. Several patients in the case series were reported to find the discomfort of IO insertion preferable to multiple intravenous attempts. The authors concluded: IO lines can be placed quickly and safely in emergency situations or in elective surgical patients with difficult intravenous access; IO access can be useful in a wide variety of clinical settings; and is an important skill for anesthesiologist to learn.
- Chatfield-Ball C, Boyle P, Autier P, van Wees SH, Sullivan R. Lessons learned from the casualties of war: Battlefield medicine and its implication for global trauma care. *J R Soc Med*. 2015;108(3):93-100. doi: 10.1177/0141076815570923** 965
- This analysis examines the current state of military trauma in high-income countries and how these developments could be applied to low/middle-income countries to help deliver affordable trauma care there. Intraosseous needles are identified as a key technology especially when working in a moving environment or on a bumpy road which would likely be encountered in a low/middle-income country. Under such circumstances normal cannulation would likely fall out, whereas an IO needle would remain in place.
- Chico-Fernández M, Terceros-Almanza L, Mudarra-Reche C. Innovation and new trends in critical trauma disease. *Med Intensiva (English Edition)* 2015;39(3):179-88. doi:10.1016/j.medine.2015.03.002** 907
- This article discusses the trends in management of critical trauma disease (CTD) in the military combat and civilian setting. Authors of the article discuss the need in ongoing innovations in the management of trauma patients in ICUs. In order to achieve more innovations there is a need for improvement in the following areas: methodology in emergency care medicine, increased knowledge in resuscitation strategies, study of epidemiology of trauma disease and its effect on patient outcomes, application of methodologies for ensuring correct trauma care team performance.
- Chreiman KM, Kim PK, Garbovsky LA, Schweickert WD. Blueprint for implementing new processes in acute care. *J Trauma Nurs* 2015;22(5):266-73** 793
- This article describes the strategies used at one hospital (Penn Presbyterian Medical Center) to increase the use of intraosseous catheter to rescue patients in all care settings.
- Eriksson M, Strandberg G, Lipcsey M, Larsson A. Troponin I can be determined in intraosseous aspirates in a porcine shock model. *Clin Lab* 2015;doi:10.7754/Clin.Lab.2015.141212** 758
- A preclinical study in which 8 anesthetized swine were put into an induced septic shock state to allow troponin I level measurements to be compared from serial venous plasma, arterial plasma and intraosseous aspirate specimens collected hourly. Two milliliters of IO aspirate were wasted before collecting each IO specimen for analysis. The levels of IO troponin I increased during the first 3 hours of shock but then plateaued at a high level while the venous and arterial levels continued to increase. Authors concluded that troponin I can be analyzed in bone marrow aspirates in a shock model and that this information may be useful in medical emergencies where cardiac damage is suspected to be involved.
- Ewy G, Bobrow B, Chikani V et al. The time dependent association of adrenaline administration and survival from out-of-hospital cardiac arrest. *Resuscitation* 2015;96:180-85. doi:10.1016/j.resuscitation.2015.08.011** 919
- This article discusses a retrospective analysis of data collected to investigate the possible time-dependent outcomes associated with adrenaline administration by personnel with Emergency Medical Services (EMS). Primary endpoint was survival to hospital discharge and positive neurological outcome. The study included 3,469 patients with out of hospital cardiac arrest (OHCA). Study concluded patients with OHCA that had been treated early with adrenaline and had a shockable rhythm had a survival rate to hospital discharge.
- Goldschalt C, Doll S, Ihle B, Kirsch J, Mutzbauer TS. Peripheral venous or tibial intraosseous access for medical emergency treatment in the dental office? *Br Dent J* 2015;281(9):E16. doi: 10.1038/sj.bdj.2015.384** 869
- This paper describes a cadaver study that evaluated the ability of dental students to successfully place peripheral venous catheters and tibial intraosseous (IO) catheters using the Vidacare/Teleflex EZ-IO. Success rates, as well as insertion times, were recorded. 29% of venous and 83% of IO placements were successful. Successful venous access was achieved in an average of 163 seconds and IO access was achieved in an average of 30 seconds. Investigators concluded that chances to perform successful vascular access for inexperienced dentist may be higher when using tibial IO for emergency vascular access compared to when using IV catheters.
- Haider AH, Piper LC, Zogg CK, et al. Military-to-civilian translation of battlefield innovations in operative trauma care. *Surgery* 2015;158(6):1686-95. doi: 10.1016/j.surg.2015.06.026** 870
- This paper describes a survey of trauma military directors that suggested that military data supporting damage control resuscitation has altered civilian practice. Among those practices are the use of intraosseous vascular access

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- Helm M, Haunstein B, Schlechtriemen T, Ruppert M, Lampl L, . Gäßler M. EZ-IO® intraosseous device implementation in German Helicopter Emergency Medical Service. *Resuscitation* 2015;88:43-7. doi: 10.1016/j.resuscitation.2014.12.015.** 737
- Retrospective analysis of IO needle insertions performed in all HEMS missions during the first three years (2009-2011) using the EZ-IO® system. Overall success rate of EZ-IO procedures (N=348) was 99.6%, with a first attempt success rate of 85.9%; and high user satisfaction rate of 93%. IO as access was mostly second line overall but first line in children <7, trauma and cardiac arrest. There was one failure and four needle insertion problems noted; no serious complications.
- Germany
- Hill SL, Thomas SHL, Flecknell PA, et al. Rapid and equivalent systemic bioavailability of the antidotes HI-6 and dicobalt edetate via the intraosseous and intravenous routes. *Emerg Med J* 2015;32(8):626-31. doi: 10.1136/emermed-2014-204171** 751
- A preclinical study evaluating the bioavailability of antidotes HI-6 oxime and dicobalt edetate when given via proximal tibia intraosseous (IO) access, established via the EZ-IO, compared to intravenous administration via central access in minipigs. Results showed rapid and similar systemic bioavailability of the antidotes when given by both routes and that IO access is an appropriate access route when IV access is impractical.
- Johnson D, Garcia-Blanco J, Burgert J, et al. Effects of humeral intraosseous versus intravenous epinephrine on pharmacokinetics and return of spontaneous circulation in a porcine cardiac arrest model: A randomized control trial. *Ann Med Surg* 2015;4(3):306-10. doi:10.1016/j.amsu.2015.08.005** 802
- Prospective preclinical study by to determine the effects of humeral IO (HIO) and IV epinephrine administration during cardiac arrest on pharmacokinetics, ROSC, and odds of survival. There were no significant differences in ROSC, maximum concentration; except at 30 s, and time-to-concentration-maximum between the HIO and IV groups. Significant differences existed between the experimental groups and the control. The HIO delivered a higher concentration of epinephrine than the IV route at 30 s, which they noted may be a survival advantage. Authors suggested clinicians consider using the IO route to administer epinephrine when IV access is unobtainable.
- Ker K, Tansley G, Beecher D, et al. *Cochrane Database Syst Rev* 2015;2:CD011386. doi: 10.1002/14651858.CD011386.pub2. Comparison of routes for achieving parenteral access with a focus on the management of patients with Ebola virus disease. *Cochrane Database Syst Rev* 2015;2:CD011386. doi: 10.1002/14651858.CD011386.pub2** 878
- This systematic review compared the reliability, ease of use and speed of insertion of different parenteral access methods with focus on relieving dehydration associated with the Ebola virus disease. Authors found that, compared to the intraosseous group, patients in the intravenous group were more likely to experience an insertion failure.
- Lantos D, Goforth D. Intraosseous needles reduce time to first medication for coding inpatients without intravenous access. *Crit Care Nurse* 2015;35(2):e69** 948
- This abstract describes data from a small hospital study after a 2013 policy change which allowed rapid response team nurses to place IO access for in-hospital cardiac arrests. Prior to the change the mean time to first medication was 4.3 minutes with 53.1% patients surviving to ICU. Post-policy change patients that received IO access had a mean time to medication of 1.7 minutes and 85.7% survival to ICU.
- Lee PMJ, Lee C, Rattner P, Wu X, Gershengorn H, Acquah S. Intraosseous versus central venous catheter utilization and performance during inpatient medical emergencies. *Crit Care Med* 2015;doi: 10.1097/CCM.0000000000000942** 762
- This single center, prospective, observational clinical study compared use of intraosseous (IO) access to central venous catheter (CVC) access for inpatient medical emergencies, managed by the medical emergency team (MET), within an urban teaching hospital. CVC access training included percutaneous, landmark-guided CVC placement without ultrasound guidance, using the femoral vein as the primary site. For IO access, the proximal tibia was the primary site and proximal humerus was secondary. Results showed IO access was significantly superior to CVC access with regard to first pass success rates, overall success rates, time to placement, and number of attempts for proper placement. On average more CVC kits were used per patient; complications were greater with CVC. There was one serious complication of tissue necrosis secondary to extravasation in the IO group.
- Link MS Berkow LC, Kudenchuk PJ, et al. Part 7: Adult advanced cardiovascular life support 2015 American Heart Association guidelines update for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care *Circulation* 2015;132(Suppl 2):S444-S464. DOI: 10.1161/CIR.0000000000000261** 950
- The 2015 updated ACLS guidelines considered a number of issues regarding cardiovascular life support; however there were no changes to those recommendations made in the 2010 guidelines in regard to intraosseous access. The 2010 guidelines stated in regard to IO drug delivery, "it is reasonable for providers to establish IO access if IV access is not readily available (Class IIa, LOE C)."
- Means L, Gimbar RP. Prothrombin complex concentrate administration through intraosseous access for reversal of rivaroxaban. *Am J Emerg Med* 2015;34(3):685.e1-2. doi:10.1016/j.ajem.2015.07.057. doi: 10.1016/j.ajem.2015.07.057** 765
- This paper describes a case study of a 64 year old man who presented to the ED with symptoms of bleeding related to rivaroxaban and clopidogrel. Due to concern for bleeding, low BP, and perceived difficulty in IV access, IO access was obtained. After access the patient experienced significant pain and was unable to tolerate large volume administration through the IO site. The patient was successfully treated with prothrombin complex concentrate (PCC), which has a smaller volume when compared to blood products. This was the first reported case of IO PCC administration.

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- Monsieurs KG, Nolan JP, Bossaert LL, et al. European Resuscitation Council Guidelines for Resuscitation 2015 Section 1. Executive summary. Resuscitation 2015;95: 1-80** 952
- This article summarizes the main updates to the 2015 ERC Guidelines for Resuscitation of adults and pediatric patients. In reference to intraosseous (IO) vascular access, the guidelines state: IO access is a "rapid, safe, and effective route to give drugs, fluids and blood products"; and recommend consideration of the IO route when peripheral venous access is difficult.
- Montez DF, Puga T, Miller L, et al. Intraosseous infusions from the proximal humerus reach the heart in less than 3 seconds in human volunteers. Ann Emerg Med 2015;66(4s):S47. <http://dx.doi.org/10.1016/j.annemergmed.2015.07.165>** 771
- In a healthy adult volunteer study contrast media was injected through the proximal humerus site and captured under fluoroscopy as it entered the heart. The mean time it took from injection at the insertion site to visualize contrast entry into the superior vena cava and the right atrium was 2.42 seconds. Abstract presented at ACEP 2015. This study was sponsored by Teleflex Incorporated.
- Northey LC, Shiraev T, Omari A. Salvage intraosseous thrombolysis and extracorporeal membrane oxygenation for massive pulmonary embolism. J Emerg Trauma Shock 2015;8(1):55-7** 929
- This is a case report of a 34 year old female with bilateral peripheral pulmonary emboli with bibasal consolidation and pleural effusions. Due to difficulty with establishing peripheral access, IO access was established in the proximal tibia and Alteplase was administered through the line. Central venous and arterial access were ultimately obtained, and extracorporeal membrane oxygenation (ECMO) was initiated. The patient ultimately recovered and was discharged from the hospital after 36 days. The authors noted that the combination of IO thrombolysis and ECMO for treatment of acute massive PE has not been previously reported and highlights the importance of appropriate access for administration of pharmacotherapy in the critically ill patient.
- Overbaugh R, Davlantes C, Miller L, Montez D, Puga T, Philbeck TE. Intraosseous vascular access catheter appears safe during extended dwell: a preliminary report. Ann Emerg Med 2015;66(4):S5** 772
- Abstract describing preliminary results for the first 24 subjects of an EZ-IO study evaluating catheter dwell times for 48 hours. Initial data indicate that IO vascular access can be safely maintained for a period up to 48 hours without risk of osteomyelitis or other serious adverse events. Authors also noted that additional analgesics for IO infusion pain management may be more effective than the current solely administering lidocaine into the IO space. This study was sponsored by Teleflex Incorporated.
- Overbey JK, Kon AA. Dermal abrasion experienced as an adverse effect of the EZ-IO. J Emerg Med 2016;50(1):e7-10. doi: 10.1016/j.jemermed.2015.09.003.** 753
- This article presents a case report of a 7 month old female who received intraosseous vascular access via the EZ-IO in the distal femur that resulted in a dermal abrasion where the needle hub contacted the skin. The wound healed without significant complication however the scar at the IO site persisted at 11 months post the event. The authors recommend that providers use the minimal force necessary when operating the EZ-IO to avoid similar adverse events.
- Paterson ML, Callahan CW. The use of intraosseous fluid resuscitation in a pediatric patient with ebola virus disease. J Emerg Med 2015;49(6):962-4. <http://dx.doi.org/10.1016/j.jemermed.2015.06.010>** 796
- Case study of 9-month-old patient (approximate weight 7 kg) presented with Ebola Virus Disease (EVD) and severe dehydration. IO access was obtained using a 15 g Jamshidi device to the right proximal tibia. A total bolus of 280 mL of lactated ringers solution was infused; then the IO infusion continued for 12 hours until an IV could be established. Authors stated it is important for emergency disaster responders, as well as their responding organizations, to know and understand that IO access is an important and safe modality to use in patients with EVD, and in the austere settings often found in disaster settings.
- Paxton J, Wilburn J, Ottolini J, Sherwin R. Does the choice of initial vascular access device delay cardiac arrest resuscitation? Crit Care Med 2015;43(12 Suppl):46. doi: 10.1097/01.ccm.0000474007.72329.42. abstract 179** 862
- This abstract describes pilot data regarding initial vascular access device use in emergency department management of patients with out-of-hospital cardiac arrest. Twenty-six patients were included, and only 10 arrived to the ED with venous access established in the field: 4 via intraosseous and 6 via peripheral IV. Of the 16 subjects without access upon ED arrival, PIV was selected for 12 and IO was selected for 4. Nine patients experienced a delay in obtaining access attributed to the selection of PIV as the initial mode of gaining access. Median time required for access was reported as: 50 seconds for IO; 95 seconds for PIV and 780 seconds for CVC. The authors concluded that selection of PIV as the initial access method may be associated with delayed vascular access in the ED.
- Paxton JH, Ottolini J, Wilburn JM, Sherwin RL, Courage C. Does the choice of vascular access device delay appropriate emergency department resuscitation of adult out-of-hospital cardiac arrest patients? Ann Emerg Med 2015;66(4s):s35** 924
- This abstract describes a pilot observational study of vascular access devices (VAD) and their use in management of 20 out of hospital cardiac arrest patients. VAD selected, number of attempts for successful placement and time to insertion were recorded. Twenty patients were included in this study, 10 of whom received IO access upon ED arrival.

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- Paxton JH, Ottolini J, Wilburn JM, Sherwin RL, Courage C. Does the choice of vascular access device delay appropriate emergency department resuscitation of adult out-of-hospital cardiac arrest patients? *Ann Emerg Med* 2015;66(4s):s35** 863
- An abstract describing preliminary data evaluating the effect of initial vascular access device selection on the management of out-of-hospital cardiac arrest (OOHCA) patients by the ED. Twenty patients were included. Success rate by vascular access device selected was: 66% IO lines (2/3); 25% for PIV lines (3/12); and 100% for CVC (1/1). Eight patients experienced a delay in access due to initial method selected, 7 were attributed to PIV and 1 to IO. The authors concluded that the results suggest use of PIV as the initial mode of access may be associated with delays in access when compared to IO access in patients with OOHCA.
- Pifko EL, Busch C, Price A, et al. An observational review of pediatric intraosseous needle placement in the pediatric emergency department. *Ann Emerg Med* 2015;66(4s):S87** 754
- A retrospective study evaluating attempts to establish intraosseous vascular access in pediatric patients using a manual device and the EZ-IO, in a tertiary care pediatric emergency department. Results showed 35 patients had IO access attempted using manual and EZ-IO devices. In patients greater than and less than 8kg the EZ-IO had a higher success rate but time to placement was longer. Overall success rate including both devices was 64%. There were 2 complications of transient leg swelling after EZ-IO placement in 2 patients.
- Puga T, Hanes MA, Miller LJ, et al. Intramedullary effects of power-infused contrast by intraosseous access. *Ann Emerg Med* 2015;66(4s):s95** 786
- A preclinical study evaluating the immediate effects of power injected contrast media on the medullary space of anesthetized swine. Contrast media (150 mL) was administered at a rate of 5 mL/second. For each limb receiving power injection a control limb was submitted for evaluation. The pathologist was blinded to which limb received power injection. Results showed no histological difference in limbs receiving and not receiving power injection. This study was sponsored by Teleflex Incorporated.
- Reuter-Rice K, Patrick D, Kantor E, Nolin C, Foley J. Characteristics of children who undergo intraosseous needle placement. *Adv Emerg Nurs J* 2015;37(4):301-7. doi:10.1097/TME.0000000000000077** 854
- A retrospective study evaluating the use of pre-hospital and emergency department placed IO access in children before transport to a children's hospital. Data were extracted from a Level 1 trauma, tertiary care children's hospital transport database from 1993-2009. There were 143 eligible patients with an average transport distance of 33 miles; all but 8 catheters were placed by the ED. The most common reasons for IO placement were no IV access (53%) and no perfusion (33.6%); the most commonly reported complication was infiltration (27.3%); 46.9% of patients experienced no complication. The authors concluded IO access plays a significant role in promoting life-saving efforts when IV access is unachievable or no perfusion is determined.
- Rottenstreich M, Malka I, Glassberg E, Schwartz O, Tarif B. Pre-hospital intra-osseous freeze dried plasma transfusion: a case report. *Disaster and Military Medicine* 2015;1(8):1-3** 935
- Case report of a 13 year old girl suffering from severe hemorrhagic shock due to blast injuries and gun shot wounds that received freeze-dried plasma via IO access as part of prehospital resuscitative efforts. Her vital signs improved upon arrival to the hospital; and she was released after 3 weeks of hospitalization.
- Salzman J, Burnett A, Frascione R, et al. Intraosseous pressure monitoring in critically ill and injured patient. *Crit Care Med* 2015;43(12 Suppl):abstract 183:47. doi: 10.1097/01.ccm.0000474011.25695.a8** 848
- A pilot study evaluating the relationship between intraosseous (IO) pressure measurements and blood pressure obtained via external blood pressure cuff in ICU patients. Patients with IO access established by EMS or in the emergency department with planned admission to the ICU or surgical ICU were included in the study. External pressures were recorded every 15 minutes and IO pressure was monitored via a transducer for 12 continuous hours. Results showed IO pressures were approximately 30% of external blood pressure cuff readings.
- Sampson CS, Bedy S-M. Lipid emulsion therapy given intraosseously in massive verapamil overdose. *Am J Emerg Med* 2015;33(12):1844.e1.doi: 10.1016/j.ajem.2015.04.061** 767
- A case study report of a 24-year old female who presented to the emergency department after consuming an over dose amount of verapamil. Central and peripheral venous access were obtained for delivery of vasopressors and intravenous fat emulsion 20% (IFE). IFE was initiated via peripheral IV (PIV) access but access was lost; administration through central access was not possible due to the potential drug interaction. Intraosseous (IO) access was established using the Arrow EZ-IO system in the proximal tibia without complication and IFE administration was resumed. The patient reported some pain with infusion. After half the bolus administration was delivered, the infusion pump alarmed due to inadequate flow. PIV access was obtained and IFE administration was resumed using the newly obtained access route. The authors suggested that the viscosity of the medication may have caused the delivery failure by infusion pump through the IO route and recommend slowing down the bolus rate of infusion for clinicians attempting this route for IFE administration in the future.
- Seghatchian J, Putter JS. Advances in transfusion science for shock-trauma: optimizing the clinical management of acute haemorrhage. *Transfus Apher Sci* 2015;53(3):412-22. http://dx.doi.org/10.1016/j.transci.2015.11.012** 852
- This review article describes various protocols for haemorrhage control, specifying routes of access, including intraosseous vascular access infusion rates and volumes of various transfusion fluids.

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- Stimac J, Paxton J. The "Golden Hour" of volume resuscitation: Pilot data from the shock access for emergent resuscitation (SAFER) study. *Ann Emerg Med* 2015;66(4s):S110** 1010
- This abstract describes a study (SAFER) reporting initial emergency department efforts in obtaining adequate vascular access (AVA) and initiating appropriate fluid resuscitation for hypovolemic patients with undifferentiated hypotension within the first 60 minutes following ED arrival. AVA was defined as any two of the following: PIV, IO, or CVC catheter. No data was given regarding time to IO access in the results
- Suominen PK, Nurmi E, Lauerma K. Intraosseous access in neonates and infants: risk of severe complications- a case report. *Acta Anaesthesiologica Scandinavica* 2015;59(10):1389-93. doi: 10.1111/aas.12602** 769
- This case study describes a neonate who suffered a cardiac arrest, had return of spontaneous circulation (ROSC) and was treated with multiple medications and therapeutic hypothermia. The patient had received three IO needle insertions, one in the left tibia that was removed following swelling with bolus injection; one in the left distal femur that dislodged with movement of the patient's legs; and one in the right proximal tibia. Twenty-four hours after initial IO needle placement the child developed pallor and discoloration and was diagnosed with compartment syndrome to the right lower extremity. Five days post-IO insertion a below the knee amputation was performed. Medications infused via the IO access included epinephrine and norepinephrine infusions.
- Ventura AMC, Shieh HH, Bousso A, et al. Double-blind prospective randomized controlled trial of dopamine versus epinephrine as first-line vasoactive drugs in pediatric septic shock. *Crit Care Med* 2015;43(11):2292-302. doi:10.1097/CCM.0000000000001260** 840
- This article describes a prospective double-blind randomized controlled study evaluating the difference between use of dopamine and epinephrine as first-line vasoactive drug in pediatric septic shock patients. This study conducted in the pediatric intensive care unit (PICU) of Hospital Universitario da Universidade de Sao Paulo, Brazil. One hundred twenty-one patients aged 1 month to 15 years who met criteria were randomized to receive either epinephrine (n=57) or dopamine (n=63) via IV or intraosseous (IO) vascular access (via EZ-IO). The authors concluded dopamine was associated with an increased risk of death and healthcare-associated infection; whereas administration of epinephrine via IV or IO routes was associated with increased survival.
- YEAR: 2014**
- Barnard EBG, Moy RJ, Kehoe AD, Bebarta VS, Smith JE. Rapid sequence induction of anesthesia via the intraosseous route: a prospective observational study. *Emerg Med J* 2014;32(6):449-52. doi:10.1136/emmermed-2014-203740** 702
- A prospective observational study that evaluated use of intraosseous vascular access for delivery of rapid sequence intubation (RSI) drugs. Data was collected between January and May 2012 at a combat hospital in Afghanistan. Thirty-four (34) patients underwent RSI with drug delivery via the IO route. Access was established in the proximal humerus and tibia using the EZ-IO and in the sternum using the FAST-1. All placements were successful on first attempt; first pass intubation success rate was 97%; a Cormack-Lehane (C-L) laryngoscopic grade view of 1 was reported 91%. Authors concluded that IO access is a safe and feasible route for delivery of anesthetic drugs for RSI.
- Bebarta VS, Vargas TE, Castaneda M, Boudreau S. Evaluation of extremity tissue and bone injury after intraosseous hypertonic saline infusion in proximal tibia and proximal humerus in adult swine. *Prehosp Emerg Care* 2014;doi:10.3109/10903127.2014.912704** 697
- Randomized comparative study of adult pigs infused intraosseously with either: 7.5% hypertonic solution (HTS), 3% HTS or normal 0.9% isotonic saline. The animals were observed daily for infection, necrosis and gait up to 5 days, then necropsy and histological analysis was performed for tissue necrosis. Observations included regular tissue morphology and normal gait scores over the 5 day observation period; and absence of gross tissue necrosis and microscopic ischemia post IO HTS infusion in this swine model. Authors concluded this study confirms the clinical safety of IO HTS infusion and its use as an alternative lifesaving treatment.
- Chansa E, Kansen K, Gustafsson B. [An intraosseous blood transfusion in a critically ill child] Une transfusion sanguine par voie intraosseuse chez un enfant gravement malade. *Afr J Emerg Med* 2014;4(2):83-5. https://doi.org/10.1016/j.afjem.2013.05.003** 658
- This article describes a case study of a 31-month old infant that suffered hypovolemic shock due to severe epistaxis. After several failed peripheral and central line attempts an 18g needle was inserted intraosseously through the proximal tibia. The child received 300 mL of Ringer's Lactate in one hour then 200 mL of blood via the IO route by syringe boluses resulting in improvement. Cloxacillin was also administered IO as prophylaxis for infection. Authors conclude an IO blood transfusion should be the immediate intervention in similar life-threatening situations.
- Zambia*
- Cheung WJ, Rosenberg H, Vaillancourt C. Barriers and facilitators to intraosseous access in adult resuscitations when peripheral intravenous access is not achievable. *Acad Emerg Med* 2014;21:250-6. doi:10.1111/acem.12329** 705
- This survey study sought to identify the barriers and facilitators to use of intraosseous vascular access for adult resuscitations when peripheral IV (PIV) access is not available, among physicians from various clinical care settings in 3 teaching hospitals in Ottawa, Ontario. Completed survey responses were received from 205 physicians; results suggest that to increase IO use educational interventions need to address their attitudinal, normative, and control beliefs. Specific beliefs that act as barriers are described.
- Canada*

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- Dawes J, Ramnarayan P, Lutman D. Stabilisation and transport of the critically ill child J Intensive Care Med 2014;15(1):34-42. doi:10.1177/175114371401500108.** 912
- The focus for the article is the need for early recognition and stabilization of a critically ill child presenting to local hospital and how hospitals admitting critically ill children must be able to resuscitate and stabilize the child prior to transferring to another hospital. The article discusses the initial assessment and resuscitation when a critically ill child presents to a local hospital and the pediatric transport process and the importance of communication between all teams. The article also discusses the need for clinicians working with critically ill children need to be properly trained and be able to maintain those skills.
- Egyptian Pediatric Association Gazette. Hot topics in neonatology: Lecture given at the EPA's national conference-1.1.10. Vascular access. Egypt Pediatr Assoc Gazette 2013;61:92-5. http://dx.doi.org/10.1016/j.epag.2013.11.007** 707
- This article identifies new concepts and changes in neonatal resuscitation discussed at the Egyptian Pediatric Association national conference. Intraosseous vascular access is included stating, "temporary intraosseous access to provide fluids and medication to resuscitate critically ill neonates may be indicated following unsuccessful attempts to establish intravenous vascular access or when caregivers are more skilled at securing intraosseous access."
- Egypt
- Fischer H, Bachmann K, Strunk G, et al. Translation of ERC resuscitation guidelines into clinical practice by emergency physicians. Scand J Trauma Resusc Emerg Med 2014;22:9. doi:10.1186/1757-7241-22-9** 708
- The objective of this study was to use a competency exam to compare different emergency skills and knowledge between out of hospital emergency physicians (OOHEP) and those who are not OOHEP at the time of their mandatory biannual refresher courses. Results from 836 respondents suggested that OOHEP are significantly more likely to initiate intraosseous access, initiate mild-therapeutic hypothermia, and had higher knowledge about the used defibrillator.
- Austria
- Johnson D, Dial J, Ard J, et al. Effects of intraosseous and intravenous administration of Hextend on time of administration and hemodynamics in a swine model. J Spec Oper Med 2014;14(1):79-85** 713
- A preclinical study comparing intraosseous (IO) and intravenous (IV) administration of Hextend in 27 swine for time of administration and hemodynamics. IO access was established in the proximal humerus using the EZ-IO. Results showed time for administration was not significant; there were no significant differences between IV and IO relative to hemodynamics. The author concluded that the IO route is an effective method of administering Hextend
- Khilani A, Mazwi M, Paquette ET. Pediatric sepsis in the global setting. Clin Pediatr Emerg Med 2014;15(2):193-203** 725
- This discussion of pediatric sepsis focuses on the "global setting" making note of inherent differences in policies, diagnostics, causes and management approach between regions. A review of basic assessment, treatment, follow-up and prevention strategies applicable regardless of resources is offered. Goal directed therapy within the first 5 minutes includes establishment of IV/IO access.
- Kurowski A, Timler D, Evrin T, Szarpak T. Comparison of three different intraosseous access devices for adults during resuscitation: randomized cross-over manikin study. Am J Emerg Med 2014;32:1490-3. DOI: http://dx.doi.org/10.1016/j.ajem.2014.09.007** 739
- Manikin study conducted in Poland with 107 paramedic operators designed to investigate the success rate, time of insertion and perceived difficulty of intraosseous access devices during simulated resuscitation using the EZ-IO, Bone Injection Gun and Jamshidi needles. Results were first attempt success: B.I.G.: 91.59%; EZ-IO: 82.66%; Jamshidi: 47.66%; mean procedure time: B.I.G.: 2.0 min ± 0.7; EZ-IO: 3.1 min ± 0.9; Jamshidi: 4.2 min ± 1.0; and ease of use (1-very easy to 5-very hard): B.I.G.: 1.83; EZ-IO: 2.92; Jamshidi: 4.68.
- Poland
- Lewis P, Wright C. Saving the critically injured trauma patient: a retrospective analysis of 1000 uses of intraosseous access. Emerg Med J 2014;31(9):784. doi:10.1136/emermed-2014-203588** 714
- This retrospective study reported IO use over a 7-year period during combat operations in Afghanistan by the UK Defence Medical Services. The EZ-IO and FAST1 IO devices were available for use; IO use data was collected from the front line, during helicopter evacuation and at the combat hospital. A total of 1014 IO devices were inserted into 830 adult patients; various medications infused via IO access are listed. Across all cases there were no serious IO complications and 14 minor complications. The author concluded that in the pre-hospital setting in particular and in severely injured trauma patients, IO access should be considered a primary method of obtaining vascular access.
- Lingner M, Niederer O, Majolk J, Kromholz K. Kasuistik: Die intraossäre Infusion als Alternative in der Sepsistherapie beim Erwachsenen [Case report: Intraosseous infusion as an alternative solution in the therapy of septicemia in an adult]. Anasthesiol Intensivmed Notfallmed Schmerzther. 2014;49(2):100-3. doi:10.1055/s-0034-1368674** 698
- Case study of 36 year-old in septic shock with co-morbidities of IV drug abuse, endocarditis, tricuspid valve insufficiency and pulmonary embolism. Initially impossible to obtain PIV or CVC access; then unable to give desired fluids through 22 gauge PIV when finally placed. Proximal humerus IO access was established with the EZ-IO 45 mm needle set and the patient was resuscitated with 30 mL/kg fluids and multiple medications given in first hour. Conclusions included that CVCs are not always possible and volume treatment with an IO placed sooner rather than later, especially in children but also in adults, can be lifesaving. IO systems should be extensively available throughout the clinical setting. Article in German.
- Germany

Intraosseous Vascular Access Bibliography

Emergency Care

- Lottenberg L, Lovato L, Bloch S, Puga T, Philbeck T. The proximal humerus may be a viable site for contrast injection using a power infuser for CT exam. Crit Care Med. 2014;42(12):abstract 1075.** 759
- This abstract describes the results of an observational clinical study that evaluated the use of IO vascular access via the proximal humerus insertion site for administration of contrast media for computed tomography examination. Eight subjects were enrolled into the study, 7 procedures were performed successfully with adequate opacification of the images. One subject experienced extreme pain with the contrast injection, the procedure was terminated and an alternative vascular access route was utilized. There were no serious complications reported. This study was sponsored by Teleflex Incorporated.
- Loughren M, Banks S, Naluan C, Portenlanger P, Wendorf A, Johnson D. Onset and duration of intravenous and intraosseous Rocuronium in swine. West J Emerg Med 2014;XV(2):241-5** 721
- A preclinical study comparing the time to onset, time to onset peak, and time to recovery of peripheral intravenous and tibial intraosseous administration of Rocuronium. Study results demonstrated there was no statistical difference from the time of administration to complete neuromuscular blockade between the IO and IV administration of Rocuronium; and the recovery of neuromuscular function was significantly longer after IO administration, however was not deemed clinically significant. The authors concluded that Rocuronium can effectively be used via the IO route without the need for dose adjustments.
- Martin Reyes B, Abolafia del Balazo R, Estepa Sanchez A, Garcia Cazalilla M, camara Anguita S, Rojas Jimenez AM. Emergencies medical services: intraosseous drill in CPR. Resuscitation 2014;85(S):S24** 715
- This abstract describes an observational study evaluating use of the intraosseous drill (EZ-IO) in 20 patients assisted by EMS and receiving CPR within a 3 year period. The study includes 4 pediatric and 16 adult patients. The authors concluded that IO access is a reliable alternative to peripheral venous access and can be implemented fast and with high success rate of CPR in which drugs and fluids are given.
- Spain*
- Montez D, Puga T, Garcia M, et al. Lactate levels in venous and intraosseous blood correlate; prothrombin time/INR levels do not. Aca Emerg Med 2014;21(5)Suppl:S304.** 773
- In a series of studies using healthy adult volunteers the objective was to add to available data comparing IO marrow/blood (initial 1 mL aspirate), IO blood (subsequent aspirate), and venous and capillary blood to determine if there is a correlation between samples for serum lactate and PT/INR levels. Two point-of-care analysers were used. Conclusions were lactate levels obtained from IO blood appear comparable to lactate levels from venous blood; the PT/INR levels did not correlate. This study was sponsored by Teleflex Incorporated.
- Oesterlie GE, Petersen KK, Knudsen L, Henriksen TB. Crural amputation of a newborn as a consequence of intraosseous needle insertion and calcium infusion. Ped Emerg Care 2014;30(6):413-4** 699
- Case study of newborn girl resuscitated with 15 mm EZ-IO catheter placed to her right proximal tibia. Medications given included antibiotics, "fluids" and calcium. Demarcation of the infants skin was noted immediately post-calcium administration; with progression to necrosis. Trans-tibial amputation was performed 1.5 months after initial IO access. Authors concluded calcium extravasation most likely caused the injury but were unable to identify extravasation cause; citing possible needle displacement. Cautionary steps to reduce risk emphasized by authors.
- Denmark*
- Puga T, Montez D, Davlantes C, et al. Whole blood transfusion via IO access does not result in gross hemolysis in a pre-clinical study. Crit Care Med 2014;42(12):A1421. abstract 251** 760
- In this pre-clinical study, 18 units of blood were transfused into 10 anesthetized swine via intraosseous (IO) access. Venous specimens were collected to evaluate free hemoglobin levels as an indicator of hemolysis. Seventeen transfusions were given via the proximal humerus site and 1 via the proximal tibia, using a pressure bag set to 300 mmHg. Mean transfusion flow rate was 61.6 ± 37.3 mL/min and the mean blood volume transfused was 266 ± 74 mL (n=18). The authors concluded that blood transfusion via IO access resulted in high flow rates and did not result in appreciable hemolysis as indicated by free hemoglobin values. This study was sponsored by Teleflex Incorporated.
- Rush S, D'Amore J, Boccio E. A review of the evolution of intraosseous access in tactical settings and a feasibility study of a human cadaver model for a humeral head approach. Mil Med 2014;179(8 Suppl):24-8. doi: 10.7205/MILMED-D-13-00484** 726
- This article explores use of IO vascular access in combat and tactical settings through a brief review of the literature describing this practice. A small feasibility study is discussed that evaluated the use of cadavers for training 26 U.S. Air Force Pararescuemen (PJs) on establishing IO access in the humeral head (proximal humerus is the descriptor used by EZ-IO for this site) using the EZ-IO powered driver and needle set system (pictured in the article) and needles inserted with a manual driver without power. First attempt placement success with the EZ-IO powered driver system was achieved in 25 of 26 attempts; first attempt placement success using the manual driver and needle set occurred in 19 of 21 attempts. The authors concluded that the humeral head (proximal humerus) IO site is the most appropriate site within the tactical setting; and that use of a human cadaver model for training is an appropriate model.
- Schlimp CJ, Solomon C, Keibl C, et al. Recovery of fibrinogen concentrate after intraosseous application is equivalent to the intravenous route in a porcine model of hemodilution. J Trauma Acute Care Surg 2014;76(5):1235-42** 717
- A preclinical study comparing the recovery of fibrinogen in a porcine model when fibrinogen concentrate is administered via IV and IO access. The study results suggested intraosseous administration of fibrinogen concentrate results in a recovery of fibrinogen similar to that of intravenous administration.

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Emergency Care

- Sheils M, Ross M, Eatough N, Caputo ND. Intraosseous access in trauma by air medical retrieval teams. *Air Med J* 2014;33(4):161-4** 718
- This article explores the use of IO access in the prehospital setting to determine if IO access is sufficient for massive fluid resuscitation in trauma patients or if central venous cannulation should be considered. Massive transfusion is defined as 10 units of blood within 24 hours at a rate of more than 150 mL/minute. Through a review of the literature the authors determine that IO access is rapid with a high success rate, IO access allows a bridge to initiate resuscitation while minimizing on scene delays, and has a low complication profile, all benefits over central venous cannulation.
- Australia
- Swaney PM, Nayman BD, Cabanas JG, Myers JB. Fatal myocardial ischemia in a 12-year-old secondary to fibromuscular dysplasia. *Am J Emerg Med* 2014;32(7):812.e5-7. doi:10.1016/j.ajem.2013.12.027** 693
- A case study report describing a 12-year-old male who expired following a fatal myocardial ischemia. The patient complained of severe chest pains within the week prior to the event and was misdiagnosed as having GERD. ECG by first responders showed STEMI; IO access was established in the PT for vascular access.
- Vassallo J, Horne S, Smith JE. Intraosseous access in the military operational setting. *J R Nav Med Serv* 2014;100(1):36-9** 794
- This article describes a prospective, observational study conducted March – July 2011 at the emergency department, Camp Bastion, Afghanistan evaluating use of IO access in 117 patients established using the EZ-IO and the FAST1 devices (76% EZ-IO).
- Vincent-Lambert C, Carpenter AP. Factors affecting the frequency of vascular access via intraosseous cannulation performed by paramedics in Johannesburg. *J Vasc Access* 2014;15(6):503-6. doi:10.5301/jva.5000263** 838
- A questionnaire and interview study evaluating the reasons paramedics do not perform intraosseous (IO) vascular access more frequently. Twelve paramedics in Johannesburg, South Africa were interviewed for the study. Results suggested access to inappropriate equipment (pink hypodermic needles), inadequate training, lack of use in hospital Emergency Departments to which they serve, and the perceived invasiveness of the procedure and pain caused during infusion dissuaded paramedics from performing the procedure.
- West B, Jule M, Prescott N, Labond VA, Zettek K, Foland W. Out-of-hospital intraosseous versus intravenous access in return of spontaneous circulation. *Ann Emerg Med* 2014;64(4s):S70-1** 797
- Abstract reporting on retrospective prehospital study to evaluate the rate of out-of hospital return of spontaneous circulation (ROSC) in the cardiac arrest patient. The following were assessed and analyzed for direct or indirect correlation on ROSC; dispatch time to arrival, number of intravascular attempts per method (IV versus IO) and rate of success. Conclusions were that ROSC can be achieved more rapidly when IO access is used as the first attempt method in obtaining vascular access in prehospital cardiac arrest. There was a trend in shorter ROSC times among the first attempt IO group compared to the IV group; the difference did not reach statistical significance, most likely due to a lack of power from the smaller sample size of the IO group.
- Winkler M, Talley C, Landwehr K, et al. Use of intraosseous needles for power injection of iodinated contrast media for emergency computed tomography angiography. *J Cardiovasc Comput Tomogr* 2014;9th annual scientific meeting abstracts:S76-7** 701
- Abstract presented at the Society of Cardiovascular Computed Tomography on preliminary findings of an observational study done after training ER physicians and techs on intraosseous (IO) catheter use and implementation of a policy for IO access use. Authors report high injection rates and excellent computed tomography angiography (CTA) scans safety with use of an IO for power injection of iodinated contrast media (ICM). Authors concluded cardiovascular imaging physicians, surgeons, ER physicians, and CT technologists should be familiar with the techniques of IO needle placement and use for power injection of ICM for CTA. The diagnosis and treatment of critically ill and unstable patients may be hastened by this technique.
- Young SW, Zhang M, Freeman JT, Mutu-Grigg J, Pavlou P, Morre GA. The Mark Coventry Award: Higher tissue concentrations of vancomycin with low-dose intraosseous regional versus systemic prophylaxis in TKA. *Clin Orthop Relat Res* 2014;472(1):57-65. doi:10.1007/s11999-013-3038-z** 620
- This randomized, controlled study compared tissue concentrations at the surgical site of regionally and systemically administered prophylactic vancomycin, in 30 patients undergoing total knee arthroscopy. The antibiotic was administered using three methods: 250mg through IO regional administration in the proximal tibia (IORA); 500mg through IORA; and 1g administered systemically through IV. Results showed the tissue concentration of vancomycin was greater in the 250mg IORA group than the systemic IV group, and the 500mg IORA group had higher concentrations than both groups.
- YEAR: 2013**
- Ahrens KL, Reeder SB, Keevil JG, Tupesis JP. Successful computed tomography angiogram through tibial intraosseous access: a case report. *J Emerg Med* 2013;45(2):182-5. doi: 10.1016/j.jemermed.2012.11.091** 632
- Case report of 54-year-old male obtunded patient requiring a CT angiogram to diagnosis a suspected massive pulmonary embolism. After several failed attempts to reestablish PIV access, 150mL of contrast were injected through the proximal tibia IO catheter placed by EMS. Excellent opacification of the pulmonary arteries was achieved and there were no immediate complications from the injection noted.

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Emergency Care

- American Academy of Pediatrics. Joint policy statement - guidelines for care of children in the emergency department. J Emerg Nurs 2013;39(2):116-27** 648
Reprint article of policy statement originally published 2009, endorsed by multiple professional societies providing guidelines for care of children in the emergency department. A recommendation for IO equipment in adult and pediatric sizes is included.
- Bloch SA, Bloch AJ, Silva P. Adult intraosseous use in academic Eds and simulated comparison of emergent vascular access techniques. Am J R Emerg Med 2013. <http://dx.doi.org/10.1016/ajem.2012.11.021>** 652
In a letter to the editor this study reports data collected (during a survey of one third of academic emergency medicine programs in the U.S.) regarding IO use in adults and comparing IO access with other vascular access techniques through simulation. Data suggest that IOs were used less than 5% of the time patients needed emergent access and a peripheral line was unobtainable. The EZ-IO was most often used IO device. Authors conclude IO use should be considered more frequently in critical, unstable patients. (This research was presented at the ACEP Research Forum in 2010).
- Byars DV, Tsuchitani SN, Yates J, Knapp B. A multijurisdictional experience with the EZ-IO intraosseous device in the prehospital setting. Am J Emerg Med 2013;31(12):1712-3. doi: 10.1016/j.ajem.2013.08.056** 656
This letter to the editor describes a prospective, observational, trial that evaluated use of the EZ-IO in critically ill and injured patients (adult and pediatric) in a multijurisdictional prehospital setting; 9 EMS agencies were included. The 25mm needle set was the only needle size allowed for the study. One-hundred-eleven EZ-IO placements were performed by EMT-Intermediates and EMT-Paramedics with 96 successful placements (86.5%); the most common cause for failure reported by the author was thought to be patient obesity and inadequate needle length. Cardiac arrest patients made up 74.7% of the study population and the most common site accessed was the proximal tibia. Device operators rated the ease of use 7.87 using a 0 to 10 scale where 10=extremely easy.
- Cleugh FM, Maconochie IK. Management of the multiply injured child. Paediatrics and Child Health 2013;23(5):194-9** 659
General overview of care of a child with multiple trauma. IO vascular access is mentioned as a treatment option after 90 seconds or 3 failed PIV attempts. The B.I.G. is cited as an option along with the manual needles.
- d'Heurle A, Archdeacon MT. Compartment syndrome after intraosseous infusion associated with a fracture of the tibia. The Journal of Bone and Joint Surgery, Incorporated Case Connect 2013;3(1):e20. <http://dx.doi.org/10.2106/JBJS.CC.L.00231>** 651
Case study of adult multi-trauma patient that had an intraosseous device placed to a fractured left tibia and developed compartment syndrome. Authors concede it is unclear if the fluid infused through the IO device caused the compartment syndrome or if it was due to the multiple-fractures in the tibia. Authors advise against placing an IO line in an injured limb and mention the proximal humerus and sternum as alternative IO sites.
- Dolister M, Miller S, Borron S, et al. Intraosseous vascular access is safe, effective and costs less than central venous catheters for patients in the hospital setting. J Vasc Access 2013;14(3):216-24. doi:10.5301/jva.5000130** 583
An observational clinical study evaluating use of the EZ-IO in patients requiring urgent vascular access that would have otherwise received a central venous catheter due to a lack of other options. One hundred five (105) patients were enrolled across five hospitals. The authors concluded that use of IO access in place of CVCs provides time savings, safety, ease of use, and is effective at significant cost savings; IO access may be used as a bridge to CVC placement under optimal conditions; and IO access may be used to replace use of CVCs all together in selective patients. This study was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.
- Erdmann L, Doll S, Ihle B, Kirsch J, Mutzbauer TS. Evaluation of the sternal intraosseous route as alternative emergency vascular access for the dental office: a manikin and cadaver model pilot study. Oral Surg Oral Med Oral Pathol Oral Radiol 2013;116(6):686-91** 657
This article describes a mannequin and cadaver study that evaluated use of the EZ-IO sternal device and the Illinois needle to establish sternal IO vascular access by dental students. Results of the cadaver study showed two cases of perforation of the posterior sternal cortex when the Illinois needle was used and one EZ-IO insertion in the soft tissue without entering the IO space. The authors concluded use of the EZ-IO sternal device with the insertion site template and scalpel incision may be more efficient and less predisposed to complication than use of the Illinois needle.
- Fenchel DD, Myers LA, Arteaga GM, Russi CS. Chart analysis of frequency and complications from intraosseous infusion in out-of-hospital pediatric and adult populations. Ann Emerg Med 2013;62(4S):S104** 663
A retrospective study that evaluated use of IO access by one EMS system whose patients were transported to a level 1 trauma center over a period of 64 months. Results showed 140 IO attempts were made with 130 successful placements (92.9%); there were no long term complications.
- Fetissov H, Nadaud J, Landy C, Millot I, Paris R, Plancade D. Amines on intraosseous vascular access: A case of skin necrosis. Ann Fr Anesth Reanim 2013;32(5):e89-90.<http://dx.doi.org/10.1016/j.annfar.2013.02.022>** 644
A letter to the editor reporting a case study of skin necrosis after IO administration of norepinephrine following resuscitation of a 74 years old in septic shock. The EZ-IO was placed to the proximal tibia; approximately 45 minutes post- norepinephrine administration symptoms of necrosis were evident. Authors cite 3 hypotheses for the cause of necrosis and consider that amines' high level concentration could induce local toxicity in the bone matrix and artery spasm; suggesting it is necessary to define an upper limit of amines' concentration that should be administered through IO vascular access.

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- Frascone RJ, Salzman JG, Bliss P, Adams A, Wewerka SS, Dries DJ. Decreasing intraosseous pressure and increasing respiratory variability track fluid volume reduction in a porcine hypovolemia model. *Ann Emerg Med* 2013;62(4S):S14** 666
A pre-clinical study that evaluated use of intraosseous (IO) pressure as an indicator of changes in fluid volume status during a hemorrhagic shock protocol. Central venous and arterial pressures were used as comparators. Results showed IO pressure decreased consistently during the controlled shock protocol. Authors concluded IO pressure appears to be equivalent to CVP as an indicator of fluid volume status. This study was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.
- Frascone RJ, Salzman JG, Ernest EV, Burnett AM. Use of an intraosseous device for invasive pressure monitoring in the ED. *Am J of Emerg Med* 2014;32(6):692.e3-692.e4.doi:10.1016/j.ajem.2013.12.029** 667
A case study describing intraosseous pressure monitoring, through tibial IO access, using a standard arterial pressure monitoring transducer during resuscitation of a 31-year-old male in cardiac arrest. Pressure readings were recorded for approximately 53 minutes and were compared to non-invasive blood pressure cuff monitoring at the same time points. IO systolic, diastolic and mean IO pressures were approximately 40% of arterial pressures. This is the first case report demonstrating IO space has a measureable blood pressure and it correlates with pressure obtained through conventional techniques.
- Grossman V. Hot Topics: CT contrast and intraosseous lines: friends or enemies? *J Radiol Nurs* 2013; 32(1):41-4. <http://dx.doi.org/10.1016/j.jradnu.2012.12.004>** 643
General discussion on use of the intraosseous vascular access route for infusion of CT contrast, with attention to clinical considerations pertinent to nurses working in the imaging suite. Author also reviews general IO principles and IO devices.
- Hafner JW, Bryant A, Huang F, Swisher K. Effectiveness of a drill-assisted intraosseous catheter versus manual intraosseous catheter by resident physicians in a swine model. *Western J Emerg Med* 2013;XIV(6):629-32** 668
This is a preclinical study comparing the EZ-IO and the Cook manual IO needle when used by 21 resident physicians to establish IO access in anesthetized swine. Results showed the drill-assisted needle was successfully placed 100% of attempts vs 76.2% successful placement with manual; time to placement and user preference also favored the EZ-IO. Technical issues reported included bending of the manual needle 33% of attempts.
- Hallas P, Brabrand M, Folkestad L. Complication with intraosseous access: Scandinavian users' experience. *West J Emerg Med* 2013;14(5):440-3. doi:10.5811/westjem.2013.1.1200** 669
A questionnaire study in which Scandinavian emergency physicians, anesthesiologist and pediatricians reported complications they have experienced with IO vascular access based on recollection alone. Complications were reported related to establishing IO access and using established IO access. Out of 1,802 IO cases reported by 386 responders, the most frequently reported complications included difficulty with periosteum penetration and bone marrow aspiration when establishing IO access; and slow infusion and needle displacement with established IO access. Osteomyelitis and compartment syndrome were reported with an occurrence of 0.4% and 0.6%. Researchers concluded that potential complications following IO insertion should be addressed during training. Devices discussed included the EZ-IO, BIG, Cook-Surfast, and other unidentified IO devices
Denmar
- Hamed RK, Hartmans S, Gausche-Hill M. Anesthesia through an intraosseous line using an 18-gauge intravenous needle for emergency pediatric surgery. *J Clin Anesth* 2013;25(6):447-51;pii: S0952-8180(13)00202-X. doi: 10.1016/j.jclinane.2013.03.013.<http://dx.doi.org/10.1016/j.jclinane.2013.03.013>. Accessed September 3, 2013** 670
This 30 pediatric patient case series describes use of IO access in the perioperative setting when peripheral and central venous access failed during anesthesia administration for emergency surgery. Due to unavailability of modern IO devices, a standard 18-gauge IV needle with a handmade IV extension set were used to establish IO access. The authors reported administering ketamine, succinylcholine, pancuronium, atracurium, halothane, neostigmine, atropine, blood products, fluids and hydrocortisone through the IO line without complication. The authors concluded that although it is not the first-line method for anesthesia, IO access should be considered by pediatric anesthesiologist when peripheral and central venous access has failed or is difficult.
Iraq
- Harris M, Balog R, Devries G. What is the evidence of utility for intraosseous blood transfusion in damage-control resuscitation? *J Trauma Acute Care Surg* 2013;75(5):904-6. doi:10.1097/TA.0b013e3182a85f71** 671
This article explores the use of IO access for blood product administration and whether or not it is clinically effective. Based upon lack of clinical evidence and physics principles, the author argues that maximum flow rates attainable for IO blood infusion are not adequate for resuscitation.
- Helm M, Richter D, Schramm A, Lampl L, Hossfeld B.. Ist die intraossare punktion ein alternativer gefabzugang beim notfall in der zahnarztlichen praxis? *Notfall Rettungsmed* 2013;16:27-32. Doi:10.1007/s10049-012-1629-y. German** 612
This article in German explores use of intraosseous access in a dental practice emergency. In a simulation study, dental students attempted to establish standard peripheral IV access and IO access using 3 different devices: EZ-IO, BIG, and manual IO. Results showed the manual was the fastest to insert, however, the EZ-IO had the highest first-attempt success rate as well as the lowest number of total attempts to IO access.
German

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Emergency Care

- Junkin R, Litchfield K. Intraosseous vascular access skill acquisition in labour ward staff: results of a training programme. *Int J Obstet Anesth* 2013;22(1):S31** 674
- This abstract describes a study in which 66 obstetric anesthetists, obstetricians and midwives were training on the EZ-IO and evaluated for successful application of the skill in a mannequin study. The participants also completed a survey following their insertion attempt regarding their perceived ease of use and likelihood to consider IO use in the future. Results showed first attempt success was 95.5%; respondents indicated they found the EZ-IO to be easier than establishing PIV access and 100% indicated they would consider IO use in the future.
- UK
- Junkin R, Selfridge J, Litchfield. Intraosseous vascular access in obstetric emergencies: an OAA approved national survey. *Int J Obstet Anesth* 2013;22(1):S31** 673
- This abstract describes the results of an online survey taken by members of the Obstetric Anaesthetists' Association, evaluating use of IO access in obstetric emergencies, and availability of IO equipment on UK labor wards. Results showed many members are trained on IO access, consider it a viable option during emergencies however have limited access to equipment.
- UK
- Kim S. Intraosseous access: an important clinical procedure for emergency physicians. *Lifeline* 2013;June:12-3** 647
- Article featured in June 2013 issue of California's ACEP monthly newsletter. This article discusses general IO principles with examples of several short case reviews and highlights the EZ-IO.
- Lairet J, Beberta V, Lairet K, et al. A comparison of proximal tibia, distal femur, and proximal humerus infusion rates using the EZ-IO intraosseous device on the adult swine (*Sus scrofa*) Model. *Prehosp Emerg Care* 2013;17:280-4. Doi:10.3109/10903127.2012.755582** 642
- Pre-clinical study comparing flow rates achieved after insertion with the EZ-IO in the proximal tibia, distal femur, and proximal humerus in a swine model. IO catheters were placed in each site and normal saline was infused for 10 minutes using a pressure bag at the highest achievable pressures greater than 300mmHg. The flow rates through the proximal humerus were statistically greater than that of the femur or proximal tibia. The femur flow rates were higher than the proximal tibia but similar. Post-mortem histopathologic evaluations done to assess for damage due to the high infusion pressures were consistent with IO catheter placement.
- Lewis GC, Crapo SA, William JG. Critical skills and procedures in emergency medicine- vascular access skills and procedures. *Emerg Med Clin N Am* 2013;31(1):59-86. doi: 10.1016/j.emc.2012.09.006** 631
- This article provides an overview of various vascular access modalities in emergency medicine including peripheral IV, venous cut-down, central venous catheter, intraosseous access, umbilical vessel access, and arterial access. The anatomy and physiology, indications and contraindications, procedure steps and special considerations are outlined for each access methods discussed.
- Lyon RM, Donald M. Intraosseous access in the prehospital setting-Ideal first-line option or best bailout? *Resuscitation* 2013;84:405-406. <http://dx.doi.org/10.1016/j.resuscitation.2013.01.027>** 615
- Editorial reviewing a case series of EZ-IO use in the pre-hospital setting in Switzerland by Santos et al., combined with a literature review. The authors conclude IO access should probably be used selectively and training on its use improved, insertion sites should be compared and further investigation of use of the EZ-IO in major trauma patients, infusing blood components, use in infants, and application of training warrant further investigation.
- Mittiga MR, Geis GL, Kerrey BT, Rinderknecht AS. The spectrum and frequency of critical procedures performed in a pediatric emergency department: Implications of a provider-level view. *Ann Emerg Med* 2013;61(30):263-70. doi.org/10.1016/j.annemergmed.2012.06.021** 588
- This retrospective study evaluated the number and type of critical procedures, including IO line placement, performed in the ED of a tertiary care pediatric institution over a 12 month period. The authors concluded that critical procedures were rarely performed in a large academic pediatric ED; pediatric emergency medicine faculty are at significant risk for skill deterioration; and fellows are unlikely to achieve competence in performing critical procedures.
- Montez DF, Puga TA, Garcia MR, et al. Intraosseous blood correlates with venous blood in healthy subjects using point-of-care analyzers. *Ann Emerg Med* 2013;62(4S):S40** 676
- A clinical study evaluating the relationship between IO blood and peripheral venous blood lactate levels analyzed using the i-STAT point-of-care analyzer in healthy volunteers. Results showed IO blood lactate levels were comparable to venous blood lactate levels with a positive statistical correlation. This study was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.
- Morton R, Krakover B, Hudson T, Alexander B. Casualty evacuation: an innovative role for emergency nurses. *J Emerg Nurs* 2013;39(6):576-80** 677
- This article describes the role of the casualty evacuation nurse role within the military. One case study briefly notes the use of proximal tibia IO access and the administration of packed red blood cells in a 22-year-old woman. No further follow up is provided other than noting the patients were expected to survive.

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Emergency Care

- Myers LA, Arteaga GM, Kolb LJ, et al. Prehospital peripheral intravenous vascular access success rates in children. *Prehosp Emerg Care* 2013;17(4):425-8. doi: 10.3109/10903127.2013.818180** 1000
- This retrospective review of medical records submitted by paramedics identified patients 18 years or younger who had prehospital peripheral IV (PIV) attempts. Over 101 months at least 1 PIV attempt was made on 4188 patients ≤18 years old. The study demonstrated that success rates are significantly associated with patient age and each 1 year increase in age increased the odds of successful PIV placement by 11%. The authors suggest that IO access with the use of a semiautomatic IO device (EZ-IO) may be a more efficient first-line method for immediate treatment after 1 PIV access failure, especially in younger patients given their higher rate of PIV insertion failure.
- Oksan D, Ayfer K. Powered intraosseous device (EZ-IO) for critically ill patients. *Indian Pediatr* 2013;50(7):689-91** 685
- A retrospective chart review evaluating use of the EZ-IO in 25 pediatric patients between July 2008 and August 2010 at a Turkish university affiliated hospital. All attempts were made in the proximal tibia and IO access was attempted following failed PIV access within 60 seconds. First attempt success was 80%; the most reported complication was simple extravasation (3 cases) and needle dislodgement (1 case).
Turkey
- Plancade D, Millot I, Fetissov H, et al.. Sternal perforation with an intraosseous device and hemomediastinum infusion *Ann Fr Anesth Reanim* 2013;http://dx.doi.org/10.1016/j.annfar.2013.01.009** 616
- A 45-year-old woman in hemorrhagic shock with multiple injuries to the limbs, secondary to a war wound, received sternal IO access using the Jamshidi trocar (not specifically intended for sternal use). After initiating a blood transfusion through the IO line a contrast CT scan revealed sternal perforation and hemomediastinum, secondary to the transfusion, as well as drainage into the left pleural cavity. The catheter was removed, right thoracic drainage was performed, and the patient was released from ICU 48 hours later. The authors conclude this case report demonstrates the difficulty in selecting emergency insertion sites and the necessity of choosing an appropriate IO catheter.
- Pozza M, Lunardi F, Pflipsen M. Emergency intraosseous access: a useful, lifesaving device use in Afghanistan. *J Spec Oper Med* 2013;13(1):25-8** 684
- A case study describing use of the EZ-IO in Afghanistan by US military on 5 patients with traumatic injury including one pediatric patient. Access was obtained in the proximal tibia on first attempt and was used to administer crystalloids in all patients along with opioids, analgesics and antibiotics. All ultimately received central venous access and peripheral access was established in one patient. There were no IO complications.
- Reinhardt L, Brenner T, Bernhard M, et al. Four years of EZ-IO system in the pre- and in-hospital emergency setting. *Central European Journal of Medicine* 2013;8(2):166-71. Doi:10.2478/s11536-012-0125-6** 618
- An observational study evaluating use of the EZ-IO by two ground and one air based physician staffed EMS and at a German surgical university hospital between January 1, 2008 and December 31, 2011. The EZ-IO was used to establish IO access 88 times in 87 patients; 83 insertions were performed in the EMS and 5 were performed in the hospital. The proximal tibia was the primary site used (97.7%) and the first attempt success rate was 94%. IO access was the first approach for vascular access in children compared to adults (38.9% vs. 86.2%). There were 5 failures attributed to missed insertions or extravasation and 2 for wrong needle length. There were no serious complications.
- Reiter DA, Strother CG, Weingart SD. The quality of cardiopulmonary resuscitation using supraglottic airways and intraosseous devices: a simulation trial. *Resuscitation* 2013;84:93-7. doi:10.1016/j.resuscitation.2012.07.003** 586
- A simulation study evaluating if use of a laryngeal mask airways (LMA) and intraosseous (IO) lines established using the EZ-IO leads to improved resuscitation in a simulated cardiac arrest when compared to standard endotracheal intubation and central line placement. Results showed mean time to airway, mean duration of airway attempt, and time to vascular access was shorter in the IO group than the CVL group. Time to defibrillation and percent hand off time was not significantly different between the groups.
- Santos D, Carron PN, Yersin B, Pasquier M. EZ-IO intraosseous device implementation in a pre-hospital emergency service: a prospective study and review of the literature. *Resuscitation* 2013;84(4):440-5. http://dx.doi.org/10.1016/j.resuscitation.2012.11.006** 604
- An observational study evaluating use of the EZ-IO in a Swiss pre-hospital EMS system between January 1, 2009 and December 31, 2011 and comparing those results to the literature. Sixty IO insertions were performed on 58 patients; the proximal tibia was used in all attempts except 1 attempt made in the proximal humerus. Overall success rate was 90%; the 6 failures were attributed to impossibility to infuse, difficult needle insertion, and incorrect insertion site (tibial plateau). Some of the indications for IO access included cardiorespiratory arrest, major trauma, and shock; general anesthesia was successfully induced in 7 patients. Drugs infused are listed. There were no serious complications.
- Sherren PB, Burns B. Prehospital blood transfusion: 5-year experience of an Australian helicopter emergency medical service [abstract P295]. *Critical Care* 2013;17(S2):S112. doi: 10.1186/cc12233** 1019
- This is an abstract of a study that analyzed prehospital missions of the Greater Sydney Area Helicopter Emergency Medical Service (GSA-HEMS) involving a blood transfusion, with IO administration recorded as one possible route of administration. The study determined that the carriage and use of blood is both feasible and safe in a physician-led helicopter emergency medical service.

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- Sherren PB, Hayes-Bradley C, Reid C, et al. Are physicians required during HEMS winch rescue missions [abstract P282]? Critical Care 2013;17(S2):S106. doi: 10.1186/cc12220** 1018
- This is an abstract of a study that analyzed the mission profiles and interventions performed during rescues involving the winching of a physician in the Greater Sydney Area Helicopter Emergency Medical Service (GSA-HEMS). A structured case-sheet for a predetermined list of physician-only interventions (POI) was conducted, of which IO access was an intervention. The study showed a high rate of POI thus supporting the winching of physicians.
- Soto F, Murphy A, Heaton H. Critical procedures in pediatric emergency medicine. Emerg Med Clin N Am 2013;31:335-76. http://dx.doi.org/10.1016/j.emc.2012.09.003** 623
- An overview of pediatric emergency medicine and critical procedures. One of the key points noted: intraosseous vascular access can be used in all ages.
- Souchtchenko SS, Benner JP, Allen JL, Brady WJ. A review of chest compression interruptions during out-of-hospital cardiac arrest and strategies for the future. J Emerg Med 2013. http://dx.doi.org/10.1016/j.jemermed.2013.01.023** 624
- This article reviews the clinical effects of both high-quality chest compressions and the effects that interruptions during chest compressions have clinically on patient outcomes. The authors indicate intraosseous vascular access should be heavily considered as the first or at least second-line method used to help prevent prolonged compression interruptions for the purpose of establishing vascular access. The authors note that when using the EZ-IO this method of access is fast, effective, can handle all resuscitation fluids, and can minimize no flow time when used properly.
- Spencer TR. Intraosseous administration of thrombolytics for pulmonary embolism. J Emerg Med 2013;45(6):e197-e200. http://dx.doi.org/10.1016/j.jemermed.2013.05.057** 682
- A case report describing administration of thrombolytics via tibial IO vascular access for pulmonary embolism in a 36-year-old woman. Due to the emergent nature of the situation, IO access was determined to be the best option for immediate vascular access. Alteplase was administered through the IO line at 100 mg over 2 hours without complication. The patient successfully recovered and was discharged from the hospital on day 7 without long-term disability. The author concluded that this case study raised the potential use of IO lines to deliver thrombolytics in patients with massive pulmonary embolism and that further evaluation is needed to compare the risk and benefits of the alternative method of administration.
- Stranden G, Skogrand H, Spinella PC, Hervig T, Rein EB. Donor performance of combat readiness skills of special forces soldiers are maintained immediately after whole blood donation: A study to support the development of a prehospital fresh whole blood transfusion program. Transfusion 2013; 53(3):526-30. doi:10.1111/j.1537-2995.2012.03767.x** 570
- This study conducted by the Norwegian Navy evaluated the ability of 25 soldiers to perform buddy transfusion by starting phlebotomy, establishing sternal IO access using the FAST1, and infusing 1 unit of whole blood. Physical performance was evaluated pre and post blood donation and lactate levels were recorded. The authors concluded that physical and combat performances are preserved within limits post whole blood donation and that soldiers are able to learn the phlebotomy and sternal reinfusion with only a short lecture on the procedure.
- Torres A, Banister N, Fernandez M, Cox K, Fletcher J. Appropriateness and complications of intraosseous needle placements during pediatric transports. Crit Care Med 2013;41(12):abstract 215** 792
- A quality initiative study conducted evaluating use of the EZ-IO needles in pediatric patients and their associated complications rates when placed by EMS/ED staff compared Air Evac Lifeteam placement in 2012. The authors concluded that the powered IO device was appropriately utilized by ED/EMS staff as well as Air Evac staff and that there was no difference in the complication rate when the device was used by the two groups.
- Torres F, Galán MD, Alonso MD, Suarez R, Camacho C, Almagro V. Intraosseous access EZ-IO in a prehospital emergency service. J Emerg Nurs 2013;39(5):511-4. doi: 10.1016/j.jen.2012.03.005** 572
- This observational pre-hospital study conducted in Madrid, Spain prospectively evaluated use of the EZ-IO Jan 2007- Dec 2009 as an alternative to peripheral IV access. During the study period, 107 patients underwent 114 EZ-IO insertions and all were successful on first attempt. IO access was established in the proximal tibia (49%), distal tibia (25.2%), radius (14.9%), and humerus (10.5%) and all lines were the first form of vascular access established in the patient. There were no adverse events or complications.
- Veldhoen ES, de Vooght KMK, Sliker MG, Versluys AB, Turner NMB. Analysis of bloodgas, electrolytes and glucose from intraosseous samples using an i-STAT point-of-care analyser. Resuscitation 2013;http://dx.doi.org/10.1016/j.resuscitation.2013.12.002** 692
- A prospective study comparing IO and venous laboratory values obtained from a point-of-care analyzer (i-STAT) in 20 children. IO blood specimens were collected from the iliac crest; 2 ml were discarded before the sample was collected analysis. Results showed differences between venous and IO sample were clinically acceptable for pH, base excess, sodium, ionized calcium and glucose in hemodynamically stable patients. Authors concluded that analysis of IO samples with a bedside point-of-care analyzer is feasible and in emergency situations may be useful to guide treatment.

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Weiser G, Poppa E, Katz Y, Bahouth H, Shavit I. Intraosseous blood transfusion in infants with traumatic hemorrhagic shock - a case report and review of the literature. Am J Emerg Med 2013;31(3):640.e3-4. doi: 10.1016/j.ajem.2012.10.036 646

This article describes a case study of a 5-month old infant that suffered a head injury resulting in shock. She received 100 mL of red blood cells via the EZ-IO in the proximal tibia, resulting in rapid hemodynamic improvement. A literature search was completed for cases of IO blood transfusion in pediatric trauma. Authors note IO availability and knowledge play an important role in hemorrhagic shock; and RBC infusions via the IO route are feasible in this age group.

YEAR: 2012

Barker LT. In the child with gastroenteritis who is unable to tolerate oral fluids, are there effective alternatives to intravenous hydration? Ann Emerg Med 2012;60(5):607-8. doi: 10.1016/j.annemergmed.2012.04.003 534

This article, part of a Review Snapshot series in Annals summarizes a literature review (Rouhani et al in Pediatrics 2011) for evidence of alternatives to traditional IV hydration in a dehydrated child. Thirty-eight articles were included for the analysis with five of them randomized controlled trials; and one of those comparing IO to IV rehydration. (Banerjee et al, which found IO placement faster with no therapeutic outcome differences). The focus of this review was on nasogastric tube rehydration as effective when IV fails and as less invasive than IO or CVC placement.

Berger E. Innovations from a decade of war: soldiers' final sacrifice has improved emergency care. Ann Emerg Med 2012;60(6):14A-5A. Http://dx.doi.org/10.1016/j.annemergmed.2012.10.012 611

This article takes a look at the emergency medicine advances that result from war, including intraosseous resuscitation.

Cairney K, Matthew I. Options for intravascular access during resuscitation of adults. Emerg Nurse 2012;20(1):24-8 536

This article discusses how IO access can be used to improve advanced life support therapy. The EZ-IO is described in this article; published comparative studies between other IO devices and peripheral IV access are cited, leading the author to conclude the EZ-IO is user friendly, and establishes intravascular access more quickly and more often on first attempt than other devices.

Carness JM, Russell JL, Lima RM, Navarro LHC, Kramer GC. Fluid resuscitation using the intraosseous route: Infusion with lactated ringers and hetastarch. Mil Med 2012;177(2):222-8. 529

This pre-clinical study evaluated IO flow rates obtainable with infusion of lactated Ringer's and hetastarch 6% through the proximal tibia and sternum IO insertion sites, using a swine model. The EZ-IO 25mm was used to facilitate tibial IO access; sternal access was established using a Jamshidi needle. Results showed that hetastarch flow rates were lower than lactated Ringer's flow rates at both insertion sites; sternal infusion of hetastarch is likely to provide greater estimated intravascular volume expansion than lactated Ringer's, despite the lower infusion rates; resuscitation using the IO rate is likely to benefit from pressure bag or high-pressure pump delivery. This study was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.

Civantos Fuentes E, Rodriguez Nunez A, Iglesias Vazquez JA, Sanchez Santos L. [Evaluacion de la actuacion de los pediatras de atencion primaria en un escenario simulado de trauma pediatrico]. An Pediatr (Barc) 2012; doi: 10.1016/j.anpedi.2012.01.027. Spanish 566

This article in Spanish describes a study in which the management of simulated pediatric multiple trauma cases was compared to the 8 tasks validated in a polytrauma training program from Cincinnati Children's Hospital. The authors concluded that primary care pediatricians have difficulty applying the sequence of trauma and cervical screening maneuvers in a simulated setting and that pediatric training programs should strengthen practical initial care for trauma.

Crowley M, Brim C, Proehl J, et al. Emergency nursing resource: difficult intravenous access. J of Emerg Nursing 2012;38(4):335-43 602

Manuscript of a literature review and critical analysis done to develop the Emergency Nurse's Association (ENA) December 2011 Emergency Nursing Resource (ENR) which focused on the clinical issue of difficult IV access. Graded recommendations and decision options are provided for alternatives to IV access, including IO.

Cunningham LM, Mattu A, O'Connor RE, Brady WJ. Cardiopulmonary resuscitation for cardiac arrest: the importance of uninterrupted chest compression in cardiac arrest resuscitation. Am J of Emerg Med 2012;30(8):1630-8.doi: 10.1016/j.ajem.2012.02.015 568

Review article citing evidence supporting uninterrupted CPR for cardiac arrest. Interventions that reduce interruptions in compressions are discussed including intraosseous (IO) vascular access as an alternative to peripheral intravenous (PIV) access especially for difficult PIV cases. Although PIV access is cited as preferred authors cite speed, high success rates, safety and ease of use of IO access with several studies as evidence. Important points made include that for multiple access sites a small time advantage for IO access is magnified; providers should have low threshold for choosing IO vs. PIV (go IO faster); and central venous placement (CVC) is likely not indicated in most arrest scenarios. IO placement is strongly encouraged.

Dandele LM, Ohler KH. Pharmacotherapy of pediatric advanced life support and toxicological emergencies. AACN Adv Crit Care 2012;23(4):398-412. doi:10.1097/NCI.0b013e31826b4c70 635

PALS 2012 guidelines on pharmacotherapy and toxicological emergencies.

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- Davis DP. The use of intraosseous devices during cardiopulmonary resuscitation: Is this the answer for which we have been searching? *Resuscitation* 2012;83(1):7-8. doi:10.1016/j.resuscitation.2011.11.017** 522
- This editorial discussed the numerous changes in practice with regard to cardiopulmonary resuscitation, and explored the scientific basis upon which the changes were made. Changes in drug administration and vascular access methods, including IO, are discussed. The author's overall view was that perhaps clinical practice in cardiopulmonary resuscitation is too quickly changed with the presentation of minimal scientific data.
- Duncan L, Cohen J, Triner W, Rea J, King C. Intraosseous administration of CT Contrast in a porcine model: a feasibility study. *Ann Emerg Med* 2012;60(4S):S92** 598
- This abstract presented at the 2012 ACEP Research Forum discusses a swine pre-clinical study evaluating CT image opacification when contrast is delivered via IV and proximal humerus IO access. The EZ-IO was used to facilitate IO access. Results showed that under blinded radiology review the IV and IO images were judged adequately opacified to meet diagnostic criteria. Authors concluded that IO administration of contrast material may be a viable alternative if other vascular access is unavailable or if establishing other access will lead to a delay in diagnostic evaluation. This study was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.
- Esteo OV. Intraosseous access in prehospital emergency care. *Emergencias* 2012;24:44-6** 764
- A prospective, observational study which evaluated use of the EZ-IO within the prehospital setting over the course of a 3 year period, in Barcelona, Spain. Included patients were in cardiac arrest or with hemodynamic instability, without peripheral venous access after 90 seconds or 3 attempts to establish access. Results showed IO access was attempted in 49 pediatric and adult patients with an overall success rate of 93.9%; complications included extravasation and pain. IO access sites included the proximal tibia (71.4%), proximal humerus (22.4%) and distal tibia (6.1%). The author concluded that IO access is a viable access route for the management of critical patients or those in cardiac arrest in the pre-hospital setting due to the ability to obtain rapid access and the high first attempt success rate.
- Goodman IS, Lu CJ. Intraosseous infusion is unreliable for adenosine delivery in the treatment of supraventricular tachycardia. *Pediatr Emerg Care* 2012;28(1):47-8** 524
- Physicians from two different emergency department settings reported 2 cases of supraventricular tachycardia (SVT) in infants (2 and 4 month old) in which IO administration of adenosine failed to convert SVT to a normal rhythm.
- Greene N, Bhananker S, Ramaiah R. Vascular access, fluid resuscitation, and blood transfusion in pediatric trauma. *Int J Crit Illn Inj Sci* 2012;2(3):135-42 doi: 10.4103/2229-5151.100890** 980
- This article is a review of techniques and available evidence for establishing intravenous access, rational approaches to fluid resuscitation, and blood product transfusion in the pediatric trauma patient. IO needle systems are available for integration into pre-existing trauma care systems for pediatric patients.
- Hoskins SL, Nascimento P Jr., Lima RM, Espana-Tenorio, JM, Kramer GC. Pharmacokinetics of intraosseous and central venous drug delivery during cardiopulmonary resuscitation. *Resuscitation* 2012;83(1):40-5. doi:10.1016/j.resuscitation.2011.07.041** 442
- Pharmacokinetics of IO drug delivery was compared using the tibia or sternum, versus central venous delivery during CPR. Anesthetized swine with KCl arrest were used for this study, CPR was initiated 8 minutes post arrest. Using 2 study groups, dye was injected as a bolus with adrenaline through either the IO sternal and tibial needles or through the IO sternal and IV central venous needles. Results showed peak arterial blood concentrations were faster for sternal IO vs tibial IO administration. Tibial IO delivered 65% of the total dose delivered with sternal administration. Peak blood concentrations were similar for sternal IO and central venous administration. Sternal IO delivered 86% of the total dose delivered by central venous administration. The EZ-IO and Jamshidi were used to facilitate IO access. This research was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.
- Ibrahim M, Cairney K. Intraosseous (IO) infusion as a means of vascular access. *Br J Resuscitation* 2012;Autumn:23-6** 599
- This article provides an overview of intraosseous vascular access, including applicable patient population, IO access sites, pain management, IO education and compares IO access to central venous access.
- Isayama K, Nakatani T, Tsuda M, Hirakawa A. Current status of establishing a venous line in CPA patients by emergency life-saving technicians in the prehospital setting in Japan and a proposal for intraosseous infusion. *Int J Emerg Med* 2012;5(1):2. doi:10.1186/1865-1380-5-2** 527
- This article discusses a retrospective review of Japanese prehospital system for intravenous infusion success rates in cardiopulmonary arrest (CPA) patients and a prospective simulation study. A nationwide database was reviewed for CPA records from 1 January 2005 to 31 December 2008 yielding 431,968 cases. Results showed the IV infusion success rate in adults increased annually, however the rate in pediatrics did not; and while the administration of adrenaline increased the 1-month survival rate did not. In the simulation study, 100 EMS technicians used the Bone Injection Gun (BIG) in simulator adult, pediatric and infant legs. There was no difference in the time to establish IO access between the simulation models. The authors concluded that IO access should be considered when IV access is difficult or impossible.
- Kerby JD, Cusick MV. Prehospital emergency trauma care and management. *Surg Clin N Am* 2012;92:823-41. doi:10.1016/j.suc.2012.04.009** 591
- An overview of pre-hospital trauma care. Endotracheal intubation, use of tourniquets, identification of shock, and clinical research in the pre-hospital setting are specifically addressed. Intraosseous vascular access is generally mentioned in relation to resuscitation.

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Emergency Care

- Lammers R, Byrwa M, Fales W. Root causes of errors in a simulated prehospital pediatric emergency. Acad Emerg Med 2012;19(1):37-47. doi: 10.1111/j.1553-2712.2011.01252.x** 590
- This simulation study evaluated the ability of 2 person EMS crews to manage a pediatric emergency and sought to determine root causes of errors made. Participating EMS crews used the BIG for IO access. The authors concluded that cognitive, procedural, affective, teamwork errors and error-producing conditions were identified as root causes for the errors made in the simulation. Authors also concluded that simulation followed by facilitated debriefing is an effective tool for identifying underlying causes of active and latent errors.
- Leidel BA, Kirchhoff C, Bogner V, Braunstein V, Biberthaler P, Kanz KG. Comparison of intraosseous versus central venous vascular access in adults under resuscitation in the emergency department with inaccessible peripheral veins. Resuscitation 2012;83(1):40-5. doi:10.1016/j.resuscitation.2011.08.017** 439
- This clinical trial evaluated the time required to establish IO access versus central venous catheter (CVC) in adults undergoing resuscitation, who had failed peripheral IV access (PIV) attempts. IO and CVC placement were performed simultaneously; two IO devices, the EZ-IO and the BIG, were used to facilitate IO access in randomized format. Forty (40) patients were enrolled, first attempt success for IO was 85% vs 60% for CVC placement; median procedure time was 2 minutes for IO vs 8 minutes for CVC. The author concluded that though IO access is safe, reliable and rapid during resuscitation, it cannot replace CVC but should be considered as a valuable bridging technique.
- Miller L, Montez DF, Philbeck TE, Puga TA, Morgan J. Infusing chilled saline via the Intraosseous route is equivalent to infusion via the intravenous route in reducing the core temperature in swine. Prehosp Emerg Care 2012;16(1):152. doi:10.3109/10903127.2011.624676** 513
- This abstract presented at the 2012 NAEMSP scientific assembly described a randomized, cross-over study in which 8 swine were administered chilled saline via IV and IO routes to determine if the two routes were equivalent. The results suggested no clinical or statistical difference between IV and IO routes for infusion of chilled saline for therapeutic hypothermia. This study was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.
- Miller LJ, Puga TA, Montez DF, Morgan J. New in therapeutic hypothermia: preclinical evidence validates the IO Route; chilled tubing works best. Ann Emerg Med 2012;60(4S):S90** 601
- This abstract presented at the 2012 ACEP Research Forum describes a preclinical swine study evaluating the ability to induce therapeutic hypothermia by infusing chilled saline via IV and IO access. The EZ-IO was used to facilitate IO access. Results showed statistical equivalence between IV and IO routes when used to deliver chilled saline to induce therapeutic hypothermia. Results also showed that use of chilled saline and infusion tubing submerged in an ice water bath provides the most effective means of cooling. This study was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.
- Murray DB, Eddleston M, Thomas S, et al. Rapid and complete bioavailability of antidotes for organophosphorus nerve agent and cyanide poisoning in minipigs after intraosseous administration. Ann Emerg Med 2012;60(4):425-30. http://dx.doi.org/10.1016/j.annemergmed.2012.05.013** 587
- A pre-clinical study evaluating the systemic bioavailability of antidotes when administered via the intraosseous (IO), intravenous (IV), and intramuscular (IM) routes is described. Results showed rapid and substantial antidote bioavailability after IO administration similar to that of the IV route. Authors concluded that the IO route of antidote administration should be considered when IV access is difficult.
- Myers LA, Russi, CS, Kolb L. Prehospital semiautomatic intraosseous placement in adults. Preshosp Emerg Care 2012;16(1):173. doi:10.3109/10903127.2011.624676** 514
- This abstract presented at 2012 NAEMSP scientific assembly described a retrospective study that evaluated success rates and features of prehospital IO placement in adults following implementation of the EZ-IO, over a 2 year period. First attempt success rate in 281 patients was 89.7%; overall placement success was achieved for 91.8%.
- Olaussen A, Williams B. Intraosseous access in the prehospital setting: literature review. Prehosp Disaster Med 2012;27(5):468-72. doi:10.1017/S1049023X12001124. http://journals.cambridge.org/abstract_S1049023X12001124** 582
- A literature review of articles describing intraosseous vascular access devices used in the pre-hospital setting. Twenty articles met the inclusion criteria and described the manual devices, BIG, Fast-1 and the EZ-IO. The authors concluded that the literature suggests that semiautomatic IO devices may be more effective than manual devices.
- Page D. Intraosseous intrigue: Studies examine success rates on pediatric, adult & obese patients. JEMS January 2012;32-3** 515
- In this article, the author discussed five recent studies on intraosseous access providing his opinion about the quality of each study.
- Pallin DJ. Intraosseous vs intravenous access for adults with out-of-hospital cardiac arrest. Journal Watch Emergency Medicine 2012; http://emergency-medicine.jwatch.org/cgi/content/full/2012/106/1?q=etoc_jwca** 526
- This editorial discussed a prior publication by Reades, et al that evaluated first attempt placement success rates for tibial IO, humeral IO, and peripheral IV in the prehospital setting. The author concluded that the research shows tibial IO access is the best route for adults with out-of-hospital cardiac arrest.

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- Paxton JH. Intraosseous vascular access: A review. *Trauma* 2012;14(3):195-232. DOI:10.1177/1460408611430175** 690
An overview of IO vascular access including a review of currently available literature. The author discusses various IO devices available and their performance metrics, IO access sites, flow rates, advantages and disadvantages of IO access compared to conventional access methods, complications and recommendations on use of the approach. The author concludes that while IO access may not be appropriate for all patients, it deserves a place in the modern provider's armamentarium.
- Plancade D, Nadaud J, Lapierre M, et al. Feasibility of a thoraco-abdominal CT with injection of iodinated contrast agent on sternal intraosseous catheter in an emergency department. *Annales Francaises d'Anesthesie et de Reanimation* 2012;http://dx.doi.org/10.1016/j.annfar.2012.10.009** 580
This letter to the editor describes a case in which sternal IO access was established using a Jamshidi needle to administer iodinated contrast for a thoraco abdominal CT on a 61-year old male who presented to the ED with respiratory distress. Picture quality was deemed excellent by the radiologists. The authors conclude that the sternal IO route can be used with excellent picture quality but it should be used only in exceptional cases due to the potential risks of a high-power injection through the bone. EZ-IO is mentioned as an alternative IO device available.
- Ribiero de Sa RA, Melo CL, Dantas RB, Delfim LVV. Vascular access through the intraosseous route in pediatric emergencies. *Rev Bras Ter Intensiva* 2012;24(4):407-14** 716
The authors evaluated use of IO access in pediatric emergencies through a literature review. The objective was to describe the techniques, professional responsibilities, and care related to obtaining IO access.
Brazil
- Rose EC. The evidence-based use of intraosseous lines in pediatric patients. *Pediatr Emerg Med Pract* 2012;9(6):1-12. www.edmedicine.net** 585
This article presents a general overview of intraosseous (IO) vascular access in the pediatric population through an IO literature review. Available IO devices were discussed.
- Rush S, Bremer J, Foresto C, Rubin AM, Anderson PI. A magnetic resonance imaging study to define optimal needle length for humeral head IO devices. *J Spec Oper Med* 2012;12(2):77-82** 577
This article describes a retrospective study in which 50 consecutive MRI images were evaluated of the humerus for the purpose of determining the optimal needle length necessary for successful proximal humerus IO insertion. Results showed the cortical thickness was 4mm in all cases and that an IO needle length ranging between 40-50mm should be used via the anterior approach. The EZ-IO is specifically discussed in relation to the proximal humerus IO insertion site; and a 24 patient post mortem review of the EZ-IO placed in the proximal humerus is discussed.
- Severyn FA. Complication after intraosseous needle removal following successful systemic thrombolysis for a massive pulmonary embolism. *Resuscitation* 2012;83(11):e207. doi:10.1016/j.resuscitation.2012.07.014** 575
This letter to the editor is written in response to the case report by Landy titled, Complication of intraosseous administration of systemic thrombolysis for a massive pulmonary embolism with cardiac arrest. The author suggests that the tissue necrosis described by Landy may have been due to the removal of the IO needle while there was still significant fibrinolytic activity at the needle insertion site. The author suggests a change in medical care after return of spontaneous circulation (ROSC) in patients following thrombolytic administration through IO access to convert the functioning IO line to a non-flowing saline lock. The EZ-IO was used to provide IO access in the case report by Landy.
- Studnek JR, Fernandez AR, Vandeventer S, Reades R. Assessing paramedic comfort with three methods for gaining vascular access during out-of-hospital cardiac arrest resuscitation. *Prehosp Emerg Care* 2012;16(1):162. doi:10.3109.10903127.2011.624676** 518
This abstract presented at the 2012 NAEMSP scientific assembly described a study in which the comfort level of paramedics was evaluated as it related to establishing vascular access in out of hospital cardiac arrest resuscitation, using a predetermined method (PIV, humeral IO, tibial IO). Results showed that paramedics were typically comfortable with the method assigned.
- Truemper EJ, Beamer CL, Miller LJ, et al. Distal femur site is a viable option for IO vascular access in pediatric patients. *Ann Emerg Med* 2012;60(4S):S90** 761
This abstract presented at the 2012 ACEP Research Forum explored the viability of the distal femur as an IO insertion site with a literature review of IO vascular access and brief overview of a post-mortem study of pediatric distal femur insertion success. Authors concluded that clinical literature, clinical studies, and a post-mortem study confirm that the distal femur is a viable option for IO infusion in pediatric patients. This study was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.
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- This abstract presented at the 2012 NAEMSP scientific assembly evaluated end-tidal carbon dioxide (ETCO₂) levels under initial induction of hypothermia, rewarming, and a second induction of hypothermia, via IO and IV infusion in the swine model. The authors concluded that there was no demonstrated association of ETCO₂ with brain temperature during the initial induction. However, during rewarming and second induction of hypothermia the association of ETCO₂ and brain temperature had a direct and proportional association. This research was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.
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This article reports a case in which IO access was used to deliver intravenous contrast agent in an adult blunt trauma patient. After placement in the proximal humerus, contrast agent was administered via the IO route, and clinicians found the CT scans of the thorax, abdomen, and pelvis to be adequate for diagnostic purposes and subjectively equivalent to those of studies using central venous access. There were no complications and the authors concluded that IO access appeared to be an effective alternative to traditional venous access for administering contrast agents for CT evaluation in adult blunt trauma patients.
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This study compared the effectiveness of infusing ice cold saline via IO and IV to induce mild therapeutic hypothermia (temperature drop to 34°C) within a 30 minute timeframe, in a swine model of cardiac arrest. Five swine were evaluated in each the IV and IO groups. Goal temperature was reached in 4/5 animals in the IV group and 0/5 animals in the IO group in the allotted time frame; IV was superior in terms of rate of infusion, rate of temperature change, and time to achieve target temperature.

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- This article describes a literature review study with the objective of establishing which intraosseous device is best for prehospital use. This short review searched Medline 1950-2010, CINAHL 1982-2010 and EMBASE 1980-2010 and identified two studies meeting their evidence search criteria, one study compared the BIG vs. manual; the second compared EZ-IO vs. FAST-1. The clinical bottom line asserted by the author was traditional manual IO devices have faster, better success rates in the pre-hospital setting; but that more randomized trials are needed to determine the best device.
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- This article describes a pre-hospital clinical study comparing IO first-attempt success between humeral and tibial sites. Of 88 cardiac arrest patients analyzed, 58 and 30 IO access attempts were made in the tibia and humerus, respectively. Of those, there was a 90% first attempt success rate for the tibia, compared to 60% for the humerus. Of successful insertions, 6% of tibial insertions became displaced during transport, compared to 33% of humeral insertions. Investigators concluded that proximal tibial IO needle placement was associated with a significantly higher frequency of first-attempt success and lower incidence of needle dislodgements compared to humeral placements.

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- The objective of this study was to determine the frequency of first-attempt success of humeral IO, tibial IO, and peripheral IV (PIV) insertions during out-of-hospital cardiac arrest. Patients were randomized to receive one of the 3 methods. There were 182 patients enrolled, 64 were assigned to tibial IO, 51 to humeral IO and 67 to PIV. Of all patients 130 (71%) were successful on first attempt with 17 (9%) needles dislodged. First attempt success within the treatment groups was 91% for tibial IO, 51% for humeral IO, and 43% for PIV.
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- In this preclinical study, 30 swine in ventricular fibrillation received IO epinephrine, IV epinephrine, or placebo. Return of spontaneous circulation, 24-hour survival, and 24-hour survival with good neurological outcome was evaluated. Results showed ROSC to be nearly universal for the IV and IO groups with no differences between rates; 24-hour survival was substantially more likely in the IO group than the IV group; survival with good neurological outcome was more likely in the IO group than the IV group.
- YEAR: 2010**
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- This abstract, which was presented at the 2010 ACEP Research Forum, describes a study conducted by investigators from the Medical College of Georgia to determine the frequency of intraosseous vascular access use in adult emergency patients. They surveyed academic emergency departments across the country and, at their own facility, compared ease and speed of standard emergency vascular access methods—including intraosseous. They concluded that IO access is underutilized and generally not the second-line choice of vascular access in unstable adult patients in academic institutions. Their simulation showed IO placement was considerably faster than both central lines and ultrasound guided peripheral IV. They opined that IO should be considered more frequently in critical unstable adult emergency department patients.

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- This abstract describes a retrospective case-series analysis of pediatric IO recipients from 1998-2009. Seventy-two (72) patients were included in the study; IO access was established in the proximal tibia (n=61), medial tibia (n=8), distal tibia (n=1), sternum (n=1), and iliac crest (n=1). IO access devices used in the proximal tibia included the Cook Critical Care needle (n=4), the Jamshidi needle (n=2), the BIG (n=1), and an 18 gauge spinal needle (n=54). The authors concluded that a spinal needle can be used to provide IO vascular access in children.
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- Authors reviewed two complications (extravasation and compartment syndrome) associated with IO access in children with meningococcal disease. Authors concluded that IO systems need formal evaluation to assess safety and complication profiles.
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- This article discusses training methodology and applies the concept to the implementation of the EZ-IO in the Montgomery County Hospital District EMS, a participant in the EZ-IO beta test.
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- This article describes a randomized, single-blind, controlled trial to determine which IO needle can be used best for gaining IO access in patients requiring acute administration of fluids or medication in a prehospital setting. The study was performed at a level 1 trauma center in the Netherlands with a Helicopter Emergency Medical Service (HEMS). Adult and pediatric patients meeting inclusion criteria were randomized between Jamshidi 15G, B.I.G. 15G/18G and F.A.S.T.1. Insertion time, success, aspiration of bone marrow, side effects, medication given, trauma mechanism, and user satisfaction were recorded. In the adult group Jamshidi was placed fastest, significantly faster than the F.A.S.T.1. (p=0.002). Time to insert the B.I.G. 15G did not differ statistically from other devices. In the pediatric group insertion time of the Jamshidi did not differ statistically from the B.I.G. 18G. On average, the devices (adult and pediatric) did not differ significantly with respect to success rate, complication rates, and user satisfaction. EZ-IO was not included in this study as it was not approved for use in the Netherlands at the time the trial began. Authors recommend comparison with EZ-IO in future research.
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- An article evaluating various methods of obtaining vascular access in the management of 21st century battlefield trauma including, peripheral IV access, intraosseous access, venous cut-down, and central venous access. The authors conclude that IO access should be the first line vascular access in casualties with severe trauma to avoid delay initiating resuscitation in pre-hospital or hospital setting.
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- This article in German describes the results of a survey of rescue assistants and physicians, in which they found that IO use was still a rarity in the Berlin emergency medical service and, therefore, presumably nationwide.
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- Authors describe a randomized, controlled trial comparing two different IO access devices in adults in the hospital setting. Twenty patients received the BIG and 20 received the EZ-IO. Success rate on first attempt was 80% for the BIG and 90% for the EZ-IO. Mean procedure time was 2.2 minutes for the BIG vs. 1.8 minutes for the EZ-IO. Differences in success rate and procedure time were not statistically significant, and there were no significant complications for any patients. Investigators concluded that IO access is a reliable and safe method for rapid vascular access for in-hospital adult patients under resuscitation.
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- In this letter to the editor, the author discusses the use of IO access concluding that a change in practice should be made in which immediate IO access should be established for initial emergency resuscitation and serve as a bridging technique when peripheral IV access has been unsuccessful 3 times over a maximum duration of 2 minutes.

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European Union
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This paper describes experiences with the EZ-IO device in Japan in 24 adult patients during CPR. The device is not sold in Japan.
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This article discusses use of IO access within the hospital setting in the emergent and non-emergent patient populations. The history of IO access, clinical situations in which IO access may be considered, devices, contraindications, and complications are discussed. Additionally, pain management, economics, education and training and risk management are explored. This article is co-published in Journal of Infusion Nursing, the Journal of Pediatric Nursing, and Critical Care Nurse and was produced by the Consortium on Intraosseous Vascular Access in Healthcare Practice.
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This article provides an overview of pediatric trauma care in the pre-hospital setting by using a literature review to evaluate the risks and benefits of various aspects of care. Topics discussed include: pre-hospital care time, pre-hospital triage and transport, airway management, intravenous (IV) and intraosseous (IO) vascular access and infusions, cervical spine immobilization, traumatic brain injury, and pain assessment and management.
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This article describes a longitudinal study of intraosseous vascular access in pre-hospital emergency medicine handled by helicopter emergency medical services. Of the 78 IO insertion attempts made on 70 patients, overall success rates were 50% using manual needles, 55% using the Bone Injection Gun, and 96% using the EZ-IO. Investigators concluded that newer IO techniques may enable faster and more reliable vascular access; and that all emergency services should be familiar with IO techniques.
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This article describes a prospective, observational study involving a convenience sample of 25 medical students, physicians and nursing staff recruited evaluate the EZIO powered drill device on a bone model. Twenty-three (92%) of the 25 study subjects required only one attempt at placing the EZ-IO. Investigators concluded that the device was easy to use with high success rates of insertion with inexperienced participants.

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Abstract only
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- This article describes thoracic trauma in the pediatric population. Includes a review of the assessment of pediatric patients. Circulation section of the article strongly recommends rapid intravascular volume expansion by the intraosseous route, and recommends the EZ-IO for "...quick and reliable vascular access during resuscitation ...".
- YEAR: 2007**
- Beamer CL, Horton M. Powered needle insertion provides safe and effective vascular access for pediatric emergency patients. *Ann Emerg Med* 2007;50(3):S40** 395
- This abstract for a presentation at the 2007 American College of Emergency Physicians Research Forum describes an observational study in which the EZ-IO was used to provide emergency vascular access for 95 pediatric patients. Successful insertion and infusion was achieved in 94% of the patients, and insertion time was within 10 seconds for 81% of the placements. There were four minor and no serious complications.
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- Data from the largest combat trauma database was analyzed to identify how new or improved devices, dressings or drugs have impacted prehospital casualty care, how guidelines and resuscitation strategy have changed, and discusses lessons learned and how concepts have crossed back into the civilian practice. Intraosseous access, particularly the sternal site, is identified as one of the advances for vascular access in combat medicine.
- Buck ML, Wiggins BS, Sesler JM. Intraosseous drug administration in children and adults during cardiopulmonary resuscitation. *Ann Pharmacother* 2007;41:1679-86** 374
- This article reviews and assesses the literature on the use of IO drug administration during cardiopulmonary resuscitation. It addresses the risks and benefits of using IO in adults and children. The article describes the FDA-cleared devices available for use including the Pyng F.A.S.T.1, Waismed Bone Injection Gun and the Vidacare EZ-IO.
- Cooper BR, Mahoney PF, Hodgetts TJ, Mellor A. Intra-osseous access (EZ-IO®) for resuscitation: UK military combat experience. *J R Army Med Corps* 2007;153(4):314-6** 379
- Describes the experience of the UK Defence Medical Service using the EZ-IO for emergency vascular access in Afghanistan. They used the device for 26 patients, including 10 children. Of the 26 EZ-IO placements, 23 were made in the emergency department. There was a 97% insertion success rate with no infection. Significant infusion pain was felt by three patients.
- de Caen A. Venous access in the critically ill child. *Pediatr Emerg Care* 2007;23:422-4** 372
- This review article states the availability of intraosseous (IO) needles for pediatric patients, outlines the limitations of traditional venous access, and discusses the various IO devices currently available, including the Vidacare EZ-IO®.
- DeBoer S, Andrews D. Infant venous access: 'Counting fingers' and 'playing baseball'. *Australasian Emerg Nurs J* 2007; 10: 46-51** 356
- This article summarized the challenges and methods of providing vascular access for infants. It describes IO techniques and devices, including the Jamshidi, Cook, EZ-IO® and Bone Injection Gun (BIG) devices.

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- Fowler R, Gallagher JV, Isaacs SM, Ossman E, Pepe P, Wayne W. The role of intraosseous vascular access in the out-of-hospital environment (resource document to NAEMSP position statement). *Prehosp Emerg Care* 2007;11:63-6** 355
Article calls for EMS medical directors to consider and use the intraosseous route for adult patients requiring immediate vascular access. Provides evidence in support of position statement by the National Association of EMS Physicians on IO use.
http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=17169880
- Fowler RL. Prehospital intraosseous access: elemental to the field? *JEMS* 2007; doi:<http://jems.com/print/9198>** 543
Discussion of the role intraosseous vascular access can play in the prehospital setting where vascular access is often difficult or impossible to establish. The EZ-IO is named as a new IO device along with descriptions of Jamshidi, Pyng Fast 1, and BIG needles.
- Frascone RJ, Jensen JP, Kaye K, Salzman JG. Consecutive field trials using two different intraosseous devices. *Prehosp Emerg Care* 2007;11(2):164-71** 357
This article describes authors' evaluation of provider performance using two IO devices; the Pyng Medical F.A.S.T.1™ and the Vidacare EZ-IO®. Of 89 insertions with each device, success rate for 72% for the F.A.S.T.1 and 87% for the EZ-IO, a significant difference (p=0.009). The time to fluid insertion for the EZ-IO was also faster (p=0.02). Authors noted that the EZ-IO is unique and much more useful than the F.A.S.T.1.
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Article in Italian describing IO access and EZ-IO
- Harrington LL, Rehbolz C, Mitchell PM, Dyer KS, King K, Moyer P. Out-of-hospital placement of adult intraosseous access using the EZ-IO device. *Ann Emerg Med* 2007;50(3):S81-2** 396
This abstract for a presentation at the 2007 American College of Emergency Physicians Research Forum describes an observational study done at Boston Medical Center in which the Vidacare EZ-IO was used to provide emergency vascular access for 50 critically-ill adult patients. Successful insertion was achieved in 92% of the patients; with 90% success on the first attempt. There was one immediate complication—a dislodgement during transport. Investigators concluded that the device is a safe and feasible device for adult patients requiring out-of-hospital vascular care.
- Hillewig E, Aghayev E, Jackowski C, Christe A, Plattner T, Thali MJ. Gas embolism following intraosseous medication application proven by post-mortem multislice computed tomography and autopsy. *Resuscitation* 2007;72:149-53** 530
This case study describes a 4-month-old boy that was found unresponsive. Resuscitation was started and continued through arrival to the ED; IO access at the proximal tibia was established using a 15 gauge aspiration needle as the only vascular access. Post mortem multislice CT examination showed gas in the hepatic veins, the right atrium, right ventricle, the upper pole of the right kidney and the cerebral vessels. Though air embolism was ruled out as the cause this death, it could have caused death in another case. The authors conclude that gas may have entered the body during resuscitation due to IO needle disconnections and that resuscitation with an inserted, disconnected IO needle should be avoided.
- Landes AH. Intra-osseous infusions: the current status. *Care of the Critically Ill* 2007; 23: 53-8** 361
Overview of IO access. Includes historical aspects, current status, indications for use, advantages and disadvantages, IO kinetics, insertion sites, complications and contraindications and description of available IO devices, including EZ-IO®.
- Mathew N, McGinnis-Hainsworth D, Megargel R, Cleary A, O'Connor R. Trends in the usage of intraosseous access in the prehospital setting. *Prehosp Emerg Care* 2007;11(1):130** 362
In this study, presented at the NAEMSP 2007 annual meeting, authors compared the success rate of conventional IO access with the EZ-IO during 245 cases in the prehospital setting. They concluded that using EZ-IO® results in a statistically significant increase in IO success rate, compared to conventional IO methods.
Abstract
- Myers BJ, Lewis R. Induced cooling by EMS (ICE): year one in Raleigh/Wake County. *JEMS* 2007;32:s13-5** 398
This article describes the experience of the Wake County (NC) EMS System in inducing hypothermia for patients with return of spontaneous circulation after cardiac arrest. Authors describe their use of the Vidacare EZ-IO (now Arrow® EZ-IO Intraosseous Vascular Access System) for the administration of chilled saline. In this report 56% of vascular access cooling was done utilizing the IO device and an additional 18 % utilized a combination of IO and IV induced cooling. The overall EZ-IO use in this program for all insertions were 414 with an insertion success rate of 94%.
- Potyka JS, Gordon DJ. Stories behind the numbers: IO experiences in providers' own words. *JEMS* 2007;32:s30-1** 400
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- Pye D. NY Paramedics get the EZ-IO. JEMS 2007; doi: <http://www.jems.com/print/5184>** 550
This article in JEMS discusses an EMS system in New York following their adoption of the EZ-IO, and the advantages.
- Scheres M. [Nieuw hulpmiddel voor intra-ossale toegang]. Vakblad V & VN Ambulancezorg 2007;1:16-7. Dutch** 373
Article in Dutch describing IO access and EZ-IO.
- Stouffer JA, Jui J, Acebo J, Hawks RW. The Portland IO experience: results of an adult intraosseous infusion protocol. JEMS 2007;32:S27-8** 397
The article describes a prospective observational study conducted by several EMS agencies in Portland, OR to determine the safety, efficacy and benefits of using the Vidacare EZ-IO in the prehospital environment. The IO device was successfully placed in 95% of the 280 cases. In 98% of the cases, placement was made within six seconds.
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Study investigating time difference in obtaining IO vs. IV access while wearing personal protective equipment (PPE) in simulated HazMat scenarios. With provider in PPE and mannequin not in PPE, vascular access was faster with IO (14 seconds vs. 46 seconds; $p<0.001$); also, fluid infusion time (28 seconds vs. 46 seconds; $p<0.001$). With provider and mannequin in PPE, all the following favored IO: needle to skin time (13 seconds vs. 25 seconds, $p<0.001$), vascular access time (17 seconds vs. 63 seconds; $p<0.001$), and fluid infusion time (30 seconds vs. 66 seconds; $p<0.001$). Investigators conclude that EZ-IO under HazMat conditions provides vascular access and fluid more quickly than IV access.
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Article describes a controlled study in which the time difference between IV and IO access was compared while providers and simulated patients (mannequins) were wearing personal protective equipment (PPE). Twenty-two EMT-P providers measured the times to skin access, vascular access and fluid infusion in three scenarios: no PPE for providers or mannequins; providers only in PPE; and both providers and mannequins in PPE. In all scenarios, there was a statistically significant difference in vascular access and fluid infusion time, in favor of the EZ-IO. Investigators concluded that, overall, the EZ-IO provides vascular access and fluid more quickly than standard IV access, and that donning PPE does not hinder providers' use of the EZ-IO.
- Wayne MA. Intraosseous vascular access: devices, sites and rationale for IO use. JEMS 2007;32:s23-5** 375
This article reviews intraosseous vascular access in general, and summarizes the various devices available. These include the Waismed B.I.G., the Vidacare EZ-IO, and Pyng F.A.S.T.1.
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This article in German (with abstract in English) describes IO infusion in detail. It includes techniques, indications, complications, and recommendations. Also describes the various devices available, including Cook, Bone Injection Gun (BIG), First Access for Shock and Trauma (F.A.S.T.1), and the EZ-IO®.
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- Buck ML. Intraosseous administration of drugs in infants and children. Pediatr Pharm 2006;12(12)** 367
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- Cataldi E, McGinni-Hainsworth D, Megargel R, Bollinger M, O'Connor R. A comparison of intraosseous and intravenous access in adults and children in the prehospital setting. Prehosp Emerg Care 2006;10(1):124** 633
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- La May G, Friese G. Pediatric fluid resuscitation and airway management - a primer on volume replacement in pediatric patients. *EMS* 2006;May:65-72** 636
An overview of managing pediatric fluid resuscitation and airway management in the pre-hospital setting.
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- Wayne M. [Perfusion intra osseuse chez l'adulte: il est temps d'y penser]. *Urgence Pratique* 2006; 77: 47-9. French** 371
Article in French describes IO access and IO devices, including B.I.G., F.A.S.T.1 and EZ-IO®.
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Article describes intraosseous access for adults and pediatrics. Describes and discusses IO devices available including Jamshidi, Bone Injection Gun, F.A.S.T.1, and EZ-IO®.
- Fiorito BA, Mirza F, Doran TM, et al. Intraosseous access in the setting of pediatric critical care transport. *Ann Emerg Med* 2005;46(5):475-6. doi:10.1016/j.annemergmed.2005.09.011** 858
This abstract describes a retrospective study evaluating use of IO access during pediatric critical care transport. From January 1, 2000 to March 31, 2002, 1,792 transports were performed and 47 patients received 58 IO catheter insertions. Insertion took a mean 1.2 attempts for placement and first attempt success was 78%. Most frequently accessed site as the proximal humerus (95%) and access was maintained for a mean 5.2 hours. The authors concluded EMT/paramedics, emergency physicians, and pediatric critical care transport teams should be familiar with IO placement.
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This study abstract discusses use of the EZ-IO to determine the pharmacokinetics (PK) and efficacy of tibial IO drug delivery during treatment of cardiac arrest in the swine model, as compared to IV access. Results showed that PK analysis of IO drug delivery via the tibial route showed a delay of 20-50 seconds compared to IV; however, physiologically significant levels of epinephrine were reached as MAP. This research was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.
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http://www.aemj.org/cgi/content/abstract/12/5_suppl_1/67
- Mackinnon MA. Permissive hypotension: a change in thinking. Air Med J 2005; 24: 70-2** 347
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Study compared the VidaPort (now EZ-IO®) and the Bone Injection Gun (B.I.G.). Of 32 cases for each device, insertion rates were 100% for the VidaPort and 88% for the B.I.G. Average insertion times were 16 seconds for the VidaPort and 21 seconds for the B.I.G.
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- Hurren JS, Dunn KW. Intraosseous infusion for burns resuscitation. Burns 1995; 21: 285-7. Review** 194
Describes 2 cases of resuscitation of a scalded child by IO infusion following failed IV attempts. Reviews IO techniques.
- Kayser SR. Pharmacologic management of cardiac arrest: an update perspective. Prog Cardiovasc Nurs 1995;10(3):35-41** 204
Nursing article on pharmacologic management of cardiac arrest discussing administration routes for cardiac medications.
- Maguer D, Delaporte B, Godde F, Amusini P. [Intraosseous infusion: another emergency vascular access]. Arch Pediatr 1995;2(7):704-5. French** 198
Article in French.
No abstract available
- YEAR: 1994**
- Anderson TE, Arthur K, Kleinman M, Drawbaugh R, Eitel DR, Ogden CS, Baker D. Intraosseous infusion: success of a standardized regional training program for prehospital advanced life support providers. Ann Emerg Med 1994;23(1):52-5** 165
Study of IO training for advanced life support providers. Providers were able to establish IO access in 13 of 15 (87%) of pediatric patients (age range 1-24 months) following completion of an 1-hour training course and supervised hands-on simulation. All procedures were performed in less than 10 minutes.
- Iwama H, Katsumi A, Shinohara K, Kawamae K, Ohtomo Y, Akama Y, Tase C, Okuaki A. Clavicular approach to intraosseous infusion in adults. Fukushima J Med Sci 1994;40:1-8** 167
Comparison of flow rates for IO infusion through the clavicle and subclavian venous infusion. Found no significant differences between the two infusion routes.
Abstract only
- Kil'diushov AN. [Use of heparin in the early post-traumatic period in burns and hemorrhage]. Anesteziol Reanimatol 1994; Sept-Oct(5):26-8. Russian** 163
Preclinical study in 86 injured dogs with hemostasis disorders. Plasma and platelet disorders normalized 3 hours after the onset of infusion therapy. The response was enhanced by IO infusion of isotonic saline.
Article in Russian-abstract only
- Losek JD, Szewczuga D, Glaeser PW. Improved prehospital pediatric ALS care after an EMT-paramedic clinical training course. Am J Emerg Med 1994;12:429-32** 176
Study demonstrating improved performance of pre-hospital endotracheal intubation and vascular access of younger children after introduction of an EMT-P PALS clinical course.
- Neal CJ, McKinley DF. Intraosseous infusion in pediatric patients. J Am Osteopath Assoc 1994;94(1):63-6. Review** 187
Describes frustration associated with difficult venous access. Recommends intraosseous infusion technique as a non-collapsible vein for parenteral infusions.
- Orlowski JP. Emergency alternatives to intravenous access. Intraosseous, intratracheal, sublingual, and other-site drug administration. Pediatr Clin North Am 1994;41(6):1183-99** 164
Seminal article describing alternatives to intravenous cannulation including intraosseous access, intratracheal drug administration, sublingual and intralingual injection, intra-penile administration, and intracardiac injection. Concludes that the intraosseous method is an effective alternative to intravenous access in emergency situations.
Review

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Emergency Care

- Rieger A, Berman JM, Striebel HW. Initial resuscitation and vascular access. *Int Anesthesiol Clin* 1994;32:47-77** 173
Discussion of the role of the trauma anesthesiologist/critical care specialist (TA/CCS) in field airway resuscitation, management and reversal of shock are covered in this chapter.
- Runyon DE, Bruttig SP, Dubick MA, Clifford CB, Kramer GC. Resuscitation from hypovolemia in swine with intraosseous infusion of a saturated salt-dextran solution. *J Trauma* 1994;36(1):11-9** 166
Preclinical study demonstrating IO infusion of a saturated salt-dextran solution restored cardiac output in a pig model of hemorrhage. Suggests that IO-administered concentrated salt-dextran solution is a viable alternative during harsh field conditions where conventional resuscitation techniques may be impractical.
Abstract only
- Weaver BL. Intraosseous infusions. *Neonatal Netw* 1994;13(8):68-9** 162
A brief overview on establishing intraosseous vascular access in the neonatal patient population. Discusses insertion techniques, anatomy and physiology, absorption rates, indications and contraindications.
- YEAR: 1993**
- Glaeser PW, Hellmich TR, Szewczuga D, Losek JD, Smith DS. Five-year experience in prehospital intraosseous infusions in children and adults. *Ann Emerg Med* 1993;22(7):1119-24** 158
Retrospective analysis of prehospital IO infusion covering 165 attempts on 152 patients over a 5-year period, found a success rate of 73%, with success rates significantly higher in younger children (<2 years old). EMT-Ps maintained proficiency in the technique over time despite infrequent use.
- Guy J, Haley K, Zuspan SJ. Use of intraosseous infusion in the pediatric trauma patient. *J Pediatr Surg* 1993;28:158-6.1** 144
Observational study finding 7 of 27 critically injured patients (ages 3mo-10y) successfully resuscitated using IO. Concluded that IO is a rapid, safe and simple method of obtaining short term vascular access in critically ill and injured children.
- Ronning G, Busund R, Revhaug A. Resuscitation of pigs with haemorrhagic shock by an intraosseous hyperosmotic solution and transfusion of autologous whole blood. *Eur J Surg* 1993;159(9):133-9** 145
Preclinical study in 18 piglets finding significant improvement in hemodynamic variables after IO infusion of hyperosmotic saline and IO transfusion of whole blood in an animal model of hemorrhagic shock. Concludes that IO infusion is easy to establish and holds utility for treatment of shock victims.
- Salino D, Cottin X, Bordenet M. [Intraosseous infusions in pediatric life-threatening emergencies]. *Ann Fr Anesth Reanim* 1993;12: 469-73. Review. French** 154
Case reports of 2 9-month-old infants with severe dehydration treated with IO infusions after failed IV attempts. IO lines were replaced shortly after venous access was obtained.
Abstract only
- YEAR: 1992**
- American Heart Association. Guidelines for cardiopulmonary resuscitation and emergency cardiac care: chain of survival. *JAMA* 1992; 268: 2171-2302** 130
Evaluation of the chain of survival from cardiac arrest using standard measurements of performance.
- Ghirga G, Ghirga P, Palazzi C, Befani P, Presti A. [Intraosseous route in pediatric emergencies. Description of 2 clinical cases and review of the literature]. *Minerva Pediatr* 1992; 44: 377-84. Italian** 123
Case reports of resuscitation of 2 pre-term infants with medications administered via the intraosseous route. Also includes a short review of the history, physiology, technique, complications and contraindications of IO procedure.
Abstract only
- Gut J, Karbula D. [Intraosseous infusions in children]. *Cesk Pediatr* 1992;47:726-7. Czech** 133
A review of intraosseous infusion and the possible applications in pediatric emergency medicine.
Abstract only
- Hapnes SA, Robertson C. CPR--drug delivery routes and systems. A statement for the Advanced Life Support Working Party of the European Resuscitation Council. *Resuscitation* 1992;24(2):137-42** 127
Descriptive comparison of the 4 available routes to provide drugs to adult patients during cardiopulmonary resuscitation.

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Emergency Care

YEAR: 1991

Brattebo G, Wisborg T, Mellesmo S. [Intra-osseous infusion--a simple, rapid and lifesaving method]. Nord Med 1991;106(1):13-5. Norwegian 118

Discussion of case reports of IO infusion, as well as physiology of IO and technique for IO access. Concludes that IO infusion is simple and safe. The technique can be successfully performed under field conditions by paramedical personnel, even by untrained personnel.

Abstract only

Driggers DA, Johnson R, Steiner JF, Jewell GS, Swedberg JA, Goller V. Emergency resuscitation in children. The role of intraosseous infusion. Postgrad Med 1991;89(4):129-32 105

Review article discussing aspects of intraosseous infusion, including indications, technique, and pharmacokinetic factors. Concludes that multiple drugs and fluids can be safely administered through the intraosseous route.

Fuchs S, LaCovey D, Paris P. A prehospital model of intraosseous infusion. Ann Emerg Med 1991;20(4):371-4 106

Comparison of IO administration in 3 simulated EMS settings: at the scene, in ambulance in steady traffic on curvy road, in ambulance at fast speed in stop and go traffic. Found that 12 EMS participants were successful in establishing IO infusions, with 84.8% of infusions achieved in less than one minute in all settings.

Jaimovich DG, Kecskes S. Intraosseous infusion: a re-discovered procedure as an alternative for pediatric vascular access. Indian J Pediatr 1991;58(3):329-34 110

Review of indications and benefits of intraosseous infusion. Concludes IO access may be especially valuable for medical personnel who rarely care for critically ill children because the IO technique is easily mastered even with limited practice.

Ryder IG, Munro HM, Doull IJ. Intraosseous infusion for resuscitation. Arch Dis Child 1991;66:1442-3 113

Case report of an 11-week old infant in cardiac arrest due to haemorrhage successfully treated using IO infusion. The child was discharged with no apparent neurological deficit.

Velasco AL, Delgado-Paredes C, Templeton J, Steigman CK, Templeton JM Jr. Intraosseous infusion of fluids in the initial management of hypovolemic shock in young subjects. J Pediatr Surg 1991;26:4-8 117

Preclinical study in 39 puppies comparing IO treatment with Ringer's lactate with antishock trousers and control group receiving no treatment. Concludes that emergency administration of IO fluids is safe and effective for the initial resuscitation of hypovolemic shock.

YEAR: 1990

Chameides L, Hazinski MF, eds. Intraosseous cannulation. In: Textbook of Pediatric Advanced Life Support. Chameides L, Hazinski MF, Eds.. Dallas: American Heart Association; 1990 102

Textbook chapter on IO.

Dollberg S, Gale R. [Intraosseous emergency infusion]. Harefuah 1990;119(11):357-8. Abstract-Hebrew 96

Case report of a critically ill preterm neonate who received needed emergency fluids via IO infusion.

Fiser DH. Intraosseous infusion. N Engl J Med 1990;322(22):1579-81 98

Review of the use of intraosseous infusion in children in the prehospital setting and in the emergency department. Outlines anatomy, indications and contraindications, technique, complications and role of intraosseous infusion in pediatrics.

Fries F, Rousset A, Bloom MC, Lelong-Tissier MC, Regnier C. [Intra-osseous route. Administration route of drugs in cardiac arrest]. Arch Fr Pediatr 1990;47(9):663-4. French 103

Case report of a 6-month-old infant in cardiac arrest successfully resuscitated with IO epinephrine.

Abstract

Goldstein B, Doody D, Briggs S. Emergency intraosseous infusion in severely burned children. Pediatr Emerg Care 1990;6:195-7 88

Case report of 2 severely burned children saved after IO was used to establish IV access.

Halvorsen L, Bay BK, Perron PR, Gunther RA, Holcroft JW, Blaisdell FW, Kramer GC. Evaluation of an intraosseous infusion device for the resuscitation of hypovolemic shock. J Trauma 1990;30(6):652-9 90

Preclinical study comparing a sternal IO infusion device to IV fluids for resuscitation. Blood pressure and cardiac output were normalized at 10 minute post infusion in both groups. Advocates use of IO infusion as a way for pre-hospital rescuers to consistently incorporate fluid therapy in their scoop and run policies.

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Emergency Care

- King ML, Moses EC. Intraosseous infusion: a lifesaving technique. *Nursing* 1990;20:32K,32N-32P** 93
Nursing article describing intraosseous infusion techniques and benefits.
- Orlowski JP, Porembka DT, Gallagher JM, Lockrem JD, VanLente F. Comparison study of intraosseous, central intravenous, and peripheral intravenous infusions of emergency drugs. *Am J Dis Child* 1990;144(1):112-7** 92
Preclinical study comparing the pharmacokinetics of 6 emergency medications in dogs. Found that IO administration resulted in similar physiologic effect and/or serum drug levels as central and peripheral venous administration.
- Salassi-Scotter M, Fiser DH. Adoption of intraosseous infusion technique for prehospital pediatric emergency care. *Pediatr Emerg Care* 1990;6:263-5** 95
Discusses current limited pre-hospital use of intraosseous infusion. Stresses need for a concerted effort to promote broad adoption.
- Tobias JD, Nichols DG. Intraosseous succinylcholine for orotracheal intubation. *Pediatr Emerg Care* 1990;6(2):108-9** 468
This article describes two cases of IO administration of succinylcholine for emergency airway management in children that resulted in adequate intubating conditions within 45 seconds for both cases.
- Vinsel PJ, Moore GP, O'Hair KC. Comparison of intraosseous versus intravenous loading of phenytoin in pigs and effect on bone marrow. *Am J Emerg Med* 1990;8(3):181-3** 429
A 15mg/kg dose of phenytoin was administered over 15 minutes to 6 pigs using the IV route and 6 pigs using the tibial IO route. Blood samples were taken every 5 minutes for 35 minutes to determine phenytoin levels. There was no statistical difference between the two groups. Bone cortex and marrow were microscopically examined and were normal after 5 weeks. Authors concluded the IO route is an effecting alternative to the IV route for administering phenytoin without permanent damage to the marrow.
- YEAR: 1989**
- Brown CG, Dzwonczyk R, Werman HA, Hamlin RL. Estimating the duration of ventricular fibrillation. *Ann Emerg Med* 1989;18(11):1181-5** 83
Preclinical study in pigs and mathematical model using mean frequency of the ECG during ventricular fibrillation to predict downtime.
- Iserson KV. Intraosseous infusions in adults. *J Emerg Med* 1989;7(6):587-91** 75
Study of 22 cardiac arrest patients arriving at the Emergency Department with no or insufficient intravenous access. Intraosseous needle placed and flow established in less than 1 minute in all patients. Observed flow rates of 5 to 12 mL/min with pressure bag attached. IO needle placed in the medial supramalleolus.
- Miner WF, Corneli HM, Bolte RG, Lehnhof D, Clawson JJ. Prehospital use of intraosseous infusion by paramedics. *Pediatr Emerg Care* 1989;5(1):5-7** 74
Study of IO infusion by paramedics on pediatric patients (>5 years of age) in cardiac arrest. Paramedics completed a training program in IO technique. Observed 85% success rate (10 of 12 IO attempts). Discusses training methods, limitations and implications for future use.
- Orlowski JP, Porembka DT, Gallagher JM, Van Lente F. The bone marrow as a source of laboratory studies. *Ann Emerg Med* 1989;18(12):1348-51** 640
This article describes a pre-clinical study comparing bone marrow, venous blood, and arterial blood specimen results when used for blood electrolytes, blood chemistries, blood gases and hemoglobin; and a clinical evaluation of bone marrow and venous blood used for cultures.
- Seigler RS, Tecklenburg FW, Shealy R. Prehospital intraosseous infusion by emergency medical services personnel: a prospective study. *Pediatrics* 1989;84:173-7** 84
Prospective study finding EMS personnel able to successfully establish IO access in 16 of 17 pediatric patients with cardiopulmonary arrest. Observed 13 successful infusions within 1 minute on first attempts at IO access. No significant complications.
- Wheeler CA. Pediatric intraosseous infusion: an old technique in modern health care technology. *J Intraven Nurs* 1989;12(6):371-6** 76
Review article for a nursing audience presenting a brief historical overview of IO technique and insertion methods, with discussion of clinical applications and nursing management aspects.
- Zimmerman JJ, Coyne M, Logsdon M. Implementation of intraosseous infusion technique by aero medical transport programs. *J Trauma* 1989;29:687-9** 79
Observational study finding nearly 70% of aeromedical transport programs do not use IO infusion. Concludes IO to be grossly under-utilized. Calls for further consideration.

Intraosseous Vascular Access Bibliography

Emergency Care

YEAR: 1988

- Brillman JC. Intraosseous infusion for emergency intravascular access. *Top Emerg Med* 1988;10(1):75-80** 73
Description of IO infusion technique, site selection, procedure, anatomy, physiology, historical perspectives, contemporary research, indications, contraindications, complications, and future direction.
- Brunette DD, Fischer R. Intravascular access in pediatric cardiac arrest. *Am J Emerg Med* 1988;6(6):577-9** 63
Retrospective chart review of 33 pediatric patients finding 83% success in establishing IO infusion. IO and percutaneous peripheral catheterization were the quickest methods for vascular access. Observed no major and minimal delayed complications.
- Glaeser PW, Losek JD, Nelson DB, Bonadio WA, Smith DS, Walsh-Kelly C, Hennes H. Pediatric intraosseous infusions: impact on vascular access time. *Am J Emerg Med* 1988;6:330-2** 48
Retrospective chart review over a 1-year period finding IO reduced vascular access time in patients with cardiac arrest when standard techniques failed.
- Neish SR, Macon MG, Moore JW, Graeber GM. Intraosseous infusion of hypertonic glucose and dopamine. *Am J Dis Child* 1988;142(8):878-80** 69
Preclinical study finding IO infusion of hypertonic glucose and dopamine to be as effective as IV administration.
- Smith RJ, Keseg DP, Manley LK, Standeford T. Intraosseous infusions by prehospital personnel in critically ill pediatric patients. *Ann Emerg Med* 1988;17(5):491-5** 67
Concludes intraosseous infusion to be a safe and viable technique in the pre-hospital setting, especially in the aeromedical area.

YEAR: 1987

- Brillman JC. Intraosseous infusion for emergency vascular access. *West J Med* 1987;146(5):603** 641
A brief overview of intraosseous vascular access. The author concluded that IO vascular access is a firmly established practice based on scientific fact and clinical significance.
- Hodge D, Delgado-Paredes C, Fleisher G. Intraosseous infusion flow rates in hypovolemic "pediatric" dogs. *Ann Emerg Med* 1987;16(3):305-7** 58
Preclinical study of IO flow rates during hypovolemia. Concludes that IO flow rates may be insufficient for definitive treatment of severe hypovolemic or hemorrhagic shock.
- McNamara RM, Spivey WH, Unger HD, Malone DR. Emergency applications of intraosseous infusion. *J Emerg Med* 1987;5:97-101** 59
Several case reports illustrating the utility of IO in the emergency department. Includes discussion of IO administration of diazepam in succinylcholine.

YEAR: 1986

- Kanter RK, Zimmerman JJ, Strauss RH, Stoeckel KA. Pediatric emergency intravenous access. Evaluation of a protocol. *Am J Dis Child* 1986;140(2):132-4** 53
Evaluation of a sequential protocol comparing femoral vein catheterization, saphenous vein cutdown, and IO (in order) when conventional IV access was impossible in a pediatric patient population. Found that IV access was attained in 4.5 minutes when the protocol was followed, compared to 10 minutes when protocol was not followed. Suggests that IV access should always be attained in 5 minutes or less.
- Mayer TA. Emergency pediatric vascular access: Old solutions to an old problem. *Am J Emerg Med* 1986;4(1):98-101** 51
Discusses rediscovery of intraosseous infusion as a straightforward technique for an extremely difficult clinical problem. Suggests that many fluids and medications can be administered via the IO route.
- Parrish GA, Turkewitz D, Skiendzielewski JJ. Intraosseous infusions in the emergency department. *Am J Emerg Med* 1986;4(1):59-63** 47
Discusses IO route as a safe, proven, and technically easy method for administration of replacement fluids, blood products, and resuscitative drugs. Presents value, historical context, technique, and complications of the IO infusion.
- Walsh-Kelly CM, Berens RJ, Glaeser PW, Losek JD. Intraosseous infusion of phenytoin. *Am J Emerg Med* 1986;4(6):523-4** 52
Case report of child with status epilepticus. IO phenytoin resulted in seizure resolution and therapeutic serum levels of drug.

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Emergency Care

YEAR: 1985

Hodge D. Intraosseous infusions: a review. *Pediatr Emerg Care* 1985;1(4):215-8 44
Review of IO insertion techniques of insertion, clinical indications, contraindications, and complications.

Spivey WH, Lathers CM, Malone DR, et al.. Comparison of intraosseous, central, and peripheral routes of sodium bicarbonate administration during CPR in pigs. *Ann Emerg Med* 1985;14(12):1135-40 43
Preclinical study in pigs examining blood pH during CPR with sodium bicarbonate administered via different vascular access routes. Found that pH of blood obtained via central venous access and intraosseous access were significantly different from the peripheral group, and that all three groups were significantly different from the control. Pathology studies showed only minor damage to bone with IO sodium bicarbonate administration.

Turkel H. Emergency bone marrow infusions. *Am J Dis Child* 1985;139(5):438-9 45
Letter to the editor asserting that while the Turkel trephine technique may stabilize the IO needle better and minimize fluid leakage into the subcutaneous tissue, few physicians are familiar with the technique and it is more time-consuming than using a standard bone marrow needle or standard hypodermic needle.

YEAR: 1984

Berg RA. Emergency infusion of catecholamines into bone marrow. *Am J Dis Child* 1984;138(9):810-1 40
Case report of continuous IO infusion of dopamine hydrochloride and dobutamine hydrochloride in a 6 month old infant. Concludes that IO infusion is efficacious and complications rare.

Orlowski JP. My kingdom for an intravenous line. *Am J Dis Child* 1984;138(9):803 41
Seminal article on IO infusion by the "Father of IO." Drugs and fluids infused through the IO space enter the central circulation as rapidly as through IV routes. Unlike peripheral veins, the intramedullary blood vessels will not collapse in shock.

Rosetti V, Thompson BM, Aprahamian C, Darin JC, Mateer JR. Difficulty and delay in intravascular access in pediatric arrests. *Ann Emerg Med* 1984;13(5):406 39
Outlines problems with conventional vascular access in emergency medicine. Discusses possible resurgence of the "old" technique of intraosseous infusion.

Turkel H. Emergency infusion through the bone. *Military Medicine* 1984;149:349-50 38
Article for military medicine audience concluding that the intraosseous route is more safe and effective than the intravenous route for several clinical indications, including burns and shock, circulatory collapse, uncooperative patients, patients in transit, shortage of physicians, especially under emergency conditions. States that IO infusion is an established alternative to intravenous infusion.

YEAR: 1983

Turkel H. Intraosseous infusions. *South Med J* 1983;76(5):692 36
Recommends IO infusion of fluids in cases of shock, burns, mass casualties, and also for long term parenteral nutrition whenever peripheral veins cannot or should not be used.

YEAR: 1977

Valdes MM. Intraosseous fluid administration in emergencies. *Lancet* 1977;1(8024):1235-6 29
Observational study of 15 patients needing emergency fluids and in whom IV's were difficult to establish. Patients received drugs and fluids via IO. Concludes that IO therapy is effective with no serious complications.

YEAR: 1954

Marill F. Death from sternal puncture. *JAMA* 1954;155:1276 25
Case report of death following pericardial rupture with hemorrhage, associated shock, and peripheral circulatory collapse.

YEAR: 1941

Tocantins LM, O'Neill JF, Jones H. Infusion of blood and other fluids via the bone marrow: Application in pediatrics. *JAMA* 1941a; 117(5):1229-34 7
Describes emergency IO infusion of citrated blood and saline into the tibia or femur of 9 infants. IV access was impossible. Found no complications upon clinical or x-ray examination post-infusion.

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Emergency Care

Tocantins LM, O'Neill JF, Price AH. Infusions of blood and other fluids via the bone marrow in traumatic shock and other forms of peripheral circulatory failure. Ann Surg 1941;114:1085-92

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Early study of 4 patients with acute failure of the peripheral circulation. IO infusion of blood, fluids, or drugs via the bone marrow resulted in a prompt recovery from the state of collapse. Recommends IO route when peripheral veins are not available and a fluids are urgently needed.

Intraosseous Vascular Access Bibliography

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YEAR: 2019

- Burgert JM, Johnson AD, O'Sullivan JC, et al. Pharmacokinetic effects of endotracheal, intraosseous, and intravenous epinephrine in a swine model of traumatic cardiac arrest. *Am J Emerg Med* 2019;(in press). doi: 10.1016/j.ajem.2019.02.035** 1046
- This pre-clinical study compared various PK parameters, return of spontaneous circulation (ROSC), time to ROSC, and odds of ROSC after epinephrine was administered via endotracheal (ETT), IO, and IV routes in a swine traumatic cardiac arrest model (TCA). IO groups included sternal IO (SIO), humeral IO (HIO), and tibial IO (TIO). CPR only and CPR plus defibrillation (CPRD) groups were included for analyzing ROSC. The Cmax of the IV epinephrine group was significantly higher than that of the IO group (p=0.049). The tmax of the TIO group was significantly longer than that of all other groups (p=0.008). There were significant differences in mean plasma concentrations over time between the IV and TIO groups at 90, 120, 150, and 180 seconds (p<0.05) with the TIO group having an unexpectedly prolonged absorption phase. There was no difference in the rate of ROSC between ETT, TIO, HIO, SIO, IV and CPRD groups. The PK findings relative to ROSC support the concept that neither epinephrine nor the route of administration influenced the outcome. All IO insertions were performed using the EZ-IO device.
- Farrokh S, Cho SM, Lefebvre AT, Zink EK, Schiavi A, Puttgen HA. Use of intraosseous hypertonic saline in critically ill patients. *J Vasc Access* 2019;20(4):427-32. doi: 10.1177/1129729818805958. Epub 2018 Oct 17** 1052
- Retrospective case report of six patients describing the use of intraosseous (IO) administration for 23.4% saline administration to treat intracranial hypertension. In all six cases sodium levels were increased and there were no IO complications.
- Itoh T, Lee-Jayaram J, Fang R, Hong T, Berg B. Just-in-time training for intraosseous needle placement and defibrillator use in a pediatric emergency department. *Pediatr Emerg Care* 2018;35(10):712-15. doi:10.1097/PEC.0000000000001516.** 984
- This article describes a study comparing medical students' comfort level in performing IO needle placement and defibrillator use in a pediatric ED before and after just-in-time training (JITT). JITT sessions were facilitated by ED attending physicians. Sessions for IO placement included group discussion of the location of IO needle set, indications, contraindications, locations on the body for placement, confirmation of placement, and selection of appropriate needle size. Participants then had hands-on practice using the EZ-IO task trainer for the humerus and tibia. The comfort level increased from pre survey 0% to post survey 48% (P<0.0001).
- Jousi M, Björkman J, Nurmi J. Point-of-care analyses of blood samples from intraosseous access in pre-hospital critical care. *Acta Anaesthesiol Scand* 2019;63(10):1419-25. doi: 10.1111/aas.13443** 1069
- Investigators conducted a prospective, observational study to compare intraosseous (IO) blood samples to arterial samples obtained from 35 patients in the prehospital setting. Blood gases, acid-base balance, electrolytes, glucose and hemoglobin results were obtained using an i-STAT® POC analyser. The analysis was successful for 23 of the 33 patients with 7 failures due to technical problems (clotting, inability of device to analyse). For the parameters of BE, pH, HCO3, Gluc, iCa and Na the IO and arterial agreement was deemed acceptable enough that it may be useful for emergency patients until venous or arterial samples can be obtained; and limitations of IO sample use must be considered.
- Jousi M, Skrifvars MB, Nelskylä A, et al. Point-of-care laboratory analyses of intraosseous, arterial and central venous samples during experimental cardiopulmonary resuscitation. *Resuscitation* 2019;137:124-32. doi: 10.1016/j.resuscitation.2019.02.014** 1055
- This pre-clinical study compared IO, arterial, and venous point-of-care blood samples taken during cardiac arrest and CPR to pre-arrest arterial values to determine which method best reflected the pre-arrest state in a swine model. IO access was achieved using the EZ-IO device. The following parameters were assessed: partial pressure of oxygen, partial pressure of carbon dioxide, base excess, standard bicarbonate, pH, lactate, sodium, potassium, ionized calcium, glucose, and hemoglobin. The study found that these values change differently during cardiac arrest and CPR depending on the source of the sample. The authors suggest that if arterial or venous samples are not available then IO samples can be considered.
- Mansfeld A, Radafshar M, Thorgeirsson H, Hoijer CJ, Segerlantz M. Palliative sedation via intraosseous vascular access: A safe and feasible way to obtain a vascular access end of life. *J Palliat Med* 2019;22(1):109-111. doi: 10.1089/jpm.2018.0398** 1056
- This is a case report of IO access for palliative sedation with propofol in a 56-year-old man with no venous access. IO access was gained using an EZ-IO driver and the patient was successfully treated with propofol for 4 days to manage intractable pain and agitation.
- Sampson CS. Extravasation from a misplaced intraosseous catheter. *Clin Pract Cases Emerg Med* 2019;3(3):303-4** 1068
- A 75-year old female presented by EMS to the Emergency Department (ED) after a ventricular fibrillation cardiac arrest. EMS defibrillated the patient and placed a right proximal tibial EZIO intraosseous (IO) catheter which multiple medications (epinephrine, magnesium, amiodarone, and calcium chloride) were administered; and she had return of spontaneous circulation prior to ED arrival. The IO catheter wasn't patent upon arrival in the ED and was removed. The patient was discharged on day four with ecchymosis near the insertion site. Three weeks post discharge the patient presented with tissue necrosis in an area surrounding the initial proximal tibial IO insertion site. The patient's leg was debrided and grafting was performed; the author reported "good healing" three months post-event.

Intraosseous Vascular Access Bibliography

Arrow® EZ-IO®

Sørgjerd R, Sunde GA, Heltne JK. Comparison of two different intraosseous access methods in a physician-staffed helicopter emergency medical service - A quality assurance study. *Scand J Trauma Resusc Emerg Med* 2019;27(1):15 doi: 10.1186/s13049-019-0594-6

1062

This study compared IO insertions with the EZ-IO device (tibial/humeral insertions) to the FAST-R device (sternal insertions only) in a physician-staffed helicopter emergency medical service. Insertion time, insertion site, flow, indication for IO access, and complications were compared. Median insertion time was 15 seconds for EZ-IO and 20 seconds for FAST-R. Overall, 35.1% of EZ-IO insertions resulted in poor flow and required a pressure bag while 85.7% of FAST-R insertions had good or very good flow. EZ-IO complications included extravasation (2.4%), aspiration failure (11.9%), and insertion time >30 seconds (4.8%). Complications associated with FAST-R included user failure (12.5%) and insertion time >30 seconds (12.5%). The authors suggest that although EZ-IO is faster the FAST-R device may be more useful when high-flow infusion rates are required. The authors indicate that a low number of insertions were made with the FAST-R device and many outliers were observed in the data. However, the article does not present the total number of insertions per device.

Wiegele M, Hamp T, Gratz J, Pablik E, Schaden E. Comparison of ROTEM parameters from venous and intraosseous blood. *Sci Rep* 2019;9(1):3741. doi: 10.1038/s41598-019-40412-0

1064

This study sought to investigate the reliability of ROTEM parameters in IO blood for the purpose of allowing a target-oriented administration of procoagulant agents in patients with IO access only. Healthy subjects and subjects undergoing minor surgery under anesthesia were enrolled. The EZ-IO device was used to obtain IO samples. Tibial and humeral sites were used. Due to clotting in a majority of samples, only 9/23 samples were evaluable and ROTEM was feasible in only 3/23. The authors conclude that ROTEM measurements from IO samples are not reliable and should not be used for guidance of procoagulant therapy in the emergency setting.

YEAR: 2018

Abramson TM, Alreshaid L, Kang T, Mailhot T, Omer T. Fasciotomy: Ultrasound evaluation of an intraosseous needle causing compartment syndrome. *Clin Pract Cases Emerg Med* 2018;2(4):323-25

1041

This case review describes a complication of compartment syndrome post IO placement in a 64 year old male initially unresponsive and hypoglycemic. Approximately 15 minutes post-ED arrival compartment syndrome signs were noted and confirmed with compartment pressures. An ultrasound confirmed lack of flow from the IO needle and x-ray showed the needle set to be inserted 2 mm beyond the posterior tibial cortex. Patient was taken to surgery for fasciotomy and four compartment release with subsequent return of pulses.

*(Correspondence by the manufacturer 12-2018 with lead author confirmed the tibial placement was lateral and the patient had a full functional recovery).

Akman N, Braunschweig T, Honickel M, et al. Reversal of dabigatran by intraosseous or intravenous idarucizumab in a porcine polytrauma model. *Br J Anaesth* 2018;120(5):978-87. doi: 10.1016/j.bja.2018.01.027

956

This study compared the efficacy and safety of IO versus IV idarucizumab for dabigatran reversal in a porcine polytrauma model. Twenty-one male pigs received oral dabigatran for 3 days and on the 4th day received dabigatran infusion while another 7 received a sham treatment. The treated pigs were then randomized to one of three groups; IO saline, IV idarucizumab, IO idarucizumab while the other 7 comprised the sham group. The pigs were subjected to polytrauma (femur fracture and blunt liver injury). Blood loss, hemodynamic values, and blood samples were measured and recorded. Blood loss was highest in the control group, followed by the two idarucizumab groups, and lowest in the sham group. Survival to 240 minutes was 100% in the sham group and both idarucizumab groups, and 14% in the control group. IO and IV idarucizumab promptly normalized global coagulation assays and thrombin generation and were comparable for reversing dabigatran.

Auten J, Mclean JB, Kemp JD, et al. A pilot study of four intraosseous blood transfusion strategies. *J Spec Oper Med* 2018;18(3):50-6

1042

This pilot study compares four different IO blood transfusion strategies with varying degrees of transfusion pressure in a swine model with similar bone density to that of an adult military servicemember. Animals were randomly assigned to one of four transfusion strategies: 1) gravity, 2) pressure-bag, 3) rapid-transfusion device, or 4) manual push-pull. Hemorrhage was simulated then IO access was obtained with the EZ-IO device. Gravity transfusion was the slowest with a flow rate 5 mL/min, followed by rapid transfusion device (31 mL/min), single site pressure bag (78 mL/min), double site pressure bag (103 mL/min), and push-pull technique (109 mL/min). Single site or double site pressure bag was determined to be the best option for IO infusion because of the high flow rate and no associated incidences of overpressure or death.

Bjerkvig CK, Fosse TK, Apelseth TO, et al. Emergency sternal intraosseous access for warm fresh whole blood transfusion in damage control resuscitation. *J Trauma Acute Care Surg* 2018;84(6S):S120-4. doi:10.1097/TA.0000000000001850. (Norway)

962

This article describes a prospective, comparative, nonrandomized study to compare flow rates using the sternal IO route with two different devices (EZ-IO and Fast1) when transfusing warm fresh whole blood as well as measuring post-infusion hemolysis when compared to IV infusion. Post procedure blood samples from all patients were within normal ranges with no statistically significant differences between groups. This study had a high catheter insertion failure rate in the IO groups. This was most likely due to subjects, healthy Norwegian military volunteers, performing the procedures on each other. The results suggest that infusion of fresh whole blood via the IO route is safe and reliable.

Intraosseous Vascular Access Bibliography

Arrow® EZ-IO®

- Bowry R, Nour M, Kus T, et al. Intraosseous administration of tissue plasminogen activator on a mobile stroke unit. *Prehosp Emerg Care* 2018;25:1-6. doi:10.1080/10903127.2018.1526355** 963
- This study describes 3 cases in which tissue plasminogen activator (tPA) was administered via intraosseous (IO) access on a mobile stroke unit as part of the BEST-MSU study. IO access was obtained with the EZ-IO device as part of the study protocol.
- Burgert J, Martinez A, O'Sullivan M, Blouin D, Long A, Johnson A. Sternal route more effective than tibial route for intraosseous amiodarone administration in a swine model of ventricular fibrillation. *Prehosp Emerg Care* 2018;22(2):266-75. doi:10.1080/10903127.2017.1358782** 903
- This study examined the measured mean plasma concentration, maximum plasma concentration (Cmax), and time to maximum concentration (Tmax) of amiodarone administered by 3 different routes, sternal IO (SIO), tibial IO (TIO), and IV over a time period of 5 minutes in 21 swine who were randomly assigned to one of the 3 routes. The swine were under general anesthesia and ventricular fibrillation was induced and CPR initiated. After 4 minutes in ventricular fibrillation the swine were administered 300 mg of amiodarone and blood samples were taken at 30 second intervals over 300 seconds. Authors concluded that the SIO and IV routes of amiodarone were comparable. The TIO group took almost 3 times longer to reach Tmax than the SIO and IV groups. In the swine model used in this study, the authors concluded that SIO route was more effective than the TIO route for the amiodarone delivery in a swine with VF and ongoing CPR.
- Chalopin T, Lemaigen A, Guillon A, et al. Acute tibial osteomyelitis caused by intraosseous access during initial resuscitation: a case report and literature review. *BMC Infectious Diseases* 2018;18(1):665. doi: 10.1186/s12879-018-3577-8** 1047
- This report from France reports a case of tibial osteomyelitis in a 40 year old male that was diagnosed by MRI and biopsy three months post-intraosseous (IO) catheter removal. The patient was given parenteral as well as oral antibiotics and had a good outcome. The initial IO catheter placement was for treatment of overdose after failed IV attempts. The catheter was removed on the first day and the patient was treated with oral antibiotics due to local inflammation at the insertion site. He left against medical advice before a full treatment course was completed.
- Chin SJ, Moore GA, Zhang M, et al. The AAHKS clinical research award: Intraosseous regional prophylaxis provides higher tissue concentrations in high BMI patients in total knee arthroplasty: A randomized trial. *J Arthroplasty* 2018;33(7S):S13-8. doi:10.1016/j.arth.2018.03.013.** 966
- This study compared tissue concentrations of low-dose vancomycin via intraosseous regional administration (IORA) vs actual body weight-adjusted IV dosing in total knee arthroplasty (TKA) in obese patients (BMI>35). The obese patient population has an increased risk of periprosthetic joint infection after TKA. 22 patients were randomized to receive either 15mg/kg (max 2 g) of systemic vancomycin or 500 mg vancomycin via IORA. Fat and bone samples were taken and antibiotic concentrations measured. The overall mean tissue concentration in the subcutaneous fat was 39.3 µg/g in the IORA group vs 4.4 µg/g in the IV group (P<0.01). Mean tissue concentrations in bones were 34.4 µg/g in the IORA group vs 6.1 µg/g in the IV group (P<0.01). Low-dose IORA vancomycin was effective in providing tissue concentrations 5-9 times higher than IV administration in this high risk patient population.
- Cho Y, You Y, Park JS, et al. Comparison of right and left ventricular enhancement times using a microbubble contrast agent between proximal humeral intraosseous access and brachial intravenous access during cardiopulmonary resuscitation in adults. *Resuscitation* 2018;129:90-3. doi:10.1016/j.resuscitation.2018.06.014** 967
- This study was a prospective, single-center, observational, cohort study of 10 patients comparing the ventricular enhancement time between humeral intraosseous (HIO) access and brachial intravenous (BIV) access during CPR in adult humans. HIO access was obtained with the EZ-IO device. Endpoints were right and left ventricular enhancement times after administration of a contrast agent. Results indicated that arrival times of medication at the right and left ventricles were significantly lower with HIO than BIV.
- Collins T. Intraosseous access use in chemical, biological, radiation, and nuclear personal protective equipment. *Prehosp Emerg Care* 2018;22(1):10. http://dx.doi.org/10.1080/10903127.2017.1377791** 910
- The objective of this study was to evaluate success and ease-of-use ratings when experienced paramedics attempted EZ-IO intraosseous (IO) access in a cadaveric model when wearing their standard uniform and wearing Chemical, Biological, Radiation and Nuclear (CBRN) personal protective equipment. There was no significant difference for the tasks of land marking, humeral site insertion, saline flush, holding and manipulating driver and catheter removal. Insertion times were statistically longer (by 9.4 seconds) wearing CBRN. Investigator concluded IO access can be effectively and promptly achieved while wearing CBRN.
- Crawford SB. Intraosseous vascular access device as a transarticular k-wire alternative in mallet finger laceration. *Clin Pract Cases Emerg Med* 2018;2(1):71-4. doi:10.5811/cpcem.2017.7.34811** 969
- This case study discusses the use of an IO vascular access device (EZ-IO) as a substitute for k-wire stabilization of mallet finger in a patient with distal fracture and tendon exposure of the third and fourth phalange. The needle driver of the EZ-IO was placed in a sterile glove and was then used to place the inner stylet of the device through the tip of the finger to achieve splint fixation in extension. The patient had a favorable outcome.

Intraosseous Vascular Access Bibliography

Arrow® EZ-IO®

- Czyz R, Wudarczyk, Leskiewicz M, Czyz I. Current advances in intraosseous access - A review of presently available devices. J Ed Health Sport 2018;8(8):939-50. doi: 10.5281/zenodo.1406964** 1049
- This paper provides a brief overview of the following IO needles and devices: the Dieckmann Modified Needle, the EZ-IO Manual Needle Set, the EZ-IO T.A.L.O.N Needle Set, the Jamshidi Needle, the Bone Injection Gun (BIG), the New Intraosseous Device (NIO), the FAST Responder Sternal Intraosseous Device, and the EZ-IO Intraosseous Vascular Access System.
- Durnford S, Bulstrode H, Durnford A, Chakraborty A, Tarmey NT. Temporising an extradural haematoma by intraosseous needle craniostomy in the District General Hospital by non-neurosurgical doctors-A case report. J Intensive Care Soc 2018;19(1):76-9. doi:10.1177/1751143717734997** 971
- This is a case report of a 69 year-old male admitted to an ED in the UK with an extradural hematoma following closed head injury. He was treated with decompression of the hematoma using a 25 mm long EZ-IO intraosseous needle. This is believed to be the first reported use of an EZ-IO device in this manner in the UK. The patient succumbed to his injuries two days later. However, the authors recommend consideration of this technique when transfer to a hospital with a neurosurgery unit for craniostomy is not a feasible option.
- El-Nawawy AA, Omar OM, Mona Khalil M. Intraosseous versus intravenous access pediatric septic shock patients admitted to Alexandria University Pediatric Intensive Care Unit. J Trop Pediatr 2018;64(2):132-40. doi:10.1093/tropej/fmx061** 932
- Prospective randomized clinical trial in which IO access was compared to peripheral intravenous access (PIV) in pediatric patients with septic shock. Children's ages ranged from 1 month to 36 months old and weights ranged from 4 to 14 kg with similar characteristics in both groups; 30 patients in each subset. The IO group had significantly shorter vascular access insertion times, shorter length of stay and reduced mortality. IO access was achieved in the proximal tibia on first attempt for all insertions; 50% of PIV attempts failed on first attempt. There were no complications for the IO subset compared to 26.7 % for PIV. There was a reduced ability to aspirate for labwork via the IO access. This study supports existing literature that early use of IO insertion is safe and effective with minimal complications.
- Feldman O, Nasrallah N, Bitterman Y, et al. Pediatric intraosseous access performed by emergency department nurses using semiautomatic devices: A randomized crossover simulation study. Pediatr Emerg Care 2018;00:1-5. doi:10.1097/PEC.0000000000001621** 975
- This study evaluated emergency department (ED) nurses' success rate, compared with paramedics, in establishing pediatric IO access using semiautomatic devices. The NIO and EZ-IO devices were used by both nurses and paramedics on uncooked bones of 8- to 12-week old piglets. A total of 34 and 30 insertion attempts were performed by 17 ED nurses and 15 paramedics, respectively. First attempt success rates were 79.4% for nurses and 83.3% for paramedics. 82.3% of nurses and 73.3% of paramedics recorded the EZ-IO as their "first choice device". The findings of this study suggest that ED nurses have the competence to perform IO insertions and this technique should be used in nursing school curriculum.
- Fenwick R, Nutbeam T, Lowther A, Mann T. Maximising flow in intraosseous: An in vitro study. Poster presented at: Trauma Care Conference; April 15, 2018; Staffordshire, United Kingdom** 976
- This poster presents the findings of an in-vitro study to measure the time taken to administer 500 mL of saline via the intraosseous (IO) route using three different methods of administration: fluid giving set placed directly on the IO needle hub (DTO), fluid giving set connected to the EZ-IO device extension set (EVS), and fluid giving set connected to a simple 3-way extension set (TWS). The EVS set produced the slowest administration times. The authors concluded that clinicians may be able to increase IO flow rates by replacing the extension set that is supplied with the EZ-IO.
- Fuchs Z, Scaal M, Haverkamp H, Koerber F, Persigehl T, Eifinger F. Anatomical investigations on intraosseous access in stillborns - Comparison of different devices and techniques. Resuscitation 2018;127:79-82** 978
- This article investigates the success rate of IO access in preterm and term stillborns using two different needles (21G butterfly and 15G EZ-IO) inserted manually and one battery-powered semi-automatic drill (EZ-IO). All insertions were performed on the tibia. Estimated success rates were 61.1% for the butterfly needle, 43.0% for the hand twisted EZ-IO, and 39.7% for the EZ-IO drill. The authors conclude that IO access in premature and term neonates is best achieved by manual access with a twisted butterfly needle.
- Gendron B, Cronin A, Monti J, Brigg A. Military medic performance with employment of a commercial intraosseous infusion device: A randomized, crossover study. Mil Med 2018;183(5-6):e216-22. doi:10.1093/milmed/usx078** 933
- Randomized crossover prospective study in which 77 of U.S. Army Combat Medics naive to the EZ-IO system were trained and then attempted IO access using the EZ-IO in bone models of the proximal tibial (PT) and proximal humerus (PH) sites. Success rate was the primary outcome with no significant differences in results between sites; and no significant learning or design confounding effects. Secondary outcomes of mean procedural time demonstrated a significant mean time advantage of 17.1 s ($p < 0.05$) in PT placement. There was no significant difference between sites for mean participant comfort level utilizing the EZ-IO® System. Authors concluded the overall first-attempt success rates with the EZ-IO® System are similar to the success rates of the FAST1® device.

Intraosseous Vascular Access Bibliography

Arrow® EZ-IO®

Markic J, Polic B, Mestrovic J, Kovacevic T, Zanchi I. Successful intraosseous therapy using EZ-IO system in a preterm neonate below 2 kg. *Minerva Pediatr* 2018;70(1):104-5. doi:10.23736/S0026-4946.16.04707-1. (Croatia) 928

This paper is a letter to the editor describing successful insertion of EZ-IO in a neonate weighing less than 2 kg with respiratory failure, signs of sepsis, and shock. After successful insertion the patient was resuscitated and later stabilized. The authors advise that IO access is safe, effective, and attainable in all age groups despite FDA approval only in patients greater than 3 kg.

Morgan R. Novel method for splinting a flail chest. *Trauma* 2018;20(4):317-8 997

This abstract describes a new technique for splinting the rib cage after a trauma resulting in flail chest using a pediatric EZ-IO needle driven through splint material and skin then into the ribs to achieve rapid fixation.

Pifko E, Price A, Busch C, et al. Observational review of paediatric intraosseous needle placement in the paediatric emergency department. *J Paediatr Child Health* 2018;54(5):546-50. doi:10.1111/jpc.13773 1011

This study compared the success rates and time to placement for Manual IO versus EZ-IO needles in pediatric emergency department (PED) patients ≤8 kg and >8 kg at a single institution. It was a retrospective, cross-sectional, descriptive study. All identified patients with an IO attempted in the PED were included. Fifty patients were identified. In patients ≤8 kg, overall success rates were 55% (17/31) for Manual IO and 47% (8/17) for EZ-IO. In patients >8 kg, Manual IO success rates were 100% (2/2) and EZ-IO success rates were 93% (14/15) for overall attempts. Time (minutes) to successful placement in patients ≤8 kg was 4.5 for Manual IO vs 12.8 for EZ-IO (P=0.02). In patients >8 kg, time to successful placement was 8.5 for Manual IO vs 10.2 for EZ-IO (P=0.70). Overall success rates in this study were poor in both groups, most likely due to lack of experience at IO insertion or inadequate device training. Access in smaller patients was more difficult and required greater time to insertion.

Reic C, Fogg T, Healy G. Deformation of a humeral intraosseous catheter due to positioning for thoracostomy. *Clin Exp Emerg Med* 2018;5(3):208-9 1013

This article describes a complication of a deformed EZ-IO catheter which was noted following removal of the catheter in an adult patient. The catheter had been placed by a helicopter emergency medical service team following a motor vehicle accident. The cause of the catheter bending was most likely the result of arm positioning for thoracostomy. No difficulties in removing the catheter were noted and it appeared to have been functioning effectively.

Rideout M, Raszka W. Hypovolemic shock in a child: A pediatric simulation case. *MedEdPORTAL* 2018;14:10694. doi:10.15766/mep_2374-8265.10694 1060

This is a learning module for fourth year medical students to learn about fluid management and IO needle placement. The module simulates hypovolemic shock in a 3 year old patient using a child mannequin. An IO kit, including an EZ-IO driver, is supplied for obtaining IO access. A pilot study was conducted in 2017 with 16 subinterns on a pediatric service. Perceived competence in management of volume depletion and procedural skills were high following the training session and students felt the case was a beneficial learning experience.

Rodda LN, Volk JA, Moffat E, et al. Evaluation of intraosseous fluid as an alternative biological specimen in postmortem toxicology. *J Anal Toxicol* 2018;42(3):163-9. doi: 10.1093/jat/bkx096 1014

This article investigates intraosseous fluid (IOF) as an alternative matrix for drug testing in deceased patients, especially in cases where the cadaver is severely compromised following death. IO access was obtained at 4 sites, bilateral proximal tibia and bilateral proximal humerus, using the EZ-IO device. Samples in 29 subjects were collected and screened for a host of illicit substances. Study results support the possible use of IOF as an alternative postmortem specimen for toxicological investigations when necessary.

Sawyer T, Nishisaki A. Intraosseous access during newborn resuscitation: It may be fast, but is it safe? *Pediatr Crit Care Med* 2018;19(5):499-501. doi:10.1097/PCC.0000000000001513 1017

This article examines emergency vascular access during newborn resuscitation. It discusses the time needed to place an emergency umbilical vein catheter (eUVC) and intraosseous kits (EZ-IO) in a series of simulated newborn resuscitations across 4 studies. In all 4 studies IO placement was significantly faster than eUVC placement. An additional study found eUVC placement to be significantly faster with real human umbilical cords than with simulated umbilical cords as used in the aforementioned studies. While IO access in newborns appears faster than eUVC in simulated models, to date, no randomized trials or large case-cohort studies have systematically evaluated the short and long-term safety of IO placement during newborn resuscitation. Current guidelines still support eUVC as the preferred method of obtaining vascular access during newborn resuscitation. The authors suggest further studies are needed to determine short and long-term safety of IO access in newborns before widespread adoption of the process can be recommended.

Schwindt EM, Hoffmann F, Deindl P, Waldhoer TJ, Schwindt JC. Emergency vascular access and how to accelerate it: A simulation-based study performed in real-life neonatal resuscitation rooms. *Pediatr Crit Care Med* 2018;19(5):468-76. doi:10.1097/PCC.0000000000001508 934

In neonatal training events in 16 hospitals over two years, clinicians with neonatal experience simulated resuscitation of an asphyxiated newborn and were recorded for retrospective analysis. Clinicians could choose either umbilical venous catheter (UVC) or intraosseous access (IO), using the EZ-IO device for vascular access. Delays for both procedures were related to equipment availability and lack of familiarity; training and prepackaged kits may decrease this variable. IO access was more than twice as fast to obtain than eUVC access.

Intraosseous Vascular Access Bibliography

Arrow® EZ-IO®

Simsek P, Bayram SB, Gursay A. İlaç uygulamaları için farklı bir yol:

Intraosseöz ulaşım ve infüzyon [A different route for drug administration: Intraosseous access and infusion]. HEAD 2018;15(1):40-44. doi: 10.5222/HEAD2018.040. Turkish

1061

This is an article published in a Turkish nursing journal and written in Turkish. From the abstract, the IO route is described as an alternative approach to vascular access when venous access via a peripheral catheter cannot be obtained quickly. Complications of IO access and how to prevent them using nursing interventions are discussed. EZ-IO is discussed in the article.

Szarpak L, Ladny JR, Dabrowski M, et al. Comparison of 4 pediatric intraosseous access devices: A randomized simulation study. Pediatr Emerg Care 2018;00:1-5. doi:10.1097/PEC.0000000000001587. [Epub ahead of print]

1026

This study aimed to compare the success rates of 4 commonly used IO devices (NIO Pediatric, BIG Pediatric, EZ-IO, and a manual Jamshidi IO needle) in a pediatric model. Speed of insertion, ease of use, and complications were secondary outcomes. Seventy-five novice physicians from Warsaw, Poland participated in this study; none of whom had prior experience with IO devices. First attempt success rates were 43% (Jamshidi), 90% (BIG), 97% (EZ-IO), and 100% (NIO-P). Median time to achieve IO access was 18 seconds (NIO), 23 seconds (EZ-IO and BIG), and 34 seconds (Jamshidi). 39/68 participants preferred the NIO device, 18/68 preferred the EZ-IO device, 11/68 preferred the BIG device, and none of the participants preferred the Jamshidi needle.

Wagner M, Olischar M, O'Reilly M, et al. Review of routes to administer medication during prolonged neonatal resuscitation. Pediatr Crit Care Med 2018;19(4):332-8. doi: 10.1097/PCC0000000000001493

1029

This article presents a review of current evidence regarding different routes for the administration of medications during neonatal resuscitation, of which the intraosseous route is included. A table comparing four different intraosseous devices, including EZ-IO, is presented in the document.

Winkler M, Issa M, Lowry C, Chornenkyy Y, Sorrell V. Intraarticular extravasation, an unusual complication of computed tomographic angiography performed with intraosseous needle intravenous access. Cardiovasc Diagn Ther 2018;8(4):516-9. doi:10.21037/cdt.2018.06.04

1033

This paper describes a case study of a 66 year-old female who presented to an emergency department with symptoms of an acute stroke. After failure of intravenous (IV) placement, humeral intraosseous (IO) access was obtained using the EZ-IO device. Contrast media (CM) for computed tomographic angiography (CTA) was later infused, off label, through the IO line. At the time of the CT scan 20 mL of CM was seen within the glenohumeral joint. The patient did not experience any ill effects from the extravasation following the procedure nor at her 1 week follow-up.

Young SW, Zhang M, Moore GA, Pitto RP, Clarke HD, Spangehl MJ. The John N. Insall Award: Higher tissue concentrations of vancomycin achieved with intraosseous regional prophylaxis in revision TKA: A randomized controlled trial. Clin Orthop Relat Res. 2018;476:66-74

1066

This is a prospective, randomized, controlled trial of patients undergoing revision total knee arthroplasty (TKA). Twenty patients were randomized to receive systemic IV or IO regional administration (IORA) of vancomycin as prophylaxis. Higher tissue and bone concentrations were consistently achieved in the IORA group with tissue concentrations during the procedure 5 to 20 times higher in the IORA group versus the IV group. The EZ-IO device was used to gain IO access in this study.

YEAR: 2017

Afzali M, Kvisselgaard AD, Lyngeraa TS, Viggers S. Intraosseous access can be taught to medical students using the four-step approach. BMC Medical Education 2017;17(50):doi:10.1186/s12909-017-0882-7. (Denmark)

831

This study evaluated the ability to teach the skill of IO access in a four hour timeframe to medical students using a modified Walker and Peyton's four-step approach teaching method and a cadaveric model. The learner's competencies were evaluated with an objective structured clinical examination checklist. This study found the teaching method was successful. Authors recommend repetitive training to be integrated to medical curriculum for maximal skill retention.

Bewick VJ. Intraosseous cannulation in children. Anaesth Intens Care Med 2017;18(11):551-4. UK

961

This article describes the anatomy and physiology of IO cannula insertion as well as indications and contraindications of IO use. Devices and techniques as applied to the pediatric population are discussed, including EZ-IO.

Bielski K, Szarpak L, Smereka J, Ladny J, Leung S, Ruetzler K. Comparison of four different intraosseous access devices during simulated pediatric resuscitation. A randomized crossover manikin trial. Eur J Pediatr 2017;176(7):865-71. doi:10.1007/s00431-017-2922-z

899

This study compared success rate, procedure time and user satisfaction of pediatric NIO vs. Pediatric BIG, EZ-IO and Jamshidi intraosseous access devices in pediatric manikins. Study was randomized, crossover trial with 87 paramedics participating. The study evaluated each device on the ease of use in performing their procedures. Results of this study found that paramedics favored the NIO in ease of use in the pediatric manikins.

Intraosseous Vascular Access Bibliography

Arrow® EZ-IO®

- Boysen SR, Pang JM, Mikler JR, Knight CG, Semple HA, Caulkett NA. Comparison of tranexamic acid plasma concentrations when administered via intraosseous and intravenous routes. Am J Emerg Med 2017;35(2):227-33. doi:http://dx.doi.org/10.1016/j.ajem.2016.10.054** 867
- Swine study comparing pharmacokinetic (pK) parameters of TXA given by the IO vs IV route. For the 4 min and 5 min results Cmax plasma concentrations were higher in the IV group but similar from injection completion onwards. Other pK parameters were not significantly different. Limitations included swine model, normotensive animals and proximity of sampling site (jugular vein) to the IV infusion site (auricular). Investigators concluded this study supports the pharmacokinetic bioequivalence of IO and IV administration of TXA in this animal model.
- Bromberg R, Dave K, Mankodi D, Danckers M. Soft tissue laceration caused by lower extremity intraosseous access insertion in an obese patient. BMJ Case Rep 2017;doi:10.1136/bcr-2017-220069. (United Kingdom)** 938
- This case report describes a complication of a laceration that occurred in an 85 year old morbidly obese female that presented in septic shock and received a proximal tibial IO placement. A 45 mm needle set was used for the initial insertion, which was completed without any initial problems; no stabilizer was placed. The patient had fluid resuscitation via the IO site with rapidly improved hemodynamics. During transport she developed a 7 cm laceration across the IO insertion site. The catheter was removed and laceration sutured. Authors opined that the lack of use of the EZ-Stabilizer dressing, the amount of soft tissue and thin skin and traction forces on the IO site applied during transport contributed to this complication.
- Budach NM, Niehues SM. CT angiography of the chest and abdomen in an emergency patient via humeral intraosseous access. Emerg Radiol 2017;24(1):105-8. doi:10.1007/s10140-016-1438-6. (Germany)** 823
- This case report describes a CT angiography of the chest and abdomen done via an EZ-IO catheter placed in a critically ill patient's proximal humerus. The contrast media was infused at a rate of 4 mL/s and the infusion pressure never exceeded 300 mmHg. No immediate or short term complications were observed. The authors describe the overall image quality and vessel contrast observed as excellent.
- Bulstrode H, Kabwamab S, Durnford A, Hempenstall J, Chakraborty A. Temporising extradural haematoma by craniostomy using an intraosseous needle. Injury 2017;45(5):1098-1100. doi:10.1016/j.injury.2017.02.011** 939
- This case report describes use of an intraosseous needle for initial management of increased intracranial pressure from an extradural bleed in a 43 year old female with a traumatic head injury. The patient was taken to surgery for a craniotomy and recovered without deficit.
- Burgert JM, Johnson AD, Garcia-Blanco J, Fulton LV, Loughren MJ. The resuscitative and pharmacokinetic effects of humeral intraosseous vasopressin in a swine model of ventricular fibrillation. Prehosp Disaster Med 2017;32(3):305-10. doi:10.1017/S1049023X17000140** 940
- This preclinical study reported data evaluating the pharmacokinetics of HIO and IV vasopressin and the ROSC in a swine model of ventricular fibrillation cardiac arrest. For the parameters of occurrence of ROSC, odds of ROSC, time to ROSC, Cmax, Tmax, and plasma concentrations over time, the IO and IV routes results were comparable.
- Collins T. Intraosseous access is effective whilst wearing CBRN protective equipment [abstract 31]. BMJ Open 2017;7(Suppl3):A1-A18. doi: 10.1136/bmjopen-2017-EMSabstracts.31** 1048
- This is an abstract of a cross-over study comparing the ease-of-use and success rates of cadaver IO insertions performed by paramedics while wearing their standard pre-hospital clothing or Chemical, Biological, Radiation and Nuclear (CBRN) personal protective equipment. There were no statistically significant differences between groups for ease-of-use scores, however, scores were generally lower in the CBRN group. Insertion times were significantly longer while wearing CBRN (25 seconds vs 34.38 seconds). IO access was obtained using the EZ-IO device.
- Iskrzycki L, Smereka J, Szarpak L. Knowledge, skills, and attitudes concerning intraosseous access among hospital physicians. Crit Care Med 2017;45(1):e117** 876
- This letter to the editor describes a manikin study that compared use of the Teleflex EZ-IO to the Persys Medical NIO intraosseous vascular access devices. Insertion times were statistically different, favoring the NIO but not considered clinically relevant. The authors concluded that, while hospital physicians' knowledge of intraosseous access was limited, with simple training they could learn the procedure and place IO needles safely in less than 30 seconds.
- Jansen G, Leimkuhler K, Mertzlufft F. Intramedullary placement of intraosseous cannulas inserted in the preclinical treatment of polytrauma patients: A retrospective, computed tomography-assisted evaluation. Anaesthesist 2017;66(3):168-76. doi:10.1007/s00101-016-0257-1** 985
- This article describes a retrospective, CT-assisted evaluation of IO cannula placement. Over a 5 year period all multislice-CT trauma scans performed in a trauma center were monitored for intraosseous devices in situ. 982 patients were evaluated and 13 IO cannulas were found in 11 patients. In all cases, the EZ-IO device was used. Evaluation of placement found that all applications were placed correctly, but none were according to current guidelines. The site of puncture deviated in all cases with the most common error of overshooting during needle introduction. (Article in German)

Intraosseous Vascular Access Bibliography

Arrow® EZ-IO®

- Jousi M, Saikko S, Nurmi, J. Intraosseous blood samples for point-of-care analysis: Agreement between intraosseous and arterial analyses. *Scand J Trauma Resusc Emerg Med* 2017;25(1):92. doi:10.1186/s13049-017-0435-4** 945
- Study using 31 healthy volunteers to evaluate IO blood samples drawn from the proximal tibia compared to arterial and venous samples using a POC lab device. Two samples were drawn from each site with no significant difference observed in the results with or without waste blood. Results varied particularly between the arterial and IO samples; and for several parameters. Authors concluded that IO blood samples may be evaluated using the i-STAT® point-of-care analyser; and results should be interpreted with care in the clinical situation context.
- Lee E. The first time. *Ann Emerg Med* 2017;70(1):99-100. DOI: <https://doi.org/10.1016/j.annemergmed.2017.01.021>** 883
- This case study describes a resident's experience treating an infant in respiratory arrest. Among the interventions were tibial intraosseous vascular access using the Arrow® EZ-IO and administration of epinephrine. The baby did not survive.
- Montez DF, Puga TA, Ruiz S, Philbeck TE. Accuracy of intraosseous lab values drawn after fluid infusion. *Ann Emerg Med* 2017;70(4 Suppl):S27. <https://doi.org/10.1016/j.annemergmed.2017.07.088>** 923
- This abstract describes a preclinical study conducted to determine how long an infusion must be stopped before drawing an IO specimen for analysis; to determine if there is a difference between IO specimen results when the first 2 mL of IO blood were discarded and not discarded; and add to existing data comparing lab results from IO vs. CVC access. Lab specimens were drawn following infusion of 0.9% NS and analyzed using a point-of-care analyzer and cartridge system. Results indicated the initial specimen drawn from the IO catheter for tested analytes may be considered for sampling, if those values are needed, and IO infusion is occurring, a wait time of two minutes post-stopping the infusion may be adequate for analysis; and IO specimen values are comparable to CVC values. This study was sponsored by Teleflex Incorporated.
- Salzman JG, Loken NM, Wewerka SS, et al. Intraosseous pressure monitoring in healthy volunteers. *Prehosp Emerg Care* 2017;21(5):567-74. doi:10.1080/10903127.2017.1302529** 927
- This article describes a prospective, observational study that attempted to establish baseline values of IO pressure (IOP) in a healthy human population. Subjects had an IO device placed in the tibia and humerus. IO pressures, vital signs, and pain scores were monitored for 60 minutes. Absolute IOP values were not consistent between subjects. Future research is needed to determine how IO pressure can be used to guide therapy in ill and injured patients.
- Santos AP, Conkin R, Dowd K. Needle break: Complication and management of intraosseous vascular access. *Am Surg* 2017;83(1):e18-20** 1016
- This report describes a case study of a 19 year-old male who had an IO catheter placement in the left proximal tibia with EZ-IO after sustaining injuries in a motorcycle accident. Upon removal of the IO access, the needle broke at the hub with the retained needle no longer exposed above the skin. Removal at the bedside using Hemostat forceps failed, as well as the use of a sternal needle holder and a wire twister. Under fluoroscopic guidance, a 4 mm Stryker Crown drill bit was used to remove the retained needle by coring it out of the bone. The site was irrigated, bone graft substitute was placed into the defect, and the surgical site was closed. The patient healed well and was discharged with no complications 3 days later.
- Shina A, Baruch EN, Shlaifer A, et al. Comparison of two intraosseous devices: The NIO versus the EZ-IO by novice users- a randomized cross over trial. *Prehosp Emerg Care* 2017;21(3):315-21. doi:10.1080/10903127.2016.1247201** 817
- Using a porcine hind leg model authors compared the success rate and ease-of-use ratings of an IO device, the NIO® in comparison to the Arrow® EZ-IO by novice users. NIO success rates were comparable to those of EZ-IO; 54% of the participants preferred using the EZ-IO over the NIO.
- Sotomayor T, Maraj C, Mott J, et al. Humeral head intraosseous access: Filling the military gap. *J Def Model Simul* 2017;14(4):361-9. doi: 10.1177/1548512916646888** 1022
- This article assesses the usability of the Partial Task Trainer (PTT) to train certain military medical providers on the technique of humeral head intraosseous infusion (HHIO). The PTT consists of an arm with functional structures and characteristics that allow trainees hands on practice locating anatomical landmarks, inserting the IO needle, and introducing the catheter into the humerus. Currently the US Army utilizes the EZ-IO Intraosseous Infusion System for HHIO infusions.
- Takei H, Nomura O, Yasuda M, Inoue N. Dermal abrasion due to semi-automatic intraosseous device. *Pediatr Int* 2017;59(5):641-2** 1027
- This paper describes a complication of dermal abrasion with the EZ-IO device in a 1 year old female in Japan who was treated in the emergency department for severe dehydration due to acute gastroenteritis.

Intraosseous Vascular Access Bibliography

Arrow® EZ-IO®

Thadikonda KM, Egro FM, Ma I, Spiess AM. Deltoid compartment syndrome: A rare complication after humeral intraosseous access. *Plast Reconstr Surg Glob Open* 2017;5(1):e1208. doi: 10.1097/GOX.0000000000001208

807

Case report of a 64 year old female in critical condition that had bilateral humeral intraosseous (IO) access sites placed for resuscitation. Past medical history included a clotting disorder. IO access was removed within 24 hours after CVC placement. Eight days post-IO catheter removal the patient developed pain, swelling, decreased motion and firmness in the area near the IO site. Conservative management failed and clinicians confirmed elevated deltoid compartment pressures and diagnosed compartment syndrome. She was taken to the operating room for a fasciotomy. Post-operatively the patient had pain relief, improved range of motion and last check-up had no pain and full range of motion.

U.S. Army, CoTCCC, TCCC Working Group. Tactical combat casualty care: Lessons and best practices. Tactical combat casualty care (TCCC): Lessons and best practices. Handbook. No. 17-13: Version 5. May 2017

1072

The CoTCCC handbook was created as a guide to best practices created by the Committee on Tactical Combat Casualty Care (CoTCCC) which includes representatives from all the U.S. Armed Services that are part of the Tactical Combat Casualty Care (TCCC) Working Group. The recommendations are based on input from the battlefield as well as evidence in the civilian literature, examined and put together to provide guidelines for care. The recommendations and required skill sets include IO access as an alternative to IV access in multiple sections. The TCCC- Medical provider skill set specifically includes the ability to demonstrate the use of IV/IO blood product administration (medical officers and operating room special operations medics) and the use of IV/IO tranexamic acid (TXA).

Winkler M, Talley C, Woodward C, et al. The use of intraosseous needles for injection of contrast media for computed tomographic angiography of the thoracic aorta. *J Cardiovasc Comput Tomogr* 2017;11(3):203-7. doi: 10.1016/j.jcct.2017.03.001

825

This retrospective study of a quality and safety database compared procedures performed by use of intraosseous vascular access for contrast media infusion to a control group of the studies in the database performed with antecubital intravenous access. The quality metrics of the two groups were similar, with the intraosseous needle group being slightly better. There were no complications related to IO use in general or specifically associated with the procedures. Limitations included this was a single-center study with small sample size and possible selection bias due to unfamiliarity with IO access.

Wolfson DL, Tandoh MA, Jindal M, Forgiione PM, Harder VS. Adult intraosseous access by advanced EMTs: A statewide non-inferiority study. *Prehosp Emerg Care* 2017;21(7):7-13. doi:10.1080/10903127.2016.1209262

816

This retrospective non-inferiority study examined EMS data extracted from a statewide EMS data system over a two year period. IO insertions performed by advanced EMTs (AEMT) and Paramedics were compared for insertion success rates. The majority of IO placements were with the EZ-IO®. The investigators concluded successful IO access was not different among AEMTs and Paramedics lending evidence in support of expanding the scope of practice of AEMTs to include establishing IO access in adults.

Yee D, Deolankar R, Marcantoni J, et al. Tibial osteomyelitis following prehospital intraosseous access. *Clin Pract Cases Emerg Med* 2017;1(4):391-4

936

Case report of a 29 year old that was diagnosed with osteomyelitis in his left tibia after a prehospital IO placement for resuscitation of cardiac arrest. Medications infused included naloxone, epinephrine, and amiodarone. The patient had ROSC and his IO catheter was removed within one hour of ED arrival due to infiltration. Diagnosis of tibial osteomyelitis occurred approximately 8 weeks post-initial placement.

Young S, Zhang M, Moore GA, et al. Higher tissue concentrations of vancomycin with low-dose intraosseous regional versus intravenous systemic prophylaxis in revision total knee arthroplasty: A randomized trial. Paper presented at: American Academy of Orthopaedic Surgeons Annual Meeting; March 14-18, 2017; San Diego, CA. Abstract P118

1036

This is an abstract of a study that compared tissue concentrations of vancomycin administered intravenously (IV) versus intraosseous regional administration (IORA) in revision TKA. Twenty patients were randomized to 2 groups: 1 g IV vancomycin or 500 mg IORA vancomycin. Overall geometric mean tissue concentrations in fat samples were 3.7 µg/g in the IV group vs 49.3 µg/g in the IORA group (P<0.001) while mean tissue concentrations in the femoral bone were 6.4 µg/g in the IV group vs 77.1 µg/g in the IORA group (P<0.001). IORA of low-dose vancomycin provided tissue concentrations 5-20 times higher than IV administration. IO access was obtained using the EZ-IO device. This study was sponsored by Teleflex Incorporated.

Young SW, Clarke HD, Moore GA, Zhang M, Spangehl MJ. Higher tissue concentrations of vancomycin are achieved with intraosseous versus intravenous administration in revision TKA. *The Knee* 2017;24(6):XIV (Abstract 0018). <https://doi.org/10.1016/j.knee.2017.08.045>.

1038

This abstract describes a study that compared tissue concentrations of vancomycin administered intravenously (IV) versus intraosseous regional administration (IORA) in revision TKA. Twenty patients were randomized to 2 groups: 1 g IV vancomycin or 500 mg IORA vancomycin. Mean tissue concentrations in fat samples were 4.1 µg/g in the IV group vs 115 µg/g in the IORA group (P<0.001) while tissue concentrations in the femoral bone were 7.2 µg/g in the IV group vs 101 µg/g in the IORA group (P<0.001). IORA of low-dose vancomycin provided tissue concentrations 5-20 times higher than IV administration. IO access was obtained using the EZ-IO device. This study was sponsored by Teleflex Incorporated.

Intraosseous Vascular Access Bibliography

Arrow® EZ-IO®

Young SW, Clarke HD, Pitto R, et al. Higher tissue concentrations of vancomycin with low-dose intraosseous regional versus intravenous systemic prophylaxis in revision TKA. ePoster presented at: International Society of Arthroscopy, Knee Surgery and Orthopaedic Sports Medicine Biennial Congress; June 4-8,2017; Shanghai, China. ePoster 1230

1037

This e-poster describes a study that compared tissue concentrations of vancomycin administered intravenously (IV) versus intraosseous regional administration (IORA) in revision TKA. Twenty-two patients were randomized to 2 groups: 1 g IV vancomycin or 500 mg IORA vancomycin with 20 patients analyzed. Mean tissue concentrations in fat samples were 4.1 µg/g in the IV group vs 115 µg/g in the IORA group (P<0.001) while tissue concentrations in the femoral bone were 7.2 µg/g in the IV group vs 101 µg/g in the IORA group (P<0.001). IORA of low-dose vancomycin provided tissue concentrations 5-20 times higher than IV administration. IO access was obtained using the EZ-IO device. This study was sponsored by Teleflex Incorporated.

Young SW, Zhang M, Moore GA, Pitto RP, Clarke HD, Spangehl MJ. Higher tissue concentrations of vancomycin with intraosseous regional prophylaxis in revision TKA- A randomized controlled trial. Manuscript submitted for publication

930

A randomized controlled study comparing antibiotic tissue concentrations when vancomycin is administered for total knee arthroscopy via IO and IV access. Ten subjects were randomized to each group. The IO group received 500 mg vancomycin injected directly into the proximal tibia IO insertion site below an inflated thigh tunicate, and the IV group received 1 gram vancomycin, both were given before skin incision. Results showed IO tissue concentrations of vancomycin were 5-20 times higher than systemic IV despite the lower dose. This study was sponsored by Teleflex Incorporated.

YEAR: 2016

Baadh AS, Singh A, Choi A, et al. Intraosseous vascular access in radiology: review of clinical status. AJR Am J Roentgenol 2016;207:W1-7. doi:10.2214/AJR.15.15784

756

This article provides a brief overview of intraosseous access for radiologists followed by a discussion of the use of IO access devices in the radiology suite, particularly for CT imaging. The protocol established at the authors' institution for use of the EZ-IO system is described which emphasizes obtaining confirmation of proper IO catheter placement by use of imagery prior to full infusion of contrast medium.

Burgert JM, Johnson AD, Garcia-Blanco J, et al. The effects of proximal and distal routes of intraosseous epinephrine administration on short-term resuscitative outcome measures in an adult swine model of ventricular fibrillation: A randomized controlled study. Am J Emerg Med 2016;34:49-53. doi:10.1016/j.ajem.2015.09.007

778

Preclinical RCT evaluating the relationships between the anatomical distance of IO epinephrine and measures of resuscitative outcome in an adult swine model of ventricular fibrillation (VF). There were no significant differences between the HIO, TIO, and IV groups relative to the occurrence of ROSC, 30-minute post-ROSC survival, and time to ROSC. The anatomical distance of IO epinephrine injection from the heart did not affect short-term measures of resuscitative outcome in an adult swine model of VF including the occurrence of ROSC, 30 minute post-ROSC survival, and time to ROSC. Rapidly administered epinephrine, irrespective of route of administration, increased the chance of ROSC and survival to 30 minutes post-ROSC in this study.

Davis J, Bates L. Rapid sequence induction via an intraosseous needle. J Intensive Care Society 2016;17(2):178-9

788

This article presents a case study of rapid sequence intubation via intraosseous (IO) access with a review of relevant literature. The authors describe a case of an adult male patient, peri-arrest with cardiogenic shock, cyanosed with un-recordable oxygen saturations and blood pressure. IO access was established in the proximal tibia and rapid sequence induction was performed using fentanyl, ketamine and suxamethonium. After 30 seconds direct laryngoscopy was attempted and intubation was secured on first attempt. The authors concluded that use of IO access for RSI can be useful in cases of difficult vascular access and rapid intubating conditions can be achieved which are comparable to using IV drug delivery.

Davlatants C, Miller LJ, Montez DF, Puga TA, Philbeck TE. Intraosseous catheter dwell-time appears safe for up to 48 hours: A preliminary report. The Journal of Vascular Access 2016;17(4):e26

782

The abstract describes the interim results of an investigational device exemption study evaluating use of EZ-IO in volunteers for a 48 hour dwell time period. At the time of the report, 39 subjects completed the study with no serious adverse event reports. Subjects were randomized to receive IO insertion in the proximal tibia or proximal humerus insertion sites. Pain has been managed using oral hydrocodone/acetaminophen and/or intravenous/intramuscular ketorolac. This study is sponsored by Teleflex Incorporated.

Davlatants C, Puga T, Montez D, Philbeck T, Miller L, DeNoia E. 48 hours dwell time for intraosseous access: A longer-term infusion using a temporary solution. Crit Care Med 2016;44(12)Suppl.:140

820

This study conducted as an IDE was conducted to evaluate the safety of IO access for a period up to 48 hours, in healthy or stable health-compromised (with diabetes or renal failure stage 2) adult volunteer subjects. The IO site was randomized to the proximal humerus or proximal tibia, and once placed the catheter was left in place with an infusion of 0.9% sodium chloride for 48 hours. 120 subjects completed the study with no serious complications. Investigators also found infusion pain can be managed with oral analgesics and an infusion of 30 mL/ hour maintained patency. This study was sponsored by Teleflex Incorporated.

Intraosseous Vascular Access Bibliography

Arrow® EZ-IO®

- Drozdz A, Madzińska M. Which vascular access technique should be chosen during hypovolemic shock? Am J Emerg Med 2016;34(9):1886-7. doi:10.1016/j.ajem.2016.06.070** 824
- In this letter to the editor authors discuss the difficulties of obtaining vascular access in patients in shock; and make a case for use of intraosseous access (IOA) in shock. Authors note IOA access as a safe, effective alternative to venous access with relatively rare complications.
- Poland
- Eriksson M, Larsson A, Lipcsey M, Strandberg G. Emergency intraosseous access: Novel diagnostic and therapeutic possibilities and limitations. ICU Manag Pract 2016;16(4):230-2** 1051
- This paper provides a brief overview of IO access and discusses advantages and disadvantages of IO use. Validation of IO blood gases by point-of-care technology, IO administration of antibiotics, IO monitoring of renal function, and IO access in acute cardiac care are also discussed.
- Eriksson M, Strandberg G, Lipcsey M, Larsson A. Evaluation of intraosseous sampling for measurements of alanine aminotransferase, alkaline phosphatase, aspartate aminotransferase, creatinine kinase, gamma-glutamyl transferase and lactate dehydrogenase. Scand J Clin Lab Invest 2016;76(8):597-600. doi:10.1080/00365513.2016.1230774** 809
- This preclinical study compared arterial and intraosseous derived biomarkers to determine if the results would correlate well enough over a period of 6 hours to consider use of IO derived blood when traditional samples are difficult to obtain. Authors noted there were no clinically relevant average differences between alanine aminotransferase, alkaline phosphatase, aspartate aminotransferase, creatinine kinase and gamma-glutamyl transferase values which may be good enough for initial estimates of these markers analyzed in intraosseous and arterial samples. However the lactate dehydrogenase levels showed less correlation; and the precision of IO samples may be limited.
- Fulkerson J, Lowe R, Anderson T, Moore H, Craig W, Johnson D. Effects of intraosseous tibial vs. intravenous vasopressin in a hypovolemic cardiac arrest model. West J Emerg Med 2016;17(2):222-8. doi:10.5811/westjem.2015.12.28825** 777
- Randomized, prospective preclinical study that examined the differences in pharmacokinetics and pharmacodynamics of tibial IO (TIO) and IV-delivered vasopressin during cardiac arrest and CPR until ROSC was achieved. No difference was noted for ROSC between TIO and IV delivered vasopressin. Authors concluded the use of IO access could avoid the time delay associated with IV access, and that it is effective for treatment of hypovolemic cardiac arrest and should be first line for rapid vascular access.
- Garside J, Prescott S, Shaw S. Intraosseous vascular access in critically ill adults- a review of the literature. Nurs Crit Care 2016;21(3):16-7. doi:10.1111/nicc.12163** 749
- Literature review on contemporary practices of intraosseous (IO) vascular access in adult patients.
- Great Britain
- Ginsberg-Peltz J. Time to bone healing after intraosseous placement in children is ill defined. Pediatr Emerg Care 2016;32(11):799-800. doi:10.1097/PEC.0000000000000652** 944
- This article discusses the difficulty in defining the time to bone healing after IO access insertion in children. A case study is presented of a 23 month old male with multiple comorbidities that had a tibial and proximal humerus IO placed then 3 weeks post IO placement had tibial swelling. Upon follow-up he was diagnosed with a tibial fracture and incomplete healing of the tibial bone accessed for IO use. Repeated IO access to a limb previously accessed is advised regardless of time after access. Authors emphasize that IO access is a "critically important tool" in pediatric emergency medicine and IO access should be used early and often.
- Greenstein YY, Koenig SJ, Mayo PH, Narasimhan M. A serious adult intraosseous catheter complication and review of the literature. Crit Care Med 2016;44(9):e904-9. doi: 10.1097/CCM.0000000000001714** 775
- This article includes a case study of an adult patient who received an intraosseous (IO) catheter, that may have extravasated, resulting in vascular compromise. The patient was treated with pharmacologic intervention and the status was reversed. A review of the literature on adult IO complications is also described.
- Hess T, Böhmer R, Arndt F, et al. Bilateral intraossärer zugang am humerus bei reanimation eines 3-Jährigen [Case Report- Bilateral humeral intraosseous access for CPR in a 3-years-old child]. Anästhesiol Intensivmed Notfallmed Schmerzther 2016;51(07-08):468-74. doi:10.1055/s-0042-110237.** 819
- This article in German describes a case study of a 3 year old child with a serious heart defect (after total cavopulmonary anastomosis) in which bilateral humeral IO access sites were obtained to manage her condition and the patient was discharged after 30 days without neurological deficits. Key messages include that IO access in children should be a primary access route in emergent and urgent situations, unless a suitable venous access is already available; the humeral head insertion site is an accepted method in emergency situations in adults and children; and IO access is intended for regular emergency administration of drugs. The purely preventive use of an IO is not indicated. Article in German.

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Arrow® EZ-IO®

- Johnson M, Inaba K, Byerly S, et al. Intraosseous infusion as a bridge to definitive access. *Am Surg* 2016;82(10):876-80** 826
This retrospective study examined indications and outcomes associated with IO use at a Level 1 trauma center from 2008-2015. All 68 IO placements were with the EZ-IO device; most patients had trauma diagnoses. Most IO placements were successful on first attempt within 3 minutes of arrival. Non-serious extravasation was the most common complication. Authors concluded IO access "should be considered as a rapid, low risk, high yield aid to long-term IV access in both adults and children, and is an important bridge to definitive access in resuscitation".
- Kehl T, Becker BA, Simmons DE, Broderick EK, Jones RA. Intraosseous access in the obese patient: Assessing the need for extended needle length. *Am J Emerg Medicine* 2016;34(9):1831-4. doi:10.1016/j.ajem.2016.06.055** 780
This study examined the relationship between body mass index (BMI), the ability to palpate the tibial tuberosity (TT), and soft tissue depth at recommended IO insertion sites in obese patients using ultrasound. Authors concluded in obese adults with a palpable TT or BMI ≤ 43 , a 25 mm IO needle is likely adequate at the proximal and distal tibial insertion sites; and at the proximal humerus site a 45 mm is recommended.
- Krishnan M, Lester K, Johnson A, Bardeloza K, Edemekong P, Berim I. Case report: Bent metal in a bone: A rare complication of an emergent procedure or a deficiency in skill set? *Case Reports in Critical Care* 2016;doi:10.1155/2016/4382481** 806
This article describes a case in which an EZ-IO catheter inserted into the proximal humerus required surgical intervention for removal after traditional removal efforts failed. Authors noted the patient refused an attempt to stabilize the insertion site. Discussion and a brief review of the literature discusses available IO devices and complications. In conclusions authors opined that with education and training, EZ-IO may become the preferred method of achieving rapid vascular access for emergent resuscitation with a low risk for complications.
- Lind T. Alternative access routes for fluid resuscitation. *Top Companion Anim Med* 2016;31(2):61-7. doi:10.1053/j.tcam.2016.08.005** 886
This veterinary care article describes vascular access methods and devices used for small animal emergencies, including intraosseous devices.
- Montez D, Puga T, Davlantes C, Philbeck T. IO infusion pain mitigation in the sternum and proximal humerus: Establishing a regimen. *Crit Care Med* 2016;44(12 Suppl):154** 822
A prospective study with 30 evaluable healthy volunteers receiving PH and sternal IO access (Arrow® EZ-IO® Vascular Access System and T.A.L.O.N.™, Teleflex, Wayne, PA) was conducted to determine if there is a significant difference between pain after a total of 60mg or 40mg of 2% preservative-free and epinephrine-free lidocaine. Endpoints were subject reported pain scores during 5 minutes of rapid infusion at 300 mmHg and 15 and 30 minutes at a rate of 125 mL/hour per pump. Authors concluded infusion pain through a PH IO may be managed with a single 40mg lidocaine prior to infusion, but a total of 60mg may be considered for sternal IO infusion. This study was sponsored by Teleflex Incorporated.
- Montez DF, Puga TA, Davlantes C, Higgins R, Miller LJ, Philbeck TE. Blood transfusion via intraosseous access: A pre-clinical study. *J Vasc Access* 2016;17(4):e5-6** 783
A preclinical study evaluating blood transfusion via IO vascular access in anesthetized swine. Results showed pressurized blood transfusion through IO vascular access resulted in acceptable flow rates and did not result in appreciable hemolysis as indicated by free hemoglobin values. This study was sponsored by Teleflex Incorporated.
- Muir SL, Sheppard LB, Maika-Wilson A, et al. A comparison of the effects of intraosseous and intravenous 5% albumin on infusion time and hemodynamic measures in a swine model of hemorrhagic shock. *Prehosp Disaster Med.* 2016;31(4):436-42** 1058
This pre-clinical study compared the performance of IO and IV administered albumin. IO access was obtained via the tibia using an EZ-IO device. Mean infusion time for TIO was 7 minutes, 35 seconds. Mean infusion time for IV was 4 minutes, 32 seconds. There were no significant differences between groups relative to mean arterial pressure, cardiac output, heart rate, or stroke volume. Hemodynamic parameters were measured for only 3 minutes.
- O'Sullivan M, Martinez A, Long A, et al. Comparison of the effects of sternal and tibial intraosseous administered resuscitative drugs on return of spontaneous circulation in a swine model of cardiac arrest. *Am J Disaster Med* 2016;11(3):175-82. doi:10.5055/ajdm.2016.0237** 1006
This study compared the effects of IO and IV administered resuscitative drugs (vasopressin, amiodarone, and epinephrine) on return of spontaneous circulation (ROSC) in a swine model of sudden cardiac arrest (SCA) with ongoing resuscitation. Swine were randomized to 1 of 5 groups; tibial IO, sternal IO, IV, CPR+defibrillation, and CPR-only. There was no significant difference in ROSC between SIO, TIO, and IV groups. However time to ROSC was significantly less for the SIO group compared to the TIO group ($p=0.003$). This is possibly related to higher fat content in tibial bone marrow relative to the sternum and the lipophilicity of amiodarone.

Intraosseous Vascular Access Bibliography

Arrow® EZ-IO®

Penketh J, McDonald M, Kelly FE. EZ-IO® intraosseous access teaching in the workplace using a mobile 'tea trolley' training method. *Resuscitation* 2016;99:e17-8. doi:10.1016/j.resuscitation.2015.11.016

860

This letter to the editor describes a novel training technique employed to provide training to clinicians on use of the EZ-IO system, in 15-minute sessions. Implementation of this program has resulted in 97% of participants reporting an increase in confidence using the EZ-IO system and 100% were able to correctly identify the locations of the devices for their clinical areas.

United Kingdom

Petitpas F, Guenezan J, Vendevre T, Scepi M, Oriot D, Mimoz O. Use of intra-osseous access in adults: A systematic review. *Crit Care* 2016;20:102. doi:10.1186/s13054-016-1277-6.

810

This article reports the results of a systematic review using PubMed for current evidence through 2015 for intraosseous (IO) vascular access use in adults requiring resuscitative procedures. General anatomy, indications and contraindications and available devices are discussed. Authors determined IO infusion is indicated in all critical situations with difficult vascular access; contraindications are few; and serious complications uncommon.

France

Philbeck TE, Montez DF, Puga TA, Davlantes C, Miller LJ. Infusion flow rates and insertion success through the sternum using a multi-site intraosseous device. *J Vasc Access* 2016;17(4):e131

784

This abstract describes the results of a healthy volunteer study evaluating use of the EZ-IO TALON in the sternal IO insertion site. IO infusion flowrate was measured and reported for gravity infusion, as well as pressured infusions at 100, 200, and 300 mmHg. The authors concluded the TALON device may be used safely and successfully in the sternum with excellent infusion flow rates. This study was sponsored by Teleflex Incorporated.

Puga T, Montez D, Philbeck T, Davlantes C. Adequacy of intraosseous vascular access insertion sites for high-volume fluid infusion. *Crit Care Med* 2016;44(12 Suppl):143

821

This study was completed on 30 healthy subjects to evaluate infusion rates via the sternum (SIO) and proximal humerus (PH) sites under 300 mmHg via pressure bag. The mean SIO infusion rate was 9,587±2,706mL/hr (n=27); mean PH infusion rate was 6,292 ±3,277mL/hr (n=52). There were no serious complications; minor complications were 5 cases of excess pain, 2 cases vagal response, and mammary tissue engorgement. The mean PH flow rate was significantly lower than that of SIO, but placing IO catheters in each humeri with simultaneous infusion could result in fluid delivery of 13,000mL/hr, surpassing that of the sternum. This study was sponsored by Teleflex Incorporated.

Puga TA, Montez DF, Davlantes C, Miller LJ, Philbeck TE. Swine study shows no intramedullary effects of power-injected contrast media using intraosseous access. *J Vasc Access* 2016;17(4):e16

785

A preclinical study evaluating the immediate effects of power injected contrast media on the medullary space of anesthetized swine. Contrast media (150 mL) was administered at a rate of 5 mL/second. For each limb receiving power injection a control limb was submitted for evaluation. The pathologist was blinded to which limb received power injection. Results showed no histological difference in limbs receiving and not receiving power injection. This study was sponsored by Teleflex Incorporated.

Savell S, Mora AG, Perez CA, Bebart VS, Maddry JK. En route intraosseous access performed in the combat setting. *Am J Disaster Med* 2016;11(4):225-31. doi:10.5055/ajdm.2016.0243

847

A retrospective study evaluating vascular access routes used for US Military personnel injured in combat and transported by MEDEVAC. Medical records were reviewed for intravenous (IV) and intraosseous (IO) use including, number of attempts and rates of success; along with events occurring in transit, hospital and ICU stays and 30 day outcomes. Results showed IV and/or IO access was attempted in 832 patients. PIV was first line of attempt in 758 cases with 93% success; IO access was first line of attempt in 74 cases with 85% success. There were 25 attempts to establish IO as the second line of access with 100% successful placement. Success rates were 100% with tibia (29); 94% with humerus (21/22); and 89% with the sternum (41/46). The overall IO success rate was 88% for all attempts made.

Smith S, Borgkvist B, Kist T, Annelin J, Johnson D, Long R. The effects of sternal intraosseous and intravenous administration of amiodarone in a hypovolemic swine cardiac arrest model. *Am J Disaster Med* 2016;11(4):271-7. doi:10.5055/ajdm.2016.0249

830

A pre-clinical study comparing the effects of IV and sternal IO administered amiodarone in a swine cardiac arrest model. Following 2 minutes of cardiac arrest, CPR was initiated and after an additional 2 minutes, amiodarone was administered via sternal IO or IV access. Blood samples were collected over 5 minutes. Results showed no statistical difference between routes for return of spontaneous circulation (ROSC), time to ROSC, T-max, or C-max. The authors concluded sternal IO route provides rapid and reliable access to administer life-saving medications during cardiac arrest.

Intraosseous Vascular Access Bibliography

Arrow® EZ-IO®

Strandberg G, Lipcsey M, Eriksson M, Lubenow N, Larsson A. Analysis of thromboelastography, PT, APTT and fibrinogen in intraosseous and venous samples-an experimental study. Scand J Trauma Resusc Emerg Med 2016;24:131. doi:10.1186/s13049-016-0318-0

814

In this porcine study IO and venous samples were analyzed for thromboelastography (TEG), prothrombin time (PT), activated partial thromboplastin time (APTT) and fibrinogen concentration. The IO samples were clinically hypercoagulable, rendering some samples unevaluable; clinically relevant differences were observed for APTT but not for PT and fibrinogen and the TEG demonstrated a shortened reaction time. The ability to use IO drawn blood for coagulation studies may be limited.

Szarpak L, Czyzewski L, Woloszczuk-Gebicka B, Krajewski P, Fudalej M, Truszcwski Z. Comparison of NIO and EZ-IO intraosseous access devices in adult patients under resuscitation performed by paramedics: A randomized crossover manikin trial. Am J Emerg Med 2016;34(6):1166-7. doi:10.1016/j.ajem.2016.03.017.

774

This randomized crossover manikin trial compared the NIO and EZ-IO devices for time to placement and ease of use. For both parameters the NIO performed better.

Poland

Szarpak L, Truszcwski Z, Smereka J, Krajewski P, Fudalej M. Ability of paramedics to perform intraosseous access. A randomized cadaver study comparing EZ-IO and NIO devices. Resuscitation 2016;104:e5-e6. doi:10.1016/j.resuscitation.2016.04.011

795

This letter to the editor describes a prospective, randomized, cross-over cadaveric study that evaluated use of the EZ-IO and NIO devices by novice paramedic device users. Following a brief in-service on use of both devices and practice insertions using a leg-trainer manikin, each participant attempted to establish IO access using each device in a resuscitation simulation with in an adult cadaver with CPR in progress. Results showed first attempt success rates of 97.4% with the NIO and 100% with the EZ-IO; and mean time to insertion was 16.8 seconds with the NIO and 42 seconds with the EZ-IO.

Uwaydah NI, Hoskins SL, Bruttig SP, et al. Intramuscular versus intraosseous delivery of nerve agent antidote pralidoxime chloride in swine. Prehosp Emerg Care 2016;20(4):485-92. doi:10.3109/10903127.2014.942479

842

A preclinical study comparing delivery of nerve agent antidote when administered via intramuscular (IM) and proximal tibia intraosseous (IO) routes, in normovolemic and hypovolemic swine. IO and IV administration of the antidote achieved and surpassed therapeutic levels in normovolemic groups; time to therapeutic level with IM was 2 minutes versus 15 seconds with IO access. Combined administration via IO route initially, followed by IM injection 60 minutes post IO injection resulted in therapeutic levels for a prolonged time, most closely mimicking standard hospital care of poisoned patients. The authors concluded the rapid increase in plasma concentrations, coupled with the sustainability of the drug in plasma supported advantages of IO over IM delivery.

Vallier DJ, Torrence AD, Stevens, III R, Arcinue PN, Johnson D. The effects of sternal and intravenous vasopressin administration on pharmacokinetics. Am J Disaster Med 2016;11(3):203-9. doi:10.5055/ajdm.2016.0240

841

A preclinical study comparing the maximum concentration (Cmax), time to maximum concentration (Tmax) when administering vasopressin via intravenous (IV) and sternal intraosseous (SIO) access in a cardiac arrest swine model. Anesthetized swine were put into cardiac arrest, after 2 minutes CPR was initiated for 2 minutes, then 40 units of vasopressin was administered via IV or SIO route. Results showed no significant difference in SIO and IV groups for Cmax or Tmax.

Wilson J, Passmore A, Leger S, Lannan J, Bentley M, Johnson D. Effects of tibial intraosseous and intravenous administration of Hextend on tiem of administration and hemodynamics in a hypovolemic swine model. Am J Disaster Med 2016;11(3):193:201. doi:10.5055/ajdm.2016.0239

836

A preclinical study comparing administration of Hextend via IV and tibial intraosseous (IO) access routes for time for administration and hemodynamic measures in a hypovolemic swine model. Following exsanguination, 500 mL of Hextend was administered via both routes; a control group received no Hextend. Hemodynamic measures data were collected every 2 minutes for 8 minutes. The mean time for administration in the IV group was 10 minutes 16 seconds (\pm 2 minutes 47 seconds), and for the IO group it was 10 minutes 12 seconds (\pm 1 minutes 36 seconds). There was no significant difference in systolic blood pressure, diastolic blood pressure, mean arterial pressure, cardiac output, and stroke volume.

Wimmer MH, Heffner K, Smithers M, et al. The comparison of humeral intraosseous and intravenous administration of vasopressin on return of spontaneous circulation and pharmacokinetics in a hypovolemic cardiac arrest swine model. Am J Disaster Med 2016;11(4):237-42. doi:10.5055/ajdm.2016.0245

827

A preclinical study comparing IV and humeral intraosseous (IO) access administration of vasopressin in a hypovolemic swine model in cardiac arrest. Following exsanguination, the swine were placed in cardiac arrest for 2 minutes, then resuscitated for 2 minutes in accordance with ACLS guidelines. Vasopressin was administered. Blood samples were collected at various time points following vasopressin injection and analyzed for maximum concentration (Cmax) and time to maximum concentration (Tmax) between groups; return of spontaneous circulation was also captured. ROSC was achieved for all HIO subjects (n=7) and in seven out of eight IV subjects; mean time to ROSC was 9.8 minutes for HIO and 10.7 for the IV group. However, statistically there was no significant difference between HIO and IV administration of vasopressin for achievement of ROSC, time to ROSC, Cmax, Tmax, concentration over time, survivability, or odds ratio.

Intraosseous Vascular Access Bibliography

Arrow® EZ-IO®

Wong MR, Reggio MJ, Morocho FR, et al. Effects of intraosseous epinephrine in a cardiac arrest swine model. J Surg Res 2016;201(2):327-33. doi:10.1016/j.jss.2015.11.015

776

Preclinical study that examined the differences in pharmacokinetics and pharmacodynamics of tibial IO (TIO) and IV-delivered epinephrine during cardiac arrest and CPR. There were no significant differences between IV versus TIO epinephrine in achieving ROSC, time to ROSC, and Cmax. In the context of ROSC, epinephrine delivered via TIO route was a clinically relevant alternative to IV administration. The authors concluded that when IV access cannot be immediately obtained in cardiac arrest patients, TIO access should be considered.

Woodhart B, Shaw J. A study to determine the EZ-IO intraosseous infusion system success rate, including impact on return of spontaneous circulation. Emerg Med J 2016;33:e5. doi: 10.1136/emered-2016-206139.19

1034

This is an abstract of a study conducted in the UK to determine the success rate of the EZ-IO Intraosseous Infusion System on return of spontaneous circulation (ROSC). Patient records were examined for 195 cardiac arrest patients who had an EZ-IO placement attempt. ROSC was achieved for 29% of patients. In patients who received IV administration of medications, 46% achieved ROSC. While IV access appears more favorable in this study, there may be other factors associated with achieving ROSC that were not taken into account.

YEAR: 2015

Anson JA, Sinz EH, Swick JT. The versatility of intraosseous vascular access in perioperative medicine: a case series. J Clin Anesth 2015;27(1):63-7. http://dx.doi.org/10.1016/j.jclinane.2014.10.002

729

This article presents a 5-case series describing use of IO vascular access by anesthesiologists in the perioperative and critical care settings. All insertions were made in the proximal tibia and there were no adverse events reported. The devices cited as being used were the EZ-IO and the Cook Surfist manual needle. A proposed perioperative vascular access algorithm incorporating IO access is presented. The authors address key topics around IO access including use of same drug dosing as IV administered drugs, frequent palpation and monitoring of the insertion site for extravasation, low complication rate and actual risks associated with fat emboli and bone injury, pain and anxiety management in the awake patient and clinician-perceived pain. Administration of blood products, ACLS drugs, Lactated Ringer's solution and anesthetics are noted without complication. Use of IO aspirate for laboratory testing is noted, however use of the initial aspirate is indicated. Several patients in the case series were reported to find the discomfort of IO insertion preferable to multiple intravenous attempts. The authors concluded: IO lines can be placed quickly and safely in emergency situations or in elective surgical patients with difficult intravenous access; IO access can be useful in a wide variety of clinical settings; and is an important skill for anesthesiologist to learn.

Chreiman KM, Kim PK, Garbovsky LA, Schweickert WD. Blueprint for implementing new processes in acute care. J Trauma Nurs 2015;22(5):266-73

793

This article describes the strategies used at one hospital (Penn Presbyterian Medical Center) to increase the use of intraosseous catheter to rescue patients in all care settings.

Eriksson M, Strandberg G, Lipcsey M, Larsson A. Intraosseös provtagning kan vara vardefull i akuta lagen [Intraosseous sampling can be valuable in emergency situations]. Lakartidningen 2015 Feb 24;112pii:DCR3. Swedish

789

This article in Swedish describes a study evaluating use of aspirate obtained from the IO space for laboratory analysis. The authors note that point-of-care equipment should be used for analysis. Creatinine, morphine and troponin was successfully analyzed; leucocytes and platelets were noted to possibly cause falsely elevated values.

Eriksson M, Strandberg G, Lipcsey M, Larsson A. Troponin I can be determined in intraosseous aspirates in a porcine shock model. Clin Lab 2015;doi:10.7754/Clin.Lab.2015.141212

758

A preclinical study in which 8 anesthetized swine were put into an induced septic shock state to allow troponin I level measurements to be compared from serial venous plasma, arterial plasma and intraosseous aspirate specimens collected hourly. Two milliliters of IO aspirate were wasted before collecting each IO specimen for analysis. The levels of IO troponin I increased during the first 3 hours of shock but then plateaued at a high level while the venous and arterial levels continued to increase. Authors concluded that troponin I can be analyzed in bone marrow aspirates in a shock model and that this information may be useful in medical emergencies where cardiac damage is suspected to be involved.

Frascone RJ, Salzman JG, Adams AB, Bliss P, Wewerka SS, Dries DJ. Evaluation of intraosseous pressure in a hypovolemic animal model. J Surg Res 2015;193(1):383-90. http://dx.doi.org/10.1016/j.jss.2014.07.007

736

Preclinical study to determine whether intraosseous pressure (IOP) could be consistently recorded and similarity of IOP to central venous and arterial pressure in a porcine hemorrhagic shock model. IOP tracings were tracked reliably from the proximal humerus, distal femur, and proximal tibia. Baseline IOP ranged from 16-18 mm Hg among the three sites, which was approximately 23% of arterial pressure. This study was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.

Intraosseous Vascular Access Bibliography

Arrow® EZ-IO®

Goldschalt C, Doll S, Ihle B, Kirsch J, Mutzbauer TS. Peripheral venous or tibial intraosseous access for medical emergency treatment in the dental office? Br Dent J 2015;281(9):E16. doi: 10.1038/sj.bdj.2015.384

869

This paper describes a cadaver study that evaluated the ability of dental students to successfully place peripheral venous catheters and tibial intraosseous (IO) catheters using the Vidacare/Teleflex EZ-IO. Success rates, as well as insertion times, were recorded. 29% of venous and 83% of IO placements were successful. Successful venous access was achieved in an average of 163 seconds and IO access was achieved in an average of 30 seconds. Investigators concluded that chances to perform successful vascular access for inexperienced dentist may be higher when using tibial IO for emergency vascular access compared to when using IV catheters.

Grabel Z, DePasse JM, Lareau CR, Born CT, Daniels AH. Intra-articular placement of an intraosseous catheter. Prehosp Disaster Med 2015;30(1):1-4. doi:10.1017/S1049023X14001290

741

Case report of a prehospital misplacement of an IO catheter into the intra-articular space of the knee joint when access was attempted in the field. Upon ED arrival IO placement was noted to be high and intra-articular placement was confirmed by xray. A sterile NS lavage was done and patient recovered without complication. Authors note this as a previously unidentified complication of IO placement and advise xray confirmation of affected sites with follow-up of intra-articular placements for the septic arthritis. (Picture of site appears to be an EZ-IO).

Hammer N, Möbius R, Gries A, Hossfeld B, Bechmann I, Bernhard M. Comparison of the fluid resuscitation rate with and without external pressure using two intraosseous infusion systems for adult emergencies, the CITRIN (comparison of intraosseous infusion systems in emergency medicine)- study. PLoS ONE 2015;10(12):e0143726. doi:10.1371/journal.pone.0143726

791

A cadaveric study performed by twenty-seven medical students, inexperienced with IO vascular access, that compared use of the EZ-IO for access in the proximal humerus and proximal tibia insertion sites and the FASTR for access in the sternum. First pass insertion success, insertion times, and one minute flow rates using external pressures from 0 to 300 mmHg were evaluated. The authors concluded that both the EZ-IO and FASTR devices may be effective IO devices and are likely suitable for fluid resuscitation using a pressure bag.

Helm M, Haunstein B, Schlechtriemen T, Ruppert M, Lampl L, . Gäßler M. EZ-IO® intraosseous device implementation in German Helicopter Emergency Medical Service. Resuscitation 2015;88:43-7. doi: 10.1016/j.resuscitation.2014.12.015.

737

Retrospective analysis of IO needle insertions performed in all HEMS missions during the first three years (2009-2011) using the EZ-IO® system. Overall success rate of EZ-IO procedures (N=348) was 99.6%, with a first attempt success rate of 85.9%; and high user satisfaction rate of 93%. IO as access was mostly second line overall but first line in children <7, trauma and cardiac arrest. There was one failure and four needle insertion problems noted; no serious complications.

Germany

Hill SL, Thomas SHL, Flecknell PA, et al. Rapid and equivalent systemic bioavailability of the antidotes HI-6 and dicobalt edetate via the intraosseous and intravenous routes. Emerg Med J 2015;32(8):626-31. doi: 10.1136/emermed-2014-204171

751

A preclinical study evaluating the bioavailability of antidotes HI-6 oxime and dicobalt edetate when given via proximal tibia intraosseous (IO) access, established via the EZ-IO, compared to intravenous administration via central access in minipigs. Results showed rapid and similar systemic bioavailability of the antidotes when given by both routes and that IO access is an appropriate access route when IV access is impractical.

Ker K, Tansley G, Beecher D, et al. Cochrane Database Syst Rev 2015;2:CD011386. doi: 10.1002/14651858.CD011386.pub2. Comparison of routes for achieving parenteral access with a focus on the management of patients with Ebola virus disease. Cochrane Database Syst Rev 2015;2:CD011386. doi: 10.1002/14651858.CD011386.pub2

878

This systematic review compared the reliability, ease of use and speed of insertion of different parenteral access methods with focus on relieving dehydration associated with the Ebola virus disease. Authors found that, compared to the intraosseous group, patients in the intravenous group were more likely to experience an insertion failure.

Lee PMJ, Lee C, Rattner P, Wu X, Gershengorn H, Acquah S. Intraosseous versus central venous catheter utilization and performance during inpatient medical emergencies. Crit Care Med 2015;doi: 10.1097/CCM.0000000000000942

762

This single center, prospective, observational clinical study compared use of intraosseous (IO) access to central venous catheter (CVC) access for inpatient medical emergencies, managed by the medical emergency team (MET), within an urban teaching hospital. CVC access training included percutaneous, landmark-guided CVC placement without ultrasound guidance, using the femoral vein as the primary site. For IO access, the proximal tibia was the primary site and proximal humerus was secondary. Results showed IO access was significantly superior to CVC access with regard to first pass success rates, overall success rates, time to placement, and number of attempts for proper placement. On average more CVC kits were used per patient; complications were greater with CVC. There was one serious complication of tissue necrosis secondary to extravasation in the IO group.

Intraosseous Vascular Access Bibliography

Arrow® EZ-IO®

- Means L, Gimbar RP. Prothrombin complex concentrate administration through intraosseous access for reversal of rivaroxaban. Am J Emerg Med 2015;34(3):685.e1-2. doi:10.1016/j.ajem.2015.07.057. doi: 10.1016/j.ajem.2015.07.057** 765
- This paper describes a case study of a 64 year old man who presented to the ED with symptoms of bleeding related to rivaroxaban and clopidogrel. Due to concern for bleeding, low BP, and perceived difficulty in IV access, IO access was obtained. After access the patient experienced significant pain and was unable to tolerate large volume administration through the IO site. The patient was successfully treated with prothrombin complex concentrate (PCC), which has a smaller volume when compared to blood products. This was the first reported case of IO PCC administration.
- Montez DF, Puga T, Miller L, et al. Intraosseous infusions from the proximal humerus reach the heart in less than 3 seconds in human volunteers. Ann Emerg Med 2015;66(4s):S47. http://dx.doi.org/10.1016/j.annemergmed.2015.07.165** 771
- In a healthy adult volunteer study contrast media was injected through the proximal humerus site and captured under fluoroscopy as it entered the heart. The mean time it took from injection at the insertion site to visualize contrast entry into the superior vena cava and the right atrium was 2.42 seconds. Abstract presented at ACEP 2015. This study was sponsored by Teleflex Incorporated.
- Ohchi F, Komazawa N, Mihara R, Minami T. Comparison of mechanical and manual bone marrow puncture needle for intraosseous access; a randomized simulation trial. Springer Plus 2015;doi:10.1186/s40064-015-0982-y** 766
- A simulation study comparing use of manual (Cook Medical) and mechanical (Arrow EZ-IO) intraosseous (IO) devices to establish IO access in mannequin bones representing infant, pediatric and adult tibias. Twenty-two anesthesiologists with no prior experience with IO devices participated in the study. The outcome measures were success rate, insertion time and operator reported difficulty of use. Results were in favor of the mechanical device for insertion time in each category, and success rate in the adult tibia group; there was no statistical difference in the difficulty of use evaluation.
- Overbaugh R, Davlantes C, Miller L, Montez D, Puga T, Philbeck TE. Intraosseous vascular access catheter appears safe during extended dwell: a preliminary report. Ann Emerg Med 2015;66(4):S5** 772
- Abstract describing preliminary results for the first 24 subjects of an EZ-IO study evaluating catheter dwell times for 48 hours. Initial data indicate that IO vascular access can be safely maintained for a period up to 48 hours without risk of osteomyelitis or other serious adverse events. Authors also noted that additional analgesics for IO infusion pain management may be more effective than the current solely administering lidocaine into the IO space. This study was sponsored by Teleflex Incorporated.
- Overbey JK, Kon AA. Dermal abrasion experienced as an adverse effect of the EZ-IO. J Emerg Med 2016;50(1):e7-10. doi: 10.1016/j.jemermed.2015.09.003.** 753
- This article presents a case report of a 7 month old female who received intraosseous vascular access via the EZ-IO in the distal femur that resulted in a dermal abrasion where the needle hub contacted the skin. The wound healed without significant complication however the scar at the IO site persisted at 11 months post the event. The authors recommend that providers use the minimal force necessary when operating the EZ-IO to avoid similar adverse events.
- Pasley J, Miller CHT, DuBose J, et al. Intraosseous infusion rates under high pressure: a cadaveric comparison of anatomic sites. J Trauma Acute Care Surg 2015;78(2):295-9. DOI: 10.1097/TA.0000000000000516** 750
- A cadaveric study evaluating intraosseous (IO) vascular access insertion sites for attainable flow rates under 300 mmHg. The EZ-IO was used to establish IO access at the proximal humerus and proximal tibia sites; the FAST1 was used to establish sternal IO access. The total volume of fluid infused at the three IO access sites was 469 ± 190 mL for the sternum; 286 ± 218 mL for the humerus; and 154 ± 94 mL for the tibia. The mean flow rate infused at each site was as follows: 93.7 ± 37.9 mL/min for the sternum; 57.1 ± 43.5 mL/min for the humerus; and 30.7 ± 18.7 mL/min for the tibia. First attempt placement success was 100% for the sternum and proximal humerus and 81% for the tibia.
- Paxton J, Wilburn J, Ottolini J, Sherwin R. Does the choice of initial vascular access device delay cardiac arrest resuscitation? Crit Care Med 2015;43(12 Suppl):46. doi: 10.1097/01.ccm.0000474007.72329.42. abstract 179** 862
- This abstract describes pilot data regarding initial vascular access device use in emergency department management of patients with out-of-hospital cardiac arrest. Twenty-six patients were included, and only 10 arrived to the ED with venous access established in the field: 4 via intraosseous and 6 via peripheral IV. Of the 16 subjects without access upon ED arrival, PIV was selected for 12 and IO was selected for 4. Nine patients experienced a delay in obtaining access attributed to the selection of PIV as the initial mode of gaining access. Median time required for access was reported as: 50 seconds for IO; 95 seconds for PIV and 780 seconds for CVC. The authors concluded that selection of PIV as the initial access method may be associated with delayed vascular access in the ED.
- Paxton JH, Ottolini J, Wilburn JM, Sherwin RL, Courage C. Does the choice of vascular access device delay appropriate emergency department resuscitation of adult out-of-hospital cardiac arrest patients? Ann Emerg Med 2015;66(4s):s35** 863
- An abstract describing preliminary data evaluating the effect of initial vascular access device selection on the management of out-of-hospital cardiac arrest (OOHCA) patients by the ED. Twenty patients were included. Success rate by vascular access device selected was: 66% IO lines (2/3); 25% for PIV lines (3/12); and 100% for CVC (1/1). Eight patients experienced a delay in access due to initial method selected, 7 were attributed to PIV and 1 to IO. The authors concluded that the results suggest use of PIV as the initial mode of access may be associated with delays in access when compared to IO access in patients with OOHCA.

Intraosseous Vascular Access Bibliography

Arrow® EZ-IO®

Paxton JH, Ottolini J, Wilburn JM, Sherwin RL, Courage C. Does the choice of vascular access device delay appropriate emergency department resuscitation of adult out-of-hospital cardiac arrest patients? *Ann Emerg Med* 2015;66(4s):s35 924

This abstract describes a pilot observational study of vascular access devices (VAD) and their use in management of 20 out of hospital cardiac arrest patients. VAD selected, number of attempts for successful placement and time to insertion were recorded. Twenty patients were included in this study, 10 of whom received IO access upon ED arrival.

Philbeck TE, Puga T, Montez DF, Miller LJ, Saussy J, Davlantes C. Sternal flow rates and insertion success using a multisite intraosseous device. *Ann Emerg Med* 2015;66(4s):s48 787

A healthy volunteer study evaluating use of the EZ-IO TALON in the sternal IO insertion site. Military trained medics performed all device insertions. IO infusion flowrate was measured and reported for gravity infusion, as well as pressured infusions at 100, 200, and 300 mmHg. The authors concluded the TALON device may be used by military and tactical medicine personnel to safely and successfully establish IO access in the sternum with excellent infusion flow rates. This study was sponsored by Teleflex Incorporated.

Pifko EL, Busch C, Price A, et al. An observational review of pediatric intraosseous needle placement in the pediatric emergency department. *Ann Emerg Med* 2015;66(4s):S87 754

A retrospective study evaluating attempts to establish intraosseous vascular access in pediatric patients using a manual device and the EZ-IO, in a tertiary care pediatric emergency department. Results showed 35 patients had IO access attempted using manual and EZ-IO devices. In patients greater than and less than 8kg the EZ-IO had a higher success rate but time to placement was longer. Overall success rate including both devices was 64%. There were 2 complications of transient leg swelling after EZ-IO placement in 2 patients.

Puga T, Hanes MA, Miller LJ, et al. Intramedullary effects of power-infused contrast by intraosseous access. *Ann Emerg Med* 2015;66(4s):s95 786

A preclinical study evaluating the immediate effects of power injected contrast media on the medullary space of anesthetized swine. Contrast media (150 mL) was administered at a rate of 5 mL/second. For each limb receiving power injection a control limb was submitted for evaluation. The pathologist was blinded to which limb received power injection. Results showed no histological difference in limbs receiving and not receiving power injection. This study was sponsored by Teleflex Incorporated.

Rubal BJ, Meyers BL, Kramer SA, Hanson MA, Andrews JM, DeLorenzo RA. Fat intravasation from intraosseous flush and infusion procedures. *Prehosp Emerg Care* 2015;19(3):376-90. doi: 10.3109/10903127.2014.980475 748

This preclinical study evaluated the occurrence of fat intravasation resulting from intraosseous (IO) flush and infusion in anesthetized swine. Intravasated fat was assessed using a lipophilic fluoroprobe (Nile red) and by vascular ultrasound imaging. Fat intravasation was observed during all IO infusion regimens, with subclinical pulmonary fat emboli persisting 24 hours post infusion. It was noted that initial flush was a significant factor in fat intravasation, low levels of intravasation occurred with infusions ≤ 300 mmHg, fat intravasation and bone marrow shear-strain increased with IO infusion rates, and intravasation was influenced by cannula insertion site.

Salzman J, Burnett A, Frascione R, et al. Intraosseous pressure monitoring in critically ill and injured patient. *Crit Care Med* 2015;43(12 Suppl):abstract 183:47. doi: 10.1097/01.ccm.0000474011.25695.a8 848

A pilot study evaluating the relationship between intraosseous (IO) pressure measurements and blood pressure obtained via external blood pressure cuff in ICU patients. Patients with IO access established by EMS or in the emergency department with planned admission to the ICU or surgical ICU were included in the study. External pressures were recorded every 15 minutes and IO pressure was monitored via a transducer for 12 continuous hours. Results showed IO pressures were approximately 30% of external blood pressure cuff readings.

Salzman JG, Frascione RJ, Zagar AE et al. Intraosseous pressure monitoring in critical care patients. *Ann Emerg Med* 2015;66(4s):S148 755

The authors described a proof of concept pilot study conducted to determine intraosseous (IO) pressure measures and their relationship to blood pressure obtained using an external blood pressure cuff in ICU patients. The average IO systolic blood pressure, IO diastolic blood pressure, and IO mean were 39.5 ± 12.7 mm Hg, 31.5 ± 7.6 mmHg, and 35.0 ± 8.8 mm Hg respectively. The ratio of IO systolic blood pressure to cuff systolic blood pressure, IO diastolic blood pressure to cuff diastolic blood pressure, and IO mean to cuff mean are $34.5 \pm 13.4\%$, $40.5 \pm 22.3\%$, and $40.1 \pm 17.1\%$ respectively. There were no adverse events reported. Investigators concluded that in their convenience sample of severely ill and injured patients, IO pressure was reliably obtained and appeared to be 35% to 40% of blood pressure readings obtained via external blood pressure cuff; and that this method of pressure monitoring may be an appropriate alternative to invasive monitoring option in the future. This study was sponsored by Teleflex Incorporated.

Intraosseous Vascular Access Bibliography

Arrow® EZ-IO®

- Sampson CS, Bedy S-M. Lipid emulsion therapy given intraosseously in massive verapamil overdose. *Am J Emerg Med* 2015;33(12):1844.e1.doi: 10.1016/j.ajem.2015.04.061** 767
- A case study report of a 24-year old female who presented to the emergency department after consuming an over dose amount of verapamil. Central and peripheral venous access were obtained for delivery of vasopressors and intravenous fat emulsion 20% (IFE). IFE was initiated via peripheral IV (PIV) access but access was lost; administration through central access was not possible due to the potential drug interaction. Intraosseous (IO) access was established using the Arrow EZ-IO system in the proximal tibia without complication and IFE administration was resumed. The patient reported some pain with infusion. After half the bolus administration was delivered, the infusion pump alarmed due to inadequate flow. PIV access was obtained and IFE administration was resumed using the newly obtained access route. The authors suggested that the viscosity of the medication may have caused the delivery failure by infusion pump through the IO route and recommend slowing down the bolus rate of infusion for clinicians attempting this route for IFE administration in the future.
- Stimac J, Paxton J. The "Golden Hour" of volume resuscitation: Pilot data from the shock access for emergent resuscitation (SAFER) study. *Ann Emerg Med* 2015;66(4s):S110** 1010
- This abstract describes a study (SAFER) reporting initial emergency department efforts in obtaining adequate vascular access (AVA) and initiating appropriate fluid resuscitation for hypovolemic patients with undifferentiated hypotension within the first 60 minutes following ED arrival. AVA was defined as any two of the following: PIV, IO, or CVC catheter. No data was given regarding time to IO access in the results
- Stimac J. Resuscitation and the humeral intraosseous line. *EM Resident* 2015; <http://www.emresident.org/resuscitation-and-the-humeral-intraosseous-line/>. Accessed June 13, 2015.** 763
- An overview of IO vascular access with a focus on the proximal humerus IO insertion site.
- Strandberg G, Larsson A, Lipcsey M, Michalek J, Eriksson M. Intraosseous and intravenous administration of antibiotics yields comparable plasma concentrations during experimental septic shock. *Acta Anaesthesiol Scand* 2015;doi: 10.1111/aas.12454** 738
- Preclinical study using a porcine model to determine whether there were differences in intraosseous (IO) and intravenous (IV) antibiotic (cefotaxime and gentamicin) concentrations during septic shock. Both methods of administration yielded comparable concentrations. Authors concluded in an emergency, IO administration of these antibiotics may be considered in severe infections when venous access is difficult
- Sweden
- Suominen P, Nurmi E, Lauerma K. Intraosseous access in neonates and infants: Increased risk of compartment syndrome and leg amputation. *Resuscitation* 2015;96(Suppl 1):S131-2. <http://dx.doi.org/10.1016/j.resuscitation.2015.09.313>** 1024
- This is an abstract of a study that analyzed possible technical and anatomical factors leading to the complication of amputation as a result of IO placement. The study was prompted by a case report of amputation in a neonate after IO access using the EZ-IO device. The study measured medullary diameter of the proximal tibia at the recommended IO access site in three groups: 1-28 day old full term neonates, 1-12 month old infants, and 3-4 year old children. The mean diameter in each group was 7.7 mm, 9.9 mm, and 12.4 mm, respectively. The small size of the IO space, especially in neonates and infants, makes correct placement difficult. As such, complications should be taken into consideration in this patient population.
- Suominen PK, Nurmi E, Lauerma K. Intraosseous access in neonates and infants: risk of severe complications- a case report. *Acta Anaesthesiologica Scandinavica* 2015;59(10):1389-93. doi: 10.1111/aas.12602** 769
- This case study describes a neonate who suffered a cardiac arrest, had return of spontaneous circulation (ROSC) and was treated with multiple medications and therapeutic hypothermia. The patient had received three IO needle insertions, one in the left tibia that was removed following swelling with bolus injection; one in the left distal femur that dislodged with movement of the patient's legs; and one in the right proximal tibia. Twenty-four hours after initial IO needle placement the child developed pallor and discoloration and was diagnosed with compartment syndrome to the right lower extremity. Five days post-IO insertion a below the knee amputation was performed. Medications infused via the IO access included epinephrine and norepinephrine infusions.
- Ventura AMC, Shieh HH, Bousso A, et al. Double-blind prospective randomized controlled trial of dopamine versus epinephrine as first-line vasoactive drugs in pediatric septic shock. *Crit Care Med* 2015;43(11):2292-302. doi:10.1097/CCM.0000000000001260** 840
- This article describes a prospective double-blind randomized controlled study evaluating the difference between use of dopamine and epinephrine as first-line vasoactive drug in pediatric septic shock patients. This study conducted in the pediatric intensive care unit (PICU) of Hospital Universitario da Universidade de Sao Paulo, Brazil. One hundred twenty-one patients aged 1 month to 15 years who met criteria were randomized to receive either epinephrine (n=57) or dopamine (n=63) via IV or intraosseous (IO) vascular access (via EZ-IO). The authors concluded dopamine was associated with an increased risk of death and healthcare-associated infection; whereas administration of epinephrine via IV or IO routes was associated with increased survival.
- Zu L, Zhou B, Wang Y, Gao W. The history, current The history, current situation and future of bone marrow intraosseous infusion. *Chin Med Frontier Mag* 2015;7(1):114-9.Chinese** 888
- This is a review article written in the Chinese language describing intraosseous vascular access.

Intraosseous Vascular Access Bibliography

Arrow® EZ-IO®

YEAR: 2014

- Abbal B, Perbet S, Pereira B, et al. Utilisation de la voie intraosseuse chez l'adulte en France en 2012 [Use of the intraosseous access in adult patients in France in 2012]. Annales Francaises d'Anesthesie et de Reanimation 2014;33(4):221-6. <http://dx.doi.org/10.1016/j.annfar.2014.02.006>** 696

This article in French is a survey of residents and doctors in France that practice in ED, ICU and anesthesiologists units seeking their opinions and practice habits in regard to IO access. Only 29% had ever used an IO kit; with a correlation between years of experience in practice and use of IO access. 555 had received some IO access training; 90% of untrained doctors believed training was necessary. The powered system was the most utilized (EZ-IO).

France

- Barlow B, Kuhn K. Orthopedic management of complications of using IO catheters. Am J Orthop 2014;43(4):186-90** 694

Literature search for complications associated with IO access included 5759 patients with overall complication rate of 2.1 %. Two cases involving retained needle fragment discussed; one with a proximal tibial EZ-IO that required surgical removal. Authors concluded IO catheters are reliable tools for fluid and drug delivery to critically ill patients with low complication rates (which can be potentially serious but managed).

- Barnard EBG, Moy RJ, Kehoe AD, Bebart VS, Smith JE. Rapid sequence induction of anesthesia via the intraosseous route: a prospective observational study. Emerg Med J 2014;32(6):449-52. doi:10.1136/emmermed-2014-203740** 702

A prospective observational study that evaluated use of intraosseous vascular access for delivery of rapid sequence intubation (RSI) drugs. Data was collected between January and May 2012 at a combat hospital in Afghanistan. Thirty-four (34) patients underwent RSI with drug delivery via the IO route. Access was established in the proximal humerus and tibia using the EZ-IO and in the sternum using the FAST-1. All placements were successful on first attempt; first pass intubation success rate was 97%; a Cormack-Lehane (C-L) laryngoscopic grade view of 1 was reported 91%. Authors concluded that IO access is a safe and feasible route for delivery of anesthetic drugs for RSI.

- Bebarta VS, Pitotti RL, Bondreau S, Tanen DA. Intraosseus versus intravenous infusion of hydroxocobalamin for the treatment of acute severe cyanide toxicity in a swine model. Aca Emerg Med 2014;21(11):1203-11** 865

Randomized swine study with the objective to compare the efficacy of IO delivery of hydroxocobalamin to intravenous (IV) injection for the management of acute cyanide toxicity. The survival rate, physiologic parameters such as reversal of hypotension, and pharmacokinetic results were similar between the IV and IO group. The primary limitation was use of a swine model. Investigators concluded intraosseous hydroxocobalamin may be as effective as the intravenous route in treatment of cyanide toxicity.

- Bebarta VS, Vargas TE, Castaneda M, Boudreau S. Evaluation of extremity tissue and bone injury after intraosseous hypertonic saline infusion in proximal tibia and proximal humerus in adult swine. Prehosp Emerg Care 2014;doi:10.3109/10903127.2014.912704** 697

Randomized comparative study of adult pigs infused intraosseously with either: 7.5% hypertonic solution (HTS), 3% HTS or normal 0.9% isotonic saline. The animals were observed daily for infection, necrosis and gait up to 5 days, then necropsy and histological analysis was performed for tissue necrosis. Observations included regular tissue morphology and normal gait scores over the 5 day observation period; and absence of gross tissue necrosis and microscopic ischemia post IO HTS infusion in this swine model. Authors concluded this study confirms the clinical safety of IO HTS infusion and its use as an alternative lifesaving treatment.

- Burgert J, Mozer J, Williams T, et al. Effects of intraosseous transfusion of whole blood on hemolysis and transfusion time in a swine model of hemorrhagic shock: a pilot study. AANA Journal 2014;82(3):198-202** 733

Preclinical study using a porcine model to determine whether there were differences in intraosseous (IO) and intravenous (IV) whole blood transfusion relative to hemolysis and transfusion time. IO transfusion does not significantly increase hemolysis (using free hemoglobin as outcome measure) or transfusion time compared with IV transfusion. Authors concluded transfusion of whole blood through an IO device is an effective transfusion method that may be used until other vascular access is obtained.

- Craiu M, Stan V, Cochino AV. Intraosseous access-A classical method for vascular access that regains an important role as resuscitation tool. Ro J Pediatr 2014;68(3):233-7. Romanian** 968

This article reviews the initial development of IO access and provides an overview of IO use in pediatric populations including insertion technique, side effects, and contraindications.

English and Romanian article

- Cullen PM. Intraosseous cannulation in children. Anaesth Intensive Care Med 2014;15(12):567-9** 734

This article presented a general overview of IO use in pediatrics. The history, techniques, anatomy and physiology, complications and a short discussion of most devices on the market, including the EZ-IO, were discussed.

UK

Intraosseous Vascular Access Bibliography

Arrow® EZ-IO®

Danz M, Schulz G, Hinkelbein J, Braunecker S. Breaking the needle: A rare complication on EZ-IO removal. Eur J Anaesthesiol 2014;31:172-80 742

This letter to the editor describes a single case of a needle breaking off after a proximal tibial insertion of the EZ-IO into a volunteer (one of the letter's authors) during a training session. "Divergent from manufacturer instructions the sterile steel stylet was put back into place to achieve better grip for a manual pull-out. Under steady pull in strict axial alignment and gentle clockwise turn, the needle broke away from the plastic connector". The needle was extracted using combination pliers and there is no evidence of damage to the leg. Authors acknowledge this can be avoided by adherence to manufacturer's directions for use.

Germany

Demir OF, Aydin K, Akay H, Erbil B, Karcioğlu O, Gulalp B. Comparison of two intraosseous devices in adult patients in the emergency setting: a pilot study. Eur J Emerg Med 2014;DOI:10.1097/MEJ.0000000000000187 735

This was a prospective, randomized controlled clinical pilot study comparing the BIG and EZ-IO intraosseous (IO) vascular access devices in 52 adult patients admitted to an emergency department with difficult peripheral venous access. Twenty-six patients were randomized to each device; results were first attempt insertion success BIG 92.3%, EZ-IO 84.6% (P=0.668); procedure time: BIG 2.8 ± 1.2 seconds, EZ-IO 5.2 ± 2.2 seconds (P<0.001), significant; difficulty of use (with visual analogue scale): BIG 8.6 ± 6.4 mm, EZ-IO 25.4 ± 12.6 mm (P<0.001), significant. Authors concluded both EZ-IO and BIG are shown to be reliable and safe methods for insertion of intravascular access in emergency conditions. There were no adverse events or complications reported.

Turkey

Derikx HJGM, Gerritse BM, Gans R, vander Meer NJM. A randomized trial comparing two intraosseous access devices in intrahospital healthcare providers with a focus on retention of knowledge, skill, and self-efficacy. Eur J Trauma and Emerg Surg 2014;doi:10.1007/s00068-014-0385-8 706

This article describes a randomized trial comparing the retention knowledge, skill and self-efficacy among anesthesiologists and registered nurses of anesthesia with use of the EZ-IO and Bone Injection Gun (B.I.G.). Participants were randomized to be trained on one device and were tested at 0, 3, and 12 months post training. The authors concluded that training anesthesiologists on use of the EZ-IO with the educational tools provided by the manufacturer will ensure optimal performance for a period of one year.

The Netherlands

Dev SP, Stefan RA, Saun T, Lee S. Insertion of an intraosseous needle in adults. N Engl J Med 2014;370(24):e35(1)-e35(5). Doi:10.1056/NEJMvcm1211371 700

Text article that accompanies video featured in The New England Journal of Medicine on intraosseous access which provides a general overview of IO access and demonstration of IO insertion using the EZ-IO and one manual IO needle set.

Goldschalt C, Doll S, Ihle B, Kirsch J, Mutzbauer TS. Intraosseous vascular access through the anterior mandible- a cadaver model pilot study. PLoS ONE 2014;9(11):e112686. doi:10.1371/journal.pone.0112686 790

A cadaveric study performed by dentistry and medical students evaluating the feasibility of gaining vascular access via the anterior mandible bone.

Gurman P, Chi A, Hood T, et al. Prefilled devices for parenteral applications. Expert Rev Med Devices 2014;11(2):205-223 981

This review provides a comprehensive summary of pharmacologic therapies that utilize prefilled devices as a delivery mechanism for parenteral application. Six categories are described: endocrine, neurological, pain management, immune disorders, anaphylaxis, and emergency medicine. Within emergency medicine IO access is recommended as an alternative to IV access when IV access cannot be obtained. Various devices for IO access, including the EZ-IO device, are listed.

Johnson D, Dial J, Ard J, et al. Effects of intraosseous and intravenous administration of Hextend on time of administration and hemodynamics in a swine model. J Spec Oper Med 2014;14(1):79-85 713

A preclinical study comparing intraosseous (IO) and intravenous (IV) administration of Hextend in 27 swine for time of administration and hemodynamics. IO access was established in the proximal humerus using the EZ-IO. Results showed time for administration was not significant; there were no significant differences between IV and IO relative to hemodynamics. The author concluded that the IO route is an effective method of administering Hextend

Kurowski A, Timler D, Evrin T, Szarpak T. Comparison of three different intraosseous access devices for adults during resuscitation: randomized cross-over manikin study. Am J Emerg Med 2014;32:1490-3. DOI: http://dx.doi.org/10.1016/j.ajem.2014.09.007 739

Manikin study conducted in Poland with 107 paramedic operators designed to investigate the success rate, time of insertion and perceived difficulty of intraosseous access devices during simulated resuscitation using the EZ-IO, Bone Injection Gun and Jamshidi needles. Results were first attempt success: B.I.G.: 91.59%; EZ-IO: 82.66%; Jamshidi: 47.66%; mean procedure time: B.I.G.: 2.0 min ± 0.7; EZ-IO: 3.1 min ± 0.9; Jamshidi: 4.2 min ± 1.0; and ease of use (1-very easy to 5-very hard): B.I.G.: 1.83; EZ-IO: 2.92; Jamshidi: 4.68.

Poland

Intraosseous Vascular Access Bibliography

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Kwon OY, Park SY, Yoon TY. Educational effect of intraosseous access for medical students. Korean J Med Educ. 2014;26(2):117-24. <http://dx.doi.org/10.3946/kjme.2014.26.2.117> 757

The objective of this study was to evaluate inclusion of IO access in Korean medical education with a selected group of 50 medical students. Students received 1 hour of didactic lecture and a 1 hour hands on session using the EZ-IO and artificial tibias and were tested. Results showed an insertion success rate of 88%. The authors concluded IO access was adequate for medical education in Korea.

Lee BK, Jeung KW, Lee HY, et al. Confirmation of intraosseous cannula placement based on pressure measured at the cannula during squeezing the extremity in a piglet model. Resuscitation 2014;85(1):143-7. doi: 10.1016/j.resuscitation.2013.09.001 678

In this pre-clinical study, investigators sought to determine if the pressure readings at the proximal tibia IO site served as a good indicator of proper IO placement when the foot of the limb was squeezed. Traditional methods used to determine correct IO placement, including needle stability, aspiration of blood, and easy infusion, were used as comparators. Results showed the increased pressure reading at the IO site successfully predicted correct IO placement in all cases; traditional methods did not consistently correctly identify proper IO needle placement.

Lewis P, Wright C. Saving the critically injured trauma patient: a retrospective analysis of 1000 uses of intraosseous access. Emerg Med J 2014;31(9):784. doi:10.1136/emmermed-2014-203588 714

This retrospective study reported IO use over a 7-year period during combat operations in Afghanistan by the UK Defence Medical Services. The EZ-IO and FAST1 IO devices were available for use; IO use data was collected from the front line, during helicopter evacuation and at the combat hospital. A total of 1014 IO devices were inserted into 830 adult patients; various medications infused via IO access are listed. Across all cases there were no serious IO complications and 14 minor complications. The author concluded that in the pre-hospital setting in particular and in severely injured trauma patients, IO access should be considered a primary method of obtaining vascular access.

Lingner M, Niederer O, Majolk J, Kromholz K. Kasuistik: Die intraossare infusion als alternative in der sepsistherapie beim erwachsenen [Case report: Intraosseous infusion as an alternative solution in the therapy of septicemia in an adult]. Anesthesiol Intensivmed Notfallmed Schmerzther. 2014;49(2):100-3. doi:10.1055/s-0034-1368674 698

Case study of 36 year-old in septic shock with co-morbidities of IV drug abuse, endocarditis, tricuspid valve insufficiency and pulmonary embolism. Initially impossible to obtain PIV or CVC access; then unable to give desired fluids through 22 gauge PIV when finally placed. Proximal humerus IO access was established with the EZ-IO 45 mm needle set and the patient was resuscitated with 30 mL/kg fluids and multiple medications given in first hour. Conclusions included that CVCs are not always possible and volume treatment with an IO placed sooner rather than later, especially in children but also in adults, can be lifesaving. IO systems should be extensively available throughout the clinical setting. Article in German.

Germany

Lottenberg L, Lovato L, Bloch S, Puga T, Philbeck T. The proximal humerus may be a viable site for contrast injection using a power infuser for CT exam. Crit Care Med. 2014;42(12):abstract 1075. 759

This abstract describes the results of an observational clinical study that evaluated the use of IO vascular access via the proximal humerus insertion site for administration of contrast media for computed tomography examination. Eight subjects were enrolled into the study, 7 procedures were performed successfully with adequate opacification of the images. One subject experienced extreme pain with the contrast injection, the procedure was terminated and an alternative vascular access route was utilized. There were no serious complications reported. This study was sponsored by Teleflex Incorporated.

Loughren M, Banks S, Naluan C, Portenlanger P, Wendorf A, Johnson D. Onset and duration of intravenous and intraosseous Rocuronium in swine. West J Emerg Med 2014;XV(2):241-5 721

A preclinical study comparing the time to onset, time to onset peak, and time to recovery of peripheral intravenous and tibial intraosseous administration of Rocuronium. Study results demonstrated there was no statistical difference from the time of administration to complete neuromuscular blockade between the IO and IV administration of Rocuronium; and the recovery of neuromuscular function was significantly longer after IO administration, however was not deemed clinically significant. The authors concluded that Rocuronium can effectively be used via the IO route without the need for dose adjustments.

Martin Reyes B, Abolafia del Balazo R, Estepa Sanchez A, Garcia Cazalilla M, camara Anguita S, Rojas Jimenez AM. Emergencies medical services: intraosseous drill in CPR. Resuscitation 2014;85(S):S24 715

This abstract describes an observational study evaluating use of the intraosseous drill (EZ-IO) in 20 patients assisted by EMS and receiving CPR within a 3 year period. The study includes 4 pediatric and 16 adult patients. The authors concluded that IO access is a reliable alternative to peripheral venous access and can be implemented fast and with high success rate of CPR in which drugs and fluids are given.

Spain

Intraosseous Vascular Access Bibliography

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Mochizuki T, Yamashita K, Matsushima H, Yoshino A. A practical seminar on intraosseous needle placement (IO) and point-of-care color Doppler ultrasound confirmation. *The Journal of Japan Society for Clinical Anesthesia* 2014;34(3):429 752

This abstract describes a practice seminar held at the 32nd annual meeting of the Japanese Society of Reanimatology for establishing intraosseous vascular access in simulation using the EZ-IO and using Doppler ultrasound to confirm placement. The authors concluded the EZ-IO system enables immediate vascular access to the central circulation and the Doppler method enables objective recognition of needle misplacement.

Montez D, Puga T, Garcia M, et al. Lactate levels in venous and intraosseous blood correlate; prothrombin time/INR levels do not. *Aca Emerg Med* 2014;21(5)Suppl:S304. 773

In a series of studies using healthy adult volunteers the objective was to add to available data comparing IO marrow/blood (initial 1 mL aspirate), IO blood (subsequent aspirate), and venous and capillary blood to determine if there is a correlation between samples for serum lactate and PT/INR levels. Two point-of-care analysers were used. Conclusions were lactate levels obtained from IO blood appear comparable to lactate levels from venous blood; the PT/INR levels did not correlate. This study was sponsored by Teleflex Incorporated.

Nadler R, Gendler S, Chen J, Lending G, Abramovitch A, Glassberg E. The Israeli Defense Force experience with intraosseous access. *Military Medicine* 2014;179(11):1254-7 740

Retrospective study of the Israeli Defense Force (IDF) registry from January 1999 through October 2012 to identify all cases in which IO access was attempted. The Bone Injection Gun (B.I.G.) was the device used for IO access. A total 37 attempts were made in 30 patients. First attempt success was 53% with an overall success rate 49% when factoring subsequent attempts. Most frequent cause for failure related to providers skill level, and due to the device design allowing little room for error. This study prompted the IDF to seek an alternative for the B.I.G.

Israel

Neuhaus D. Intraosseous infusion in elective and emergency pediatric anesthesia: when should we use it? *Curr Opin Anaesthesiol* 2014;27(3):282-7. DOI: 10.1097/ACO.0000000000000069 723

General review of IO access, with particular attention to perioperative setting and includes published guidelines of the German Scientific Working Group for Pediatric Anesthesia for use of intraosseous access. The author recommends that for children with known difficult venous access physicians discuss the possibility of IO access preoperatively with the family.

Switzerland

Oesterlie GE, Petersen KK, Knudsen L, Henriksen TB. Crural amputation of a newborn as a consequence of intraosseous needle insertion and calcium infusion. *Ped Emerg Care* 2014;30(6):413-4 699

Case study of newborn girl resuscitated with 15 mm EZ-IO catheter placed to her right proximal tibia. Medications given included antibiotics, "fluids" and calcium. Demarcation of the infants skin was noted immediately post-calcium administration; with progression to necrosis. Trans-tibial amputation was performed 1.5 months after initial IO access. Authors concluded calcium extravasation most likely caused the injury but were unable to identify extravasation cause; citing possible needle displacement. Cautionary steps to reduce risk emphasized by authors.

Denmark

Pasley J, Miller C, Dubose J, et al. Intraosseous infusion rates under high pressure: a cadaveric comparison of anatomic sites. 2014 Annual Scientific Assembly for the Eastern Assoc for the Surgery of Trauma meeting. <http://www.dtic.mil/cgi-bin/GetTRDoc?AD=ADA597324>. Published January 2014. Accessed May 12, 2014 728

This report describes a study conducted by the Air Force Research Laboratory comparing intraosseous infusion rates between IO sites in a cadaveric model to determine if there is a site that is most effective for volume resuscitation. Using 16 cadavers procured within 72 hours of death, IO access was established in the proximal tibia and proximal humerus using the EZ-IO and in the sternum using the FAST1. Results showed the mean flow rate in the sternum was 1.6 times greater than the humerus and 3.1 times greater than the tibia. An abstract describing this report was presented by oral presentation at the 2014 annual scientific assembly for the Eastern Association for the Surgery of Trauma meeting.

Polat O, Oguz AB, Comert A, Demirkan A, Gunalp M, Tuccar E. Intraosseous access learning curve; is it really practical? *Am J Emerg Med* 2014; 32(12):1543-4.doi: 10.1016/j.ajem.2014.09.018 747

This letter to the editor describes a cadaver study performed by 50 interns who had never performed IO insertion, to determine if there is a learning curve associated with use of the EZ-IO for establishing IO vascular access in the proximal tibia. Following training each intern performed 10 IO insertions and were timed. The results showed a difference between the first and the eighth attempts resulting in a decrease in time to insertion by half. The authors concluded that practice insertions are necessary to become comfortable with the device.

Turkey

Intraosseous Vascular Access Bibliography

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Puga T, Montez D, Davlantes C, et al. Whole blood transfusion via IO access does not result in gross hemolysis in a pre-clinical study. *Crit Care Med* 2014;42(12):A1421. abstract 251

760

In this pre-clinical study, 18 units of blood were transfused into 10 anesthetized swine via intraosseous (IO) access. Venous specimens were collected to evaluate free hemoglobin levels as an indicator of hemolysis. Seventeen transfusions were given via the proximal humerus site and 1 via the proximal tibia, using a pressure bag set to 300 mmHg. Mean transfusion flow rate was 61.6 ± 37.3 mL/min and the mean blood volume transfused was 266 ± 74 mL (n=18). The authors concluded that blood transfusion via IO access resulted in high flow rates and did not result in appreciable hemolysis as indicated by free hemoglobin values. This study was sponsored by Teleflex Incorporated.

Rush S, D'Amore J, Boccio E. A review of the evolution of intraosseous access in tactical settings and a feasibility study of a human cadaver model for a humeral head approach. *Mil Med* 2014;179(8 Suppl):24-8. doi: 10.7205/MILMED-D-13-00484

726

This article explores use of IO vascular access in combat and tactical settings through a brief review of the literature describing this practice. A small feasibility study is discussed that evaluated the use of cadavers for training 26 U.S. Air Force Pararescuemen (PJs) on establishing IO access in the humeral head (proximal humerus is the descriptor used by EZ-IO for this site) using the EZ-IO powered driver and needle set system (pictured in the article) and needles inserted with a manual driver without power. First attempt placement success with the EZ-IO powered driver system was achieved in 25 of 26 attempts; first attempt placement success using the manual driver and needle set occurred in 19 of 21 attempts. The authors concluded that the humeral head (proximal humerus) IO site is the most appropriate site within the tactical setting; and that use of a human cadaver model for training is an appropriate model.

Schlimp CJ, Solomon C, Keibl C, et al. Recovery of fibrinogen concentrate after intraosseous application is equivalent to the intravenous route in a porcine model of hemodilution. *J Trauma Acute Care Surg* 2014;76(5):1235-42

717

A preclinical study comparing the recovery of fibrinogen in a porcine model when fibrinogen concentrate is administered via IV and IO access. The study results suggested intraosseous administration of fibrinogen concentrate results in a recovery of fibrinogen similar to that of intravenous administration.

Sontgerath JS, Rubal BJ, DeLorenzo RA, Morgan TL, Ward JA. Variability in intraosseous flush practices of emergency physicians. *Am J Emerg Med* 2014;<http://dx.doi.org/10.1016/j.ajem.2014.03.001>

719

This prospective study sought to evaluate intraosseous flush practices of emergency physicians. Using cadavers, 15 emergency physicians were asked to flush an IO catheter placed in the proximal tibia and proximal humerus IO insertion sites with 10 mL normal saline as they would in clinical practice; IO pressure measurements were recorded using an IO catheter inserted in the diaphysis of the target bones. Results showed the median IO pressure generated was 903 mmHg and the median flush duration was 5.2 seconds. Result showed significant interoperator variability with greater than 35-fold difference in flush forces. The authors concluded that it may be prudent practice for providers to extend the flush over several seconds to limit the maximal pressures.

Vassallo J, Horne S, Smith JE. Intraosseous access in the military operational setting. *J R Nav Med Serv* 2014;100(1):36-9

794

This article describes a prospective, observational study conducted March – July 2011 at the emergency department, Camp Bastion, Afghanistan evaluating use of IO access in 117 patients established using the EZ-IO and the FAST1 devices (76% EZ-IO).

Vincent-Lambert C, Carpenter AP. Factors affecting the frequency of vascular access via intraosseous cannulation performed by paramedics in Johannesburg. *J Vasc Access* 2014;15(6):503-6. doi:10.5301/jva.5000263

838

A questionnaire and interview study evaluating the reasons paramedics do not perform intraosseous (IO) vascular access more frequently. Twelve paramedics in Johannesburg, South Africa were interviewed for the study. Results suggested access to inappropriate equipment (pink hypodermic needles), inadequate training, lack of use in hospital Emergency Departments to which they serve, and the perceived invasiveness of the procedure and pain caused during infusion dissuaded paramedics from performing the procedure.

Winkler M, Talley C, Landwehr K, et al. Use of intraosseous needles for power injection of iodinated contrast media for emergency computed tomography angiography. *J Cardiovasc Comput Tomogr* 2014;9th annual scientific meeting abstracts:S76-7

701

Abstract presented at the Society of Cardiovascular Computed Tomography on preliminary findings of an observational study done after training ER physicians and techs on intraosseous (IO) catheter use and implementation of a policy for IO access use. Authors report high injection rates and excellent computed tomography angiography (CTA) scans safety with use of an IO for power injection of iodinated contrast media (ICM). Authors concluded cardiovascular imaging physicians, surgeons, ER physicians, and CT technologists should be familiar with the techniques of IO needle placement and use for power injection of ICM for CTA. The diagnosis and treatment of critically ill and unstable patients may be hastened by this technique.

Intraosseous Vascular Access Bibliography

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Young SW, Zhang M, Freeman JT, Mutu-Grigg J, Pavlou P, Morre GA. The Mark Coventry Award: Higher tissue concentrations of vancomycin with low-dose intraosseous regional versus systemic prophylaxis in TKA. Clin Orthop Relat Res 2014;472(1):57-65. doi:10.1007/s11999-013-3038-z

620

This randomized, controlled study compared tissue concentrations at the surgical site of regionally and systemically administered prophylactic vancomycin, in 30 patients undergoing total knee arthroscopy. The antibiotic was administered using three methods: 250mg through IO regional administration in the proximal tibia (IORA); 500mg through IORA; and 1g administered systemically through IV. Results showed the tissue concentration of vancomycin was greater in the 250mg IORA group than the systemic IV group, and the 500mg IORA group had higher concentrations than both groups.

YEAR: 2013

Ahrens KL, Reeder SB, Keevil JG, Tupesis JP. Successful computed tomography angiogram through tibial intraosseous access: a case report. J Emerg Med 2013;45(2):182-5. doi: 10.1016/j.jemermed.2012.11.091

632

Case report of 54-year-old male obtunded patient requiring a CT angiogram to diagnosis a suspected massive pulmonary embolism. After several failed attempts to reestablish PIV access, 150mL of contrast were injected through the proximal tibia IO catheter placed by EMS. Excellent opacification of the pulmonary arteries was achieved and there were no immediate complications from the injection noted.

Barratt JW. Re: reasons for not using intraosseous access in critical illness. Emerg Med J 2013;30(6):516-7. doi:10.1136/emered-2012-202120

703

This article describes a questionnaire study that was given to UK Role One military clinicians deployed to Afghanistan to assess the level of experience and confidence rating with use of IO access, using the FAST-1 and EZ-IO, and IV access. Thirty-three responses were received; clinicians felt more confident with IV access over IO access; clinicians felt more confident with FAST-1 IO access than EZ-IO IO access.

UK

Bloch SA, Bloch AJ, Silva P. Adult intraosseous use in academic Eds and simulated comparison of emergent vascular access techniques. Am J R Emerg Med 2013. http://dx.doi.org/10.1016/ajem.2012.11.021

652

In a letter to the editor this study reports data collected (during a survey of one third of academic emergency medicine programs in the U.S.) regarding IO use in adults and comparing IO access with other vascular access techniques through simulation. Data suggest that IOs were used less than 5% of the time patients needed emergent access and a peripheral line was unobtainable. The EZ-IO was most often used IO device. Authors conclude IO use should be considered more frequently in critical, unstable patients. (This research was presented at the ACEP Research Forum in 2010).

Byars DV, Tsuchitani SN, Yates J, Knapp B. A multijurisdictional experience with the EZ-IO intraosseous device in the prehospital setting. Am J Emerg Med 2013;31(12):1712-3. doi: 10.1016/j.ajem.2013.08.056

656

This letter to the editor describes a prospective, observational, trial that evaluated use of the EZ-IO in critically ill and injured patients (adult and pediatric) in a multijurisdictional prehospital setting; 9 EMS agencies were included. The 25mm needle set was the only needle size allowed for the study. One-hundred-eleven EZ-IO placements were performed by EMT-Intermediates and EMT-Paramedics with 96 successful placements (86.5%); the most common cause for failure reported by the author was thought to be patient obesity and inadequate needle length. Cardiac arrest patients made up 74.7% of the study population and the most common site accessed was the proximal tibia. Device operators rated the ease of use 7.87 using a 0 to 10 scale where 10=extremely easy.

Dolister M, Miller S, Borron S, et al. Intraosseous vascular access is safe, effective and costs less than central venous catheters for patients in the hospital setting. J Vasc Access 2013;14(3):216-24. doi:10.5301/jva.5000130

583

An observational clinical study evaluating use of the EZ-IO in patients requiring urgent vascular access that would have otherwise received a central venous catheter due to a lack of other options. One hundred five (105) patients were enrolled across five hospitals. The authors concluded that use of IO access in place of CVCs provides time savings, safety, ease of use, and is effective at significant cost savings; IO access may be used as a bridge to CVC placement under optimal conditions; and IO access may be used to replace use of CVCs all together in selective patients. This study was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.

Erdmann L, Doll S, Ihle B, Kirsch J, Mutzbauer TS. Evaluation of the sternal intraosseous route as alternative emergency vascular access for the dental office: a manikin and cadaver model pilot study. Oral Surg Oral Med Oral Pathol Oral Radiol 2013;116(6):686-91

657

This article describes a mannequin and cadaver study that evaluated use of the EZ-IO sternal device and the Illinois needle to establish sternal IO vascular access by dental students. Results of the cadaver study showed two cases of perforation of the posterior sternal cortex when the Illinois needle was used and one EZ-IO insertion in the soft tissue without entering the IO space. The authors concluded use of the EZ-IO sternal device with the insertion site template and scalpel incision may be more efficient and less predisposed to complication than use of the Illinois needle.

Intraosseous Vascular Access Bibliography

Arrow® EZ-IO®

Fetissov H, Nadaud J, Landy C, Millot I, Paris R, Plancade D. Amines on intraosseous vascular access: A case of skin necrosis. Ann Fr Anesth Reanim 2013;32(5):e89-90.<http://dx.doi.org/10.1016/j.annfar.2013.02.022> 644

A letter to the editor reporting a case study of skin necrosis after IO administration of norepinephrine following resuscitation of a 74 years old in septic shock. The EZ-IO was placed to the proximal tibia; approximately 45 minutes post- norepinephrine administration symptoms of necrosis were evident.

Authors cite 3 hypotheses for the cause of necrosis and consider that amines' high level concentration could induce local toxicity in the bone matrix and artery spasm; suggesting it is necessary to define an upper limit of amines' concentration that should be administered through IO vascular access.

Frascone RJ, Salzman JG, Bliss P, Adams A, Wewerka SS, Dries DJ. Decreasing intraosseous pressure and increasing respiratory variability track fluid volume reduction in a porcine hypovolemia model. Ann Emerg Med 2013;62(4S):S14 666

A pre-clinical study that evaluated use of intraosseous (IO) pressure as an indicator of changes in fluid volume status during a hemorrhagic shock protocol. Central venous and arterial pressures were used as comparators. Results showed IO pressure decreased consistently during the controlled shock protocol. Authors concluded IO pressure appears to be equivalent to CVP as an indicator of fluid volume status. This study was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.

Frascone RJ, Salzman JG, Bliss P, Adams A, Wewerka SS, Dries DJ. Intraosseous pressure tracings mimics arterial pressure tracings in timing and contour. Ann Emerg Med 2013;62(4S):S13 - 4 665

A pre-clinical study that compared intraosseous (IO), central venous and arterial pressure tracings in a porcine model. Results showed that IO pressure was approximately 25% of arterial pressure. A sampling of IO blood gases revealed oxygenation levels of venous blood. This study was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.

Frascone RJ, Salzman JG, Ernest EV, Burnett AM. Use of an intraosseous device for invasive pressure monitoring in the ED. Am J of Emerg Med 2014;32(6):692.e3-692.e4.[doi:10.1016/j.ajem.2013.12.029](http://dx.doi.org/10.1016/j.ajem.2013.12.029) 667

A case study describing intraosseous pressure monitoring, through tibial IO access, using a standard arterial pressure monitoring transducer during resuscitation of a 31-year-old male in cardiac arrest. Pressure readings were recorded for approximately 53 minutes and were compared to non-invasive blood pressure cuff monitoring at the same time points. IO systolic, diastolic and mean IO pressures were approximately 40% of arterial pressures. This is the first case report demonstrating IO space has a measureable blood pressure and it correlates with pressure obtained through conventional techniques.

Grossman V. Hot Topics: CT contrast and intraosseous lines: friends or enemies? J Radiol Nurs 2013; 32(1):41-4. <http://dx.doi.org/10.1016/j.jradnu.2012.12.004> 643

General discussion on use of the intraosseous vascular access route for infusion of CT contrast, with attention to clinical considerations pertinent to nurses working in the imaging suite. Author also reviews general IO principles and IO devices.

Hafner JW, Bryant A, Huang F, Swisher K. Effectiveness of a drill-assisted intraosseous catheter versus manual intraosseous catheter by resident physicians in a swine model. Western J Emerg Med 2013;XIV(6):629-32 668

This is a preclinical study comparing the EZ-IO and the Cook manual IO needle when used by 21 resident physicians to establish IO access in anesthetized swine. Results showed the drill-assisted needle was successfully placed 100% of attempts vs 76.2% successful placement with manual; time to placement and user preference also favored the EZ-IO. Technical issues reported included bending of the manual needle 33% of attempts.

Hallas P, Brabrand M, Folkestad L. Complication with intraosseous access: Scandinavian users' experience. West J Emerg Med 2013;14(5):440-3. [doi:10.5811/westjem.2013.1.1200](http://dx.doi.org/10.5811/westjem.2013.1.1200) 669

A questionnaire study in which Scandinavian emergency physicians, anesthesiologist and pediatricians reported complications they have experienced with IO vascular access based on recollection alone. Complications were reported related to establishing IO access and using established IO access. Out of 1,802 IO cases reported by 386 responders, the most frequently reported complications included difficulty with periosteum penetration and bone marrow aspiration when establishing IO access; and slow infusion and needle displacement with established IO access. Osteomyelitis and compartment syndrome were reported with an occurrence of 0.4% and 0.6%. Researchers concluded that potential complications following IO insertion should be addressed during training. Devices discussed included the EZ-IO, BIG, Cook-Surfast, and other unidentified IO devices

Denmar

Helm M, Richter D, Schramm A, Lampl L, Hossfeld B.. Ist die intraossare punktion ein alternativer gefabzugang beim notfall in der zahnarztlichen praxis? Notfall Rettungsmed 2013;16:27-32. [Doi:10.1007/s10049-012-1629-y](http://dx.doi.org/10.1007/s10049-012-1629-y). German 612

This article in German explores use of intraosseous access in a dental practice emergency. In a simulation study, dental students attempted to establish standard peripheral IV access and IO access using 3 different devices: EZ-IO, BIG, and manual IO. Results showed the manual was the fastest to insert, however, the EZ-IO had the highest first-attempt success rate as well as the lowest number of total attempts to IO access.

German

Intraosseous Vascular Access Bibliography

Arrow® EZ-IO®

Hunsaker S, Hillis D. Intraosseous vascular access for alert patients. Am J Nurs 2013;113(11):34-9

672

This article presents an overview of IO access focused on nurses' use of the technique. A list of available devices, history and support for use and possible complications are included.

Junkin R, Litchfield K. Intraosseous vascular access skill acquisition in labour ward staff: results of a training programme. Int J Obstet Anesth 2013;22(1):S31

674

This abstract describes a study in which 66 obstetric anesthetists, obstetricians and midwives were training on the EZ-IO and evaluated for successful application of the skill in a mannequin study. The participants also completed a survey following their insertion attempt regarding their perceived ease of use and likeliness to consider IO use in the future. Results showed first attempt success was 95.5%; respondents indicated they found the EZ-IO to be easier than establishing PIV access and 100% indicated they would consider IO use in the future.

UK

Junkin R, Selfridge J, Litchfield. Intraosseous vascular access in obstetric emergencies: an OAA approved national survey. Int J Obstet Anesth 2013;22(1):S31

673

This abstract describes the results of an online survey taken by members of the Obstetric Anaesthetists' Association, evaluating use of IO access in obstetric emergencies, and availability of IO equipment on UK labor wards. Results showed many members are trained on IO access, consider it a viable option during emergencies however have limited access to equipment.

UK

Kim S. Intraosseous access: an important clinical procedure for emergency physicians. Lifeline 2013;June:12-3

647

Article featured in June 2013 issue of California's ACEP monthly newsletter. This article discusses general IO principles with examples of several short case reviews and highlights the EZ-IO.

Lairet J, Bebartha V, Lairet K, et al. A comparison of proximal tibia, distal femur, and proximal humerus infusion rates using the EZ-IO intraosseous device on the adult swine (Sus scrofa) Model. Prehosp Emerg Care 2013;17:280-4. Doi:10.3109/10903127.2012.755582

642

Pre-clinical study comparing flow rates achieved after insertion with the EZ-IO in the proximal tibia, distal femur, and proximal humerus in a swine model. IO catheters were placed in each site and normal saline was infused for 10 minutes using a pressure bag at the highest achievable pressures greater than 300mmHg. The flow rates through the proximal humerus were statistically greater than that of the femur or proximal tibia. The femur flow rates were higher than the proximal tibia but similar. Post-mortem histopathologic evaluations done to assess for damage due to the high infusion pressures were consistent with IO catheter placement.

Lewis GC, Crapo SA, William JG. Critical skills and procedures in emergency medicine- vascular access skills and procedures. Emerg Med Clin N Am 2013;31(1):59-86. doi: 10.1016/j.emc.2012.09.006

631

This article provides an overview of various vascular access modalities in emergency medicine including peripheral IV, venous cut-down, central venous catheter, intraosseous access, umbilical vessel access, and arterial access. The anatomy and physiology, indications and contraindications, procedure steps and special considerations are outlined for each access methods discussed.

Lyon RM, Donald M. Intraosseous access in the prehospital setting-Ideal first-line option or best bailout? Resuscitation 2013;84:405-406. http://dx.doi.org/10.1016/j.resuscitation.2013.01.027

615

Editorial reviewing a case series of EZ-IO use in the pre-hospital setting in Switzerland by Santos et al., combined with a literature review. The authors conclude IO access should probably be used selectively and training on its use improved, insertion sites should be compared and further investigation of use of the EZ-IO in major trauma patients, infusing blood components, use in infants, and application of training warrant further investigation.

Mills A, Pappin D, Field V, Thorp-Jones D. Intraosseous access in the peripartum patient: is your needle long enough? Int J Obstet Anesth 2013;22(1):S30

675

This abstract describes a study in which the investigators sought to determine the approximate patient population in which the 25mm EZ-IO needle set was sufficient length to establish IO access in peripartum patients. Ultrasound was used to determine the tissue depth at four insertion sites. Twenty-six women were recruited with a median gestation of 34 weeks. In 88% of patients with a BMI<40 kg/m² the 25mm needle is sufficient to reach the bone marrow at both tibial sites. For the humeral site, IO placement may be more difficult for patients with a BMI>25 kg/m².

UK

Intraosseous Vascular Access Bibliography

Arrow® EZ-IO®

- Montez DF, Puga TA, Garcia MR, et al. Intraosseous blood correlates with venous blood in healthy subjects using point-of-care analyzers. *Ann Emerg Med* 2013;62(4S):S40** 676
- A clinical study evaluating the relationship between IO blood and peripheral venous blood lactate levels analyzed using the i-STAT point-of-care analyzer in healthy volunteers. Results showed IO blood lactate levels were comparable to venous blood lactate levels with a positive statistical correlation. This study was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.
- Myers LA, Arteaga GM, Kolb LJ, et al. Prehospital peripheral intravenous vascular access success rates in children. *Prehosp Emerg Care* 2013;17(4):425-8. doi: 10.3109/10903127.2013.818180** 1000
- This retrospective review of medical records submitted by paramedics identified patients 18 years or younger who had prehospital peripheral IV (PIV) attempts. Over 101 months at least 1 PIV attempt was made on 4188 patients ≤18 years old. The study demonstrated that success rates are significantly associated with patient age and each 1 year increase in age increased the odds of successful PIV placement by 11%. The authors suggest that IO access with the use of a semiautomatic IO device (EZ-IO) may be a more efficient first-line method for immediate treatment after 1 PIV access failure, especially in younger patients given their higher rate of PIV insertion failure.
- Oksan D, Ayfer K. Powered intraosseous device (EZ-IO) for critically ill patients. *Indian Pediatr* 2013;50(7):689-91** 685
- A retrospective chart review evaluating use of the EZ-IO in 25 pediatric patients between July 2008 and August 2010 at a Turkish university affiliated hospital. All attempts were made in the proximal tibia and IO access was attempted following failed PIV access within 60 seconds. First attempt success was 80%; the most reported complication was simple extravasation (3 cases) and needle dislodgement (1 case). Turkey
- Plancade D, Ruttimann M, Wagnon G, et al.. La perfusion intraosseuse chez l'adulte. *Annales Francaises d'Anesthesie et de Reanimation* 2013;http://dx.doi.org/10.1016/j.annfar.2013.02.024. French** 617
- This article in French gives an overview of intraosseous vascular access including the physiology of IO infusion, insertion sites, indications, and complications. Available IO devices on the market are described including, time to insertion, success rate and cost.
- Pozza M, Lunardi F, Pflipsen M. Emergency intraosseous access: a useful, lifesaving device use in Afghanistan. *J Spec Oper Med* 2013;13(1):25-8** 684
- A case study describing use of the EZ-IO in Afghanistan by US military on 5 patients with traumatic injury including one pediatric patient. Access was obtained in the proximal tibia on first attempt and was used to administer crystalloids in all patients along with opioids, analgesics and antibiotics. All ultimately received central venous access and peripheral access was established in one patient. There were no IO complications.
- Reinhardt L, Brenner T, Bernhard M, et al. Four years of EZ-IO system in the pre- and in-hospital emergency setting. *Central European Journal of Medicine* 2013;8(2):166-71. Doi:10.2478/s11536-012-0125-6** 618
- An observational study evaluating use of the EZ-IO by two ground and one air based physician staffed EMS and at a German surgical university hospital between January 1, 2008 and December 31, 2011. The EZ-IO was used to establish IO access 88 times in 87 patients; 83 insertions were performed in the EMS and 5 were performed in the hospital. The proximal tibia was the primary site used (97.7%) and the first attempt success rate was 94%. IO access was the first approach for vascular access in children compared to adults (38.9% vs. 86.2%). There were 5 failures attributed to missed insertions or extravasation and 2 for wrong needle length. There were no serious complications.
- Reiter DA, Strother CG, Weingart SD. The quality of cardiopulmonary resuscitation using supraglottic airways and intraosseous devices: a simulation trial. *Resuscitation* 2013;84:93-7. doi:10.1016/j.resuscitation.2012.07.003** 586
- A simulation study evaluating if use of a laryngeal mask airways (LMA) and intraosseous (IO) lines established using the EZ-IO leads to improved resuscitation in a simulated cardiac arrest when compared to standard endotracheal intubation and central line placement. Results showed mean time to airway, mean duration of airway attempt, and time to vascular access was shorter in the IO group than the CVL group. Time to defibrillation and percent hand off time was not significantly different between the groups.
- Santos D, Carron PN, Yersin B, Pasquier M. EZ-IO intraosseous device implementation in a pre-hospital emergency service: a prospective study and review of the literature. *Resuscitation* 2013;84(4):440-5. http://dx.doi.org/10.1016/j.resuscitation.2012.11.006** 604
- An observational study evaluating use of the EZ-IO in a Swiss pre-hospital EMS system between January 1, 2009 and December 31, 2011 and comparing those results to the literature. Sixty IO insertions were performed on 58 patients; the proximal tibia was used in all attempts except 1 attempt made in the proximal humerus. Overall success rate was 90%; the 6 failures were attributed to impossibility to infuse, difficult needle insertion, and incorrect insertion site (tibial plateau). Some of the indications for IO access included cardiorespiratory arrest, major trauma, and shock; general anesthesia was successfully induced in 7 patients. Drugs infused are listed. There were no serious complications.

Intraosseous Vascular Access Bibliography

Arrow® EZ-IO®

Souchtchenko SS, Benner JP, Allen JL, Brady WJ. A review of chest compression interruptions during out-of-hospital cardiac arrest and strategies for the future. J Emerg Med 2013. <http://dx.doi.org/10.1016/j.jemermed.2013.01.023>

624

This article reviews the clinical effects of both high-quality chest compressions and the effects that interruptions during chest compressions have clinically on patient outcomes. The authors indicate intraosseous vascular access should be heavily considered as the first or at least second-line method used to help prevent prolonged compression interruptions for the purpose of establishing vascular access. The authors note that when using the EZ-IO this method of access is fast, effective, can handle all resuscitation fluids, and can minimize no flow time when used properly.

Torres A, Banister N, Fernandez M, Cox K, Fletcher J. Appropriateness and complications of intraosseous needle placements during pediatric transports. Crit Care Med 2013;41(12):abstract 215

792

A quality initiative study conducted evaluating use of the EZ-IO needles in pediatric patients and their associated complications rates when placed by EMS/ED staff compared Air Evac Lifeteam placement in 2012. The authors concluded that the powered IO device was appropriately utilized by ED/EMS staff as well as Air Evac staff and that there was no difference in the complication rate when the device was used by the two groups.

Torres F, Galán MD, Alonso MD, Suarez R, Camacho C, Almagro V. Intraosseous access EZ-IO in a prehospital emergency service. J Emerg Nurs 2013;39(5):511-4. doi: 10.1016/j.jen.2012.03.005

572

This observational pre-hospital study conducted in Madrid, Spain prospectively evaluated use of the EZ-IO Jan 2007- Dec 2009 as an alternative to peripheral IV access. During the study period, 107 patients underwent 114 EZ-IO insertions and all were successful on first attempt. IO access was established in the proximal tibia (49%), distal tibia (25.2%), radius (14.9%), and humerus (10.5%) and all lines were the first form of vascular access established in the patient. There were no adverse events or complications.

Weiser G, Poppa E, Katz Y, Bahouth H, Shavit I. Intraosseous blood transfusion in infants with traumatic hemorrhagic shock - a case report and review of the literature. Am J Emerg Med 2013;31(3):640.e3-4. doi: 10.1016/j.ajem.2012.10.036

646

This article describes a case study of a 5-month old infant that suffered a head injury resulting in shock. She received 100 mL of red blood cells via the EZ-IO in the proximal tibia, resulting in rapid hemodynamic improvement. A literature search was completed for cases of IO blood transfusion in pediatric trauma. Authors note IO availability and knowledge play an important role in hemorrhagic shock; and RBC infusions via the IO route are feasible in this age group.

Wiese CHR, Semmel T. Aktuelles zum intraossaren Zugang- Weib das team bescheid? Notfall + Rettungsmedizin. 2013; doi:10.1007/s10049-013-1698-6. German

621

Young SW, Zhang M, Freeman JT, Vince KG, Coleman B. Higher cefazolin concentrations with intraosseous regional prophylaxis in TKA. Clin Orthop Relat Res 2013;471(1):244-9. doi:10.1007/s11999-012-2469-2

576

A clinical study comparing Cefazolin concentrations found at the operation site following total knee arthroscopy when prophylactic antibiotics are administered systemically, through IV administration, and regionally, through IO injection directly at the site using the EZ-IO. Subcutaneous fat and bone samples were collected for evaluation from 22 subjects. Authors concluded that regional IO administration of prophylactic antibiotics can achieve tissues levels higher than with systemic administration.

YEAR: 2012

Abrams-Ogg AC, Defarges A, Foster RA, Bienzle D. Comparison of canine core bone marrow biopsies from multiple sites using different techniques and needles. Vet Clin Pathol 2012;41(2):235-42. doi: 10.1111/j.1939-165X.2012.00422.x

664

A pre-clinical study that compared the EZ-IO 15 gauge 25mm needle set and the 13 gauge Jamshidi aspiration/biopsy needle when used to obtain core biopsy specimens in canines.

Canada

Burgert J, Gegel B, Loughren M. Comparison of tibial intraosseous, sternal intraosseous, and intravenous routes of administration on pharmacokinetics of epinephrine during cardiac arrest: A pilot study. AANA Journal 2012;80(4):S6-S10

660

Preclinical study using a porcine model comparing the maximum concentration and time to maximum concentration of epinephrine administered via the tibial IO, sternal IO and IV routes during CPR. The IV route of administration of 1mg of epinephrine resulted in a serum concentration 5.87 and 2.86 times greater than the tibial route and sternal route respectively. The times to peak concentration was similar for IV and sternal IO groups but delayed for the tibial route. Authors conclude that due to limitations of their study the guidelines of administering 1mg of epinephrine via the IO route should not be changed; further studies using larger sample size, larger volume flush, arterial blood samples and the use of a more precise method of measuring serum epinephrine should be done.

Intraosseous Vascular Access Bibliography

Arrow® EZ-IO®

- Cairney K, Matthew I. Options for intravascular access during resuscitation of adults. Emerg Nurse 2012;20(1):24-8** 536
This article discusses how IO access can be used to improve advanced life support therapy. The EZ-IO is described in this article; published comparative studies between other IO devices and peripheral IV access are cited, leading the author to conclude the EZ-IO is user friendly, and establishes intravascular access more quickly and more often on first attempt than other devices.
- Carness JM, Russell JL, Lima RM, Navarro LHC, Kramer GC. Fluid resuscitation using the intraosseous route: Infusion with lactated ringers and hetastarch. Mil Med 2012;177(2):222-8.** 529
This pre-clinical study evaluated IO flow rates obtainable with infusion of lactated Ringer's and hetastarch 6% through the proximal tibia and sternum IO insertion sites, using a swine model. The EZ-IO 25mm was used to facilitate tibial IO access; sternal access was established using a Jamshidi needle. Results showed that hetastarch flow rates were lower than lactated Ringer's flow rates at both insertion sites; sternal infusion of hetastarch is likely to provide greater estimated intravascular volume expansion than lactated Ringer's, despite the lower infusion rates; resuscitation using the IO rate is likely to benefit from pressure bag or high-pressure pump delivery. This study was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.
- Carr BG, Proehl JA, Fox M, Miller LJ, Philbeck TE. Intraosseous vascular access: physicians and nurses identify knowledge gaps and barriers to implementation. J Vasc Access 2012;13:13A. doi:10.5301/JVA.2012.9362** 596
This abstract presented at the 2nd World Congress on Vascular Access 2012 reports data collected on the knowledge gaps and barriers to IO vascular access use. Two focus group discussions were held at professional conferences (American College of Emergency Physicians and the Emergency Nurses Association) and facilitated by clinical researchers. Data was qualitatively evaluated and researchers identified several main areas of concern for clinicians in both implementation and knowledge gap areas. This study was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.
- Duncan L, Cohen J, Triner W, Rea J, King C. Intraosseous administration of CT Contrast in a porcine model: a feasibility study. Ann Emerg Med 2012;60(4S):S92** 598
This abstract presented at the 2012 ACEP Research Forum discusses a swine pre-clinical study evaluating CT image opacification when contrast is delivered via IV and proximal humerus IO access. The EZ-IO was used to facilitate IO access. Results showed that under blinded radiology review the IV and IO images were judged adequately opacified to meet diagnostic criteria. Authors concluded that IO administration of contrast material may be a viable alternative if other vascular access is unavailable or if establishing other access will lead to a delay in diagnostic evaluation. This study was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.
- Esteo OV. Intraosseous access in prehospital emergency care. Emergencias 2012;24:44-6** 764
A prospective, observational study which evaluated use of the EZ-IO within the prehospital setting over the course of a 3 year period, in Barcelona, Spain. Included patients were in cardiac arrest or with hemodynamic instability, without peripheral venous access after 90 seconds or 3 attempts to establish access. Results showed IO access was attempted in 49 pediatric and adult patients with an overall success rate of 93.9%; complications included extravasation and pain. IO access sites included the proximal tibia (71.4%), proximal humerus (22.4%) and distal tibia (6.1%). The author concluded that IO access is a viable access route for the management of critical patients or those in cardiac arrest in the pre-hospital setting due to the ability to obtain rapid access and the high first attempt success rate.
- Greene N, Bhananker S, Ramaiah R. Vascular access, fluid resuscitation, and blood transfusion in pediatric trauma. Int J Crit Illn Inj Sci 2012;2(3):135-42 doi: 10.4103/2229-5151.100890** 980
This article is a review of techniques and available evidence for establishing intravenous access, rational approaches to fluid resuscitation, and blood product transfusion in the pediatric trauma patient. IO needle systems are available for integration into pre-existing trauma care systems for pediatric patients.
- Hoskins SL, Nascimento P Jr., Lima RM, Espana-Tenorio, JM, Kramer GC. Pharmacokinetics of intraosseous and central venous drug delivery during cardiopulmonary resuscitation. Resuscitation 2012;83(1):40-5. doi:10.1016/j.resuscitation.2011.07.041** 442
Pharmacokinetics of IO drug delivery was compared using the tibia or sternum, versus central venous delivery during CPR. Anesthetized swine with KCl arrest were used for this study, CPR was initiated 8 minutes post arrest. Using 2 study groups, dye was injected as a bolus with adrenaline through either the IO sternal and tibial needles or through the IO sternal and IV central venous needles. Results showed peak arterial blood concentrations were faster for sternal IO vs tibial IO administration. Tibial IO delivered 65% of the total dose delivered with sternal administration. Peak blood concentrations were similar for sternal IO and central venous administration. Sternal IO delivered 86% of the total dose delivered by central venous administration. The EZ-IO and Jamshidi were used to facilitate IO access. This research was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.
- Ibrahim M, Cairney K. Intraosseous (IO) infusion as a means of vascular access. Br J Resuscitation 2012;Autumn:23-6** 599
This article provides an overview of intraosseous vascular access, including applicable patient population, IO access sites, pain management, IO education and compares IO access to central venous access.

Intraosseous Vascular Access Bibliography

Arrow® EZ-IO®

Kalechstein S, Permual A, Cameron BM, et al. Evaluation of a new pediatric intraosseous needle insertion device for low-resource setting. *J Pediatr Surg* 2012;47(5):974-9. doi: 10.1016/j.pedsurg.2012.01.055

546

This article describes a study evaluating a new manual needle insertion device, the Near Needle Holder, which uses hollow-bore needles to establish IO access. In a comparative study, healthcare professionals attempted IO insertion in the proximal tibia insertion site of a mannequin using the NNH and a standard Cook manual IO needle. Participants then completed a questionnaire regarding their experience. The most reported complication was the plunging of the needle into the medullary space from the decrease in resistance once the cortex was penetrated. Other IO devices on the market are mentioned, including the EZ-IO.

Landy C, Plancade D, Gagnon N, Schaeffer E, Nadaud J, Favier JC. Complication of intraosseous administration of systemic fibrinolysis for a massive pulmonary embolism with cardiac arrest. *Resuscitation* 2012;83(6):e149-50. doi: 10.1016/j.resuscitation.2012.01.044

547

This letter to the editor describes a case in which a 53-year-old male in ventricular fibrillation received IO access via the EZ-IO in the ED with suspected massive pulmonary embolism. The patient was successfully resuscitated. Necrosis of the anteromedial side of the leg, at the IO site, presented 48 hrs post IO use. After 18 weeks the patient underwent surgical grafting. The authors linked the necrosis to adrenaline extravasation and local ischaemia. While the authors conclude that thrombolysis or repeated high doses of adrenaline should be given via the IO route when needed, it is not without the risk of complication.

Leidel BA, Kirchhoff C, Bogner V, Braunstein V, Biberthaler P, Kanz KG. Comparison of intraosseous versus central venous vascular access in adults under resuscitation in the emergency department with inaccessible peripheral veins. *Resuscitation* 2012;83(1):40-5. doi:10.1016/j.resuscitation.2011.08.017

439

This clinical trial evaluated the time required to establish IO access versus central venous catheter (CVC) in adults undergoing resuscitation, who had failed peripheral IV access (PIV) attempts. IO and CVC placement were performed simultaneously; two IO devices, the EZ-IO and the BIG, were used to facilitate IO access in randomized format. Forty (40) patients were enrolled, first attempt success for IO was 85% vs 60% for CVC placement; median procedure time was 2 minutes for IO vs 8 minutes for CVC. The author concluded that though IO access is safe, reliable and rapid during resuscitation, it cannot replace CVC but should be considered as a valuable bridging technique.

Miller L, Montez DF, Philbeck TE, Puga TA, Morgan J. Infusing chilled saline via the Intraosseous route is equivalent to infusion via the intravenous route in reducing the core temperature in swine. *Prehosp Emerg Care* 2012;16(1):152. doi:10.3109/10903127.2011.624676

513

This abstract presented at the 2012 NAEMSP scientific assembly described a randomized, cross-over study in which 8 swine were administered chilled saline via IV and IO routes to determine if the two routes were equivalent. The results suggested no clinical or statistical difference between IV and IO routes for infusion of chilled saline for therapeutic hypothermia. This study was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.

Miller LJ, Montez DF, Puga TA, Philbeck TE. Intraosseous vascular access in the 21st century: improvements further reduce complication rates. *Ann Emerg Med* 2012;60(4S):S112

597

This abstract presented at the 2012 ACEP Research Forum discusses a literature review of intraosseous access publications since 1985 providing an updated safety profile for IO access. The search resulted in 192 articles describing IO access with 6 cases of osteomyelitis and 6 cases of compartment syndrome secondary to extravasation reported. Of the 192 articles identified, 140 described the EZ-IO. This study was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.

Miller LJ, Puga TA, Montez DF, Morgan J. New in therapeutic hypothermia: preclinical evidence validates the IO Route; chilled tubing works best. *Ann Emerg Med* 2012;60(4S):S90

601

This abstract presented at the 2012 ACEP Research Forum describes a preclinical swine study evaluating the ability to induce therapeutic hypothermia by infusing chilled saline via IV and IO access. The EZ-IO was used to facilitate IO access. Results showed statistical equivalence between IV and IO routes when used to deliver chilled saline to induce therapeutic hypothermia. Results also showed that use of chilled saline and infusion tubing submerged in an ice water bath provides the most effective means of cooling. This study was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.

Myers LA, Russi, CS, Kolb L. Prehospital semiautomatic intraosseous placement in adults. *Prehosp Emerg Care* 2012;16(1):173. doi:10.3109/10903127.2011.624676

514

This abstract presented at 2012 NAEMSP scientific assembly described a retrospective study that evaluated success rates and features of prehospital IO placement in adults following implementation of the EZ-IO, over a 2 year period. First attempt success rate in 281 patients was 89.7%; overall placement success was achieved for 91.8%.

Olaussen A, Williams B. Intraosseous access in the prehospital setting: literature review. *Prehosp Disaster Med* 2012;27(5):468-72. doi:10.1017/S1049023X12001124. http://journals.cambridge.org/abstract_S1049023X12001124

582

A literature review of articles describing intraosseous vascular access devices used in the pre-hospital setting. Twenty articles met the inclusion criteria and described the manual devices, BIG, Fast-1 and the EZ-IO. The authors concluded that the literature suggests that semiautomatic IO devices may be more effective than manual devices.

Intraosseous Vascular Access Bibliography

Arrow® EZ-IO®

Page D. Intraosseous intrigue: Studies examine success rates on pediatric, adult & obese patients. JEMS January 2012;32-3

515

In this article, the author discussed five recent studies on intraosseous access providing his opinion about the quality of each study.

Paxton JH. Intraosseous vascular access: A review. Trauma 2012;14(3):195-232. DOI:10.1177/1460408611430175

690

An overview of IO vascular access including a review of currently available literature. The author discusses various IO devices available and their performance metrics, IO access sites, flow rates, advantages and disadvantages of IO access compared to conventional access methods, complications and recommendations on use of the approach. The author concludes that while IO access may not be appropriate for all patients, it deserves a place in the modern provider's armamentarium.

Plancade D, Nadaud J, Lapierre M, et al. Feasibility of a thoraco-abdominal CT with injection of iodinated contrast agent on sternal intraosseous catheter in an emergency department. Annales Francaises d'Anesthesie et de Reanimation 2012;http://dx.doi.org/10.1016/j.annfar.2012.10.009

580

This letter to the editor describes a case in which sternal IO access was established using a Jamshidi needle to administer iodinated contrast for a thoraco abdominal CT on a 61-year old male who presented to the ED with respiratory distress. Picture quality was deemed excellent by the radiologists. The authors conclude that the sternal IO route can be used with excellent picture quality but it should be used only in exceptional cases due to the potential risks of a high-power injection through the bone. EZ-IO is mentioned as an alternative IO device available.

Rogers J, Fox M. The safety of intraosseous vascular access. Emergency Medicine Patient Safety Foundation Forum. Fall 2012:18-21

606

An article discussing the technique and safety profile of intraosseous access using the EZ-IO device. Needle selection, contraindications, insertion sites and techniques, catheter stabilization and removal are all discussed along with the safety profile of the EZ-IO against other IO devices and central venous catheters. The authors concluded that IO access should be considered whenever immediate vascular access is required. This article was co-written by an employee of Vidacare Corporation, acquired by Teleflex Incorporated.

Rogers JJ, Fox M, Miller LJ, Philbeck TE. Safety of intraosseous vascular access in the 21st century. J Vasc Access 2012;13:19A

579

This abstract presented at the 2nd World Congress on Vascular Access 2012 describes the results of an analysis of published IO complications since 1985. The safety profile of the EZ-IO is also discussed in this abstract. The authors conclude that new devices and techniques have resulted in an approved IO safety profile. This study was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.

Rose EC. The evidence-based use of intraosseous lines in pediatric patients. Pediatr Emerg Med Pract 2012;9(6):1-12. www.edmedicine.net

585

This article presents a general overview of intraosseous (IO) vascular access in the pediatric population through an IO literature review. Available IO devices were discussed.

Rubal BJ, McKay K, Armstrong KR, Rubal MP, Marbach MJ. Variability in intraosseous pressure induced by saline flush of an intraosseous cannula by multiple practitioners. Lab Animal 2012;41(8):224-9

578

This pre-clinical study sought to evaluate the various pressure levels obtained by 22 veterinary clinicians when administering a 10ml normal saline flush of an IO catheter. The EZ-IO was used to establish access in an isolated, cadaveric swine femur. The authors found the median peak intraosseous pressure was 615 mmHg with a range of 57 to 1,100 mmHg. Authors concluded that there is a great deal of variability between clinicians and their flush pressure and that a standardized flush protocol may be beneficial.

Rush S, Bremer J, Foresto C, Rubin AM, Anderson PI. A magnetic resonance imaging study to define optimal needle length for humeral head IO devices. J Spec Oper Med 2012;12(2):77-82

577

This article describes a retrospective study in which 50 consecutive MRI images were evaluated of the humerus for the purpose of determining the optimal needle length necessary for successful proximal humerus IO insertion. Results showed the cortical thickness was 4mm in all cases and that an IO needle length ranging between 40-50mm should be used via the anterior approach. The EZ-IO is specifically discussed in relation to the proximal humerus IO insertion site; and a 24 patient post mortem review of the EZ-IO placed in the proximal humerus is discussed.

Intraosseous Vascular Access Bibliography

Arrow® EZ-IO®

Severyn FA. Complication after intraosseous needle removal following successful systemic thrombolysis for a massive pulmonary embolism. *Resuscitation* 2012;83(11):e207. doi:10.1016/j.resuscitation.2012.07.014 575

This letter to the editor is written in response to the case report by Landy titled, Complication of intraosseous administration of systemic thrombolysis for a massive pulmonary embolism with cardiac arrest. The author suggests that the tissue necrosis described by Landy may have been due to the removal of the IO needle while there was still significant fibrinolytic activity at the needle insertion site. The author suggests a change in medical care after return of spontaneous circulation (ROSC) in patients following thrombolytic administration through IO access to convert the functioning IO line to a non-flowing saline lock. The EZ-IO was used to provide IO access in the case report by Landy.

Tan BKK, Chong S, Koh ZX, Ong MEH. EZ-IO in the ED: an observational, prospective study comparing flow rates with proximal and distal tibia intraosseous access in adults. *Am J Emerg Med* 2012;30(8):1602-6.doi.10.1016/j.ajem.2011.10.025 519

This prospective observational study compared flow rates between distal and proximal tibia IO access in adults, with each adult serving as their own control. The EZ-IO was used to facilitate IO access. IO infusion was performed with and without pressure. The authors concluded that infusion flow rates were significantly higher in the proximal tibia as compared to the distal tibia, and that flow rates are significantly higher with pressured infusion vs. non-pressured infusion. This study was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.

Truemper EJ, Beamer CL, Miller LJ, et al. Distal femur site is a viable option for IO vascular access in pediatric patients. *Ann Emerg Med* 2012;60(4S):S90 761

This abstract presented at the 2012 ACEP Research Forum explored the viability of the distal femur as an IO insertion site with a literature review of IO vascular access and brief overview of a post-mortem study of pediatric distal femur insertion success. Authors concluded that clinical literature, clinical studies, and a post-mortem study confirm that the distal femur is a viable option for IO infusion in pediatric patients. This study was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.

Vassallo J, Horne ST, Smith JE. Intraosseous access on military operations: a 4 month review. Poster presentation at International Conference on Emergency Medicine, Dublin, Ireland. June 27-30, 2012 593

This poster presented at the 2012 International Conference of Emergency Medicine described a 4 month review of intraosseous access in UK military operations in Afghanistan. During the timeframe the EZ-IO was used to establish IO access in the proximal humerus and tibia sites; the FAST1 was used to establish sternal IO access. Of the 87 EZ-IO applications there were 12 functional issues and the placement success rate for both sites combined was 86.3%. In 24 FAST1 applications there were 4 functional issues and the placement success rate was 83.4%.

Voigt J, Waltzman M, Lottenberg L. Intraosseous vascular access for in-hospital emergency use: A systematic clinical review of the literature and analysis. *Pediatr Emerg Care* 2012;28(2):185-99 562

In this article the authors review the evidence supporting the use of IO access; determine the utilization IO access as described in the literature; and assess the level of specialty society support. Various IO devices are mentioned including the EZ-IO

Wampler D, Schwartz D, Shumaker J, Bolleter S, Beckett R, Manifold C. Paramedics successfully perform humeral EZ-IO intraosseous access in adult out-of-hospital cardiac arrest patients. *Am J of Emerg Med* 2012;30:1095-9. doi:10.1016/j.ajem.2011.07.010 520

This study conducted by the San Antonio Fire Department evaluated the first-attempt success rate for humeral EZ-IO placement by paramedics in prehospital adult cardiac arrest patients. Humeral placement was attempted in 247 cardiac arrest patients; first attempt placement success rate was 91%. Authors concluded that humeral IO placement is a reliable method for vascular access in this patient population. This research was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.

Weiser G, Hoffmann Y, Galbraith R, Shavit I. Current advances in intraosseous infusion - a systematic review. *Resuscitation* 2012;83(1):20-6. doi:10.1016/j.resuscitation.2011.07.020 454

A literary search of electronic databases was performed to identify publications comparing IO access devices. Publications qualifying for study evaluation must have compared two or more semi-automatic IO devices or at least one semi-automatic device and a manual device. Reviews, editorials, surveys, and case reports were excluded. Ten comparative studies met the qualifications for inclusion and are briefly discussed. The studies evaluated suggested superiority of the battery powered IO driver over manual needles and other semi-automatic IO infusion devices.

YEAR: 2011

Auerhammer J. [Lebensbedrohliche arterielle blutung aus der a. carotis communis: Fallstricke bei der intraossaren punktion]. *Notfall Rettungsmedizin* 2011;14(2)147-150;doi 10.1007/s10049-010-1380-1. German 490

This article in German presents a case of a 67-year-old female patient with an arterial bleed and venous access difficulties in whom IO access was attempted unsuccessfully two times using two different IO systems. The author concluded that IO success is dependent upon IO anatomy and physiology knowledge as well as knowledge of the device being used.

Intraosseous Vascular Access Bibliography

Arrow® EZ-IO®

- Borron SW, Arias JC, Bauer CR, et al. Intraosseous line placement for antidote injection by first responders and receivers wearing personal protective equipment. *Am J Emerg Med* 2011;29(4):373-81. doi:10.1016/j.ajem.2009.10.009** 424
- This article describes a preclinical trial with a caprine model that assessed the ability of protected, experienced first responders and limited-experience first receivers to place IO lines for antidote administration using the EZ-IO device. First responders placed IO lines successfully in 100% of cases, and first receivers placed IO lines successfully in 91% of the cases. Investigators concluded that IO lines may facilitate earlier administration of antidotes to hazardous material victims.
- Brady M. Intraosseous infusion: A 'humerus' subject? *J Paramed Pract*. 2011;3(4):198.** 1045
- This paper summarizes a study comparing first attempt success rates between TIO and HIO insertions during out-of-hospital cardiac arrest (OHCA). Insertions were performed by paramedics using an EZ-IO device. During the first month insertions were first attempted via the HIO route followed by the TIO route if unsuccessful; and vice versa during the second month. The overall TIO insertion success rate was 84.5%. The overall HIO insertion success rate was 40%.
- Chatterjee DJ, Bukunola B, Samuels TL, Induruwage L, Uncles DR. Resuscitation in massive obstetric haemorrhage using an intraosseous needle. *Anaesthesia* 2011;66(4):306-10. doi:10.1111/j.1365-2044.2011.06629.x** 472
- The case report describes a woman experiencing massive hemorrhaging following emergency caesarean delivery. Though the patient possessed a peripheral IV catheter, additional IV access was needed and gained through the proximal humerus IO space using an EZ-IO. This vascular stabilization and additional filling of the central volume through the IO route allowed placement of a subclavian central line. Authors concluded that a key to the resuscitation process was the rapid utilization of the IO.
- Cotte J, Prunet B, d'Aranda E, Asencio Y, Kaiser E. [A compartment syndrome secondary to intraosseous infusion]. *Ann Fr Anesth Reanim* 2011;30(1):90-1. doi: 10.1016/j.annfar.2010.05.038. French** 691
- A case study report in French describing compartment syndrome secondary to intraosseous infusion in a 57-year-old burn patient. IO access was established in the proximal tibia on second attempt; both attempts were made in the same limb though it was noted that the first attempt did not penetrate the cortex. Drug and fluid infusion was initiated; ten hours later the limb was found to appear ischemic. The IO catheter was removed and compartment release was performed. The author concluded that IO access remains an important mode of vascular access and that adherence to contraindications and careful clinical monitoring should decrease risk of complications.
- France
- Coutry L, Hssain I, Joshi G, Diemunsch P. Intraosseous access for fluid administration in a simulation setting: Comparison with intravenous access. *American Society of Anesthesiologists (ASA) Annual Meeting 2012; abstract number A895.*** 539
- This simulation study compared intraosseous (IO) vascular access, via EZ-IO, with peripheral venous (PIV) access for time to access, perceived ease of placement, rapidity, and safety, and which will be first choice in life threatening situation among 73 prehospital care providers with no prior experience with IO access. Results showed time to placement for IO access was significantly faster than that of PIV; the majority of device operators graded the device superior to PIV for ease of placement, rapidity and safety.
- Cullen PM. Intraosseous cannulation in children. *Paediatric Critical Care* 2011;13(1):28-30** 523
- This article presented a general overview of IO use in pediatrics. The history, techniques, anatomy and physiology, complications and a short discussion of most devices on the market, including the EZ-IO, were discussed.
- UK
- Day MW. Intraosseous devices for intravascular access in adult trauma patients. *Crit Care Nurs* 2011;31:76-90. doi: 10.4037/ccn2011615** 540
- An overview of available intraosseous vascular access devices, including the EZ-IO.
- de Vogel J, Heydanus R, Mulders AGM, Smalbrakk DJC, Papatsonis DNM, Gerritse BM. Lifesaving intraosseous access in a patient with a massive obstetric hemorrhage. *Am J Perinatol Rep* 2011;1(2):119-122. doi: http://dx.doi.org/10.1055/s-0031-1293514** 541
- Case study of a 42 year-old woman with massive obstetric hemorrhage ultimately resulting in postpartum hysterectomy. Massive blood loss and inability to stop bleed prevented sufficient resuscitation via established PIV lines. IO access was established with the EZ-IO and used for fluid replacement and administration of cardiac resuscitation drugs. Fluid administered through IO access was 75% of the total infusion volume.

Intraosseous Vascular Access Bibliography

Arrow® EZ-IO®

- Dolister M, Miller ST, Borron S, Truemper E, Shah MR. Intraosseous vascular access can be used safely and effectively, and at a lower cost than central venous catheters, for pediatric and adult patients in the hospital setting. *Ann Emerg Med* 2011;58(4S):S311** 453
- This abstract describes the interim results of an observational clinical trial evaluating use of the EZ-IO to establish venous access in patients that would typically receive a central line due to lack of other options. At interim analysis, 50 patients had been enrolled in the study. First attempt IO access success rate was 96%; mean time to IO access was 95.1 seconds. The authors concluded that IO access in place of or as a bridge to central venous catheters is safe, fast, and effective for adult and pediatric patients in the hospital setting with substantial cost savings potential. This research was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.
- Eich C, Weiss M, Neuhaus D, et al. Handlungsempfehlung zur intraossären Infusion in der Kinderanästhesie [Recommended action for intraosseous infusion in children's anesthesia]. *Anästhesiologie Intensivmedizin* 2011;52:S46-52. German** 770
- German Society of Anaesthesiology and Intensivmedizin eV" (DGAI), includes a general discussion of intraosseous (IO) as vascular access, overview of devices and recommendations for pediatric anesthesia with indications for intraosseous infusion in pediatric anesthesia and perioperative care in children. Early or primary IO indications are respiratory and circulatory arrest; critical hemodynamic instability before or during anesthesia introduction; severe laryngospasm; anesthesia induction in respiratory bleeding. Urgent indications (decision based on each case is necessary) include urgent induction of anesthesia in non-fasted children (Ileus, RSI); induction of anesthesia in children with unstable circulation or severe cardiac insufficiency. Semi-elective indications (decision based on each case is necessary) after mask induction of anaesthesia (if vascular access required); mandatory induction of "intravenous" anaesthesia (as in malignant hyperthermia). This article is in German.
- Gazin N, Auger H, Jabre P, et al. Efficacy and safety of the EZ-IO™ intraosseous device: Out-of-hospital implementation of a management algorithm for difficult vascular access. *Resuscitation* 2011;82(1):126-9** 494
- This article describes an observational study to assess the safety and efficacy of the EZ-IO when using a management algorithm for difficult vascular access in an out-of-hospital setting. Over a one-year period, the device was used in 30 cardiac arrest and 9 other cases. Overall success rate was 97% and first attempt success was 84%. There was one complication—transient local inflammation. Investigators concluded that the device is suitable as a first-line option for difficult vascular access in the out-of-hospital setting.
- Hafeez W, Ronca LT, Maldonado TE. Pediatric advanced life support update for the emergency physician: Review of 2010 guideline changes. *Clin Pediatr Emerg Med* 2011;12(4):255-65** 525
- General overview of PALS updates. Various IO devices were specifically mentioned in the vascular access section, including the EZ-IO.
- Harcke HT, Crawley G, Mabry R, Mazuchowski E. Placement of tibial intraosseous infusion devices. *Mil Med* 2011;176(7):824-7** 469
- This article describes a military study in which post-mortem preautopsy multidetector CT was used to assess placement of tibial IO needles in battlefield trauma deaths where IO was used as part of the medical intervention. Results showed 58 of 61 (95%) tibial IO needles were correctly placed. In this study, the device used for IO placement was not recorded, but may have been the manual device or EZ-IO as the Army has access to both.
- Harcke T, Crawley G, Ritter B, Mazuchowski E. Feedback to the field: an assessment of sternal intraosseous (IO) infusion. *J Spec Oper Med* 2011;11(1):23-6** 544
- This article summarizes the case-based observations made by the Armed Forces Medical Examiner System on soldiers killed in action/died of wounds who had evidence of sternal intraosseous access. The Pyng Fast-1 is noted in the article as the sternal IO device most widely distributed by the department of defense (DOD); the EZ-IO is listed as another device that may be seen in emergency care facilities within the DOD. Of 98 cases, 78 (80%) showed proper placement; 20% were unsuccessful. It should be noted that the article incorrectly states that the EZ-IO using the powered driver is indicated for sternal placement.
- Heyder-Musolf J, Giest J, Straub J. Kasuistik-Intraossärer Zugang bei einem 1300 g schweren septischen Neugeborenen[Case history-Intraosseous access on a 1300 g septic premature infant]. *Anesthesiologie Intensivmedizin Notfallmedizin Schmerztherapie* 2011;46(10):654-7. doi: 10.1055/s-0031-1291943. [German]** 864
- Case description of a critically ill 15 day old premature infant weighing 1300 g. Tibial IO access was placed perioperatively for an urgent surgery.
- Howarth D. Adult intraosseous access: experiences in a remote emergency department. *Australian Family Physician* 2011;40(7):510-1** 483
- In this article, the author makes a supporting case for remote emergency departments to stock adult intraosseous kits by referencing two adult septic shock cases in which IO access was used for rapid IV fluid replacement as well as IV antibiotics and inotrope support.

Intraosseous Vascular Access Bibliography

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Jackson EE, Ashley TC, Snowden KF, et al. Performance and longevity of a novel intraosseous device in a goat (*capra hircus*) model. J Am Assoc Lab Anim Sci 2011;50(3):365-73 473

This manuscript describes two studies conducted to assess the function and longevity of EZ-IO catheter when placed in the goat model. The authors concluded that the EZ-IO catheter can be left in place for more than 24 hours in animals and can be used in many different veterinary settings when IV access is not immediately available. They also concluded that the EZ-IO system is useful in larger or adult bones.

Khan LAK, Anakwe RE, Murray A, Godwin Y. A severe complication following intraosseous infusion used during resuscitation of a child. Inj Extra 2011;doi:10.1016/j.injury.2011.05.015 485

This article describes the case of an 11-year-old boy who suffered compartment syndrome of the lower leg following use of the EZ-IO for resuscitation and 24 hours of intraosseous infusion of adrenaline, calcium and potassium. The author concluded that further work is needed to develop recommendations for maximum duration, dose, volume and rates for intraosseous infusion.

Knuth TE, Paxton JH, Myers D. Intraosseous injection of iodinated computed tomography contrast agent in an adult blunt trauma patient. Ann Emerg Med 2011;57(4):382-6. doi:10.1016/j.annemergmed.2010.09.025 463

This article reports a case in which IO access was used to deliver intravenous contrast agent in an adult blunt trauma patient. After placement in the proximal humerus, contrast agent was administered via the IO route, and clinicians found the CT scans of the thorax, abdomen, and pelvis to be adequate for diagnostic purposes and subjectively equivalent to those of studies using central venous access. There were no complications and the authors concluded that IO access appeared to be an effective alternative to traditional venous access for administering contrast agents for CT evaluation in adult blunt trauma patients.

Laiet J, Beberta V, Laiet K, et al. A comparison of proximal tibia, proximal humerus, and distal femur infusion rates under high pressure (>300mmHg) using the EZ-IO intraosseous device on an adult swine (*sus scrofa*) model. Prehosp Emerg Care 2011;15(1):117 493

This abstract describes a swine study presented at the 2011 National Association of EMS Physicians Annual Conference that examined infusion rates through 3 anatomical sites via the powered EZ-IO device. Investigators concluded that the infusion rate was greater via the humerus compared to the tibia and femur.

Larabee TM, Campbell JA, Severyn FA, Little CM. Intraosseous infusion of ice cold saline is less efficacious than intravenous infusion for induction of mild therapeutic hypothermia in a swine model of cardiac arrest. Resuscitation 2011;82(5):603-6.doi:10.1016/j.resuscitation.2011.01.007 476

This study compared the effectiveness of infusing ice cold saline via IO and IV to induce mild therapeutic hypothermia (temperature drop to 34°C) within a 30 minute timeframe, in a swine model of cardiac arrest. Five swine were evaluated in each the IV and IO groups. Goal temperature was reached in 4/5 animals in the IV group and 0/5 animals in the IO group in the allotted time frame; IV was superior in terms of rate of infusion, rate of temperature change, and time to achieve target temperature.

Lowther A. Intraosseous access and adults in the emergency department. Nurs Stand 2011;25(48):35-8 887

This is a review article describing intraosseous vascular access, including techniques and device used, and contraindications.

Mikrogianakis A, Kam A, Silver S, et al. Telesimulation: An innovative and effective tool for teaching novel intraosseous insertion techniques in developing countries. Acad Emerg Med 2011;18(4):420-7.doi:10.1111/j.1553-2712.2011.01038.x 440

This study evaluated the use of telesimulation by Canadian pediatricians to teach a relatively new IO insertion technique (EZ-IO System) to physicians in Africa. Self-assessment questionnaires were completed before and after training, multiple-choice tests were given and a demonstration of competency was done within 3 training sessions. Twenty-two physicians participated; the sessions improved physicians' knowledge, self-reported confidence, and comfort level in inserting the IO needle. The author concluded that telesimulation offers potential for teaching other procedural skills over distances.

Miller LJ, Philbeck TE, Montez DF, et al. Utility of an intraosseous vascular access system to deliver contrast dye using a power injector for computerized tomography studies. Ann Emerg Med 2011;58(4S):S240 443

This abstract describes an evaluation performed in the goat model, using the EZ-IO, to determine the ability of IO access to accommodate a typical contrast dye infusion and withstand the power injection pressure. Bench testing was done to determine the max pressure deliverable through the EZ-IO using the power injector; various injection occlusion scenarios were established. Results showed the mean pressure through the humerus was 56.5psi; through the tibia was 163.5psi. There were 2 tibial extraosseous distal venous ruptures visible by fluoroscopy but not on gross examination. Under bench testing, for all tests, at pressures up to 750psi no failure or leakage was observed in the IO catheter. The EZ-IO extension tubing should not be used for power injection, particularly if the IO is in the tibia. This research was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.

Intraosseous Vascular Access Bibliography

Arrow® EZ-IO®

Miller LJ, Philbeck TE, Puga TA, Montez DF, Escobar GP. A pre-clinical study to determine the time to bone sealing and healing following intraosseous vascular access. *Ann Emerg Med* 2011;58(4S):S240

475

The objectives of this study were to evaluate the amount of time necessary following IO insertion and infusion for the bone to heal such that a second IO catheter can be placed in the same bone without the risk of extravasation from the first hole; and to determine the length of time required to show radiological evidence of closure. Four anesthetized goats were used for the study. Twenty-four hours post insertion, extravasation was observed in 2 of 4 tibial sites with no extravasation in 4 humeral sites. Forty-eight hours post insertion, no extravasation was observed in tibial or humeral sites. Authors concluded that IO infusion should not be attempted in the same bone as a previous IO insertion within 48 hours of removal of the first IO catheter. Radiological examination showed evidence of bone healing as early as 6 days post IO placement. This research was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.

Myers L, Russi CS, Arteaga GM. Semiautomatic intraosseous devices in pediatric prehospital care. *Prehosp Emerg Care* 2011;15(4):473-6.doi:10.3109/10903127.2011.598611

431

This article describes the changes in practice experienced when a 12-site statewide ambulance service changed from the manual to the semi-automatic IO device (EZ-IO). There was no statistically significant change in first-attempt success or the number of successes per attempt. However, the use of IO access more than tripled when changing from the manual to the semi-automatic device and PIV access attempts before IO access went from occurring in 35.5% of patients to 1.7% of patients.

Myers LA, Russi CS, Arteaga GM. The introduction of a semiautomated (EZ-IO) device in pediatric prehospital care replacing a manual intraosseous (IO) device improves the success rate for attempts at vascular access. *Prehosp Emerg Care* 2011;15(1):110

508

This abstract describes a 93 patient study presented at the 2011 National Association of EMS Physicians Annual Conference that examined the characteristics of pediatric patients receiving IO infusions and the primary EMS clinical impressions, success rates, and subsequent treatments delivered via manual IO vs. the powered EZ-IO device. Investigators concluded that for the pediatric cohort use of the powered device offered a marginally higher first-attempt success rate compared to the manual device; and that the rate of IO access utilization by EMS more than tripled after adoption of the powered device.

Nagler J, Krauss B. Intraosseous catheter placement in children. *NEJM* 2011;364(8):e14-8

491

This article provides an overview of intraosseous vascular access for pediatrics and discusses general indications, contraindications, complications, and intraosseous devices.

Neuhaus D. [Intraossärer zugang]. *Notfall Rettungsmed* 2011;14(7):543. doi:10.1007/s10049-011-1445-9. German

480

This article in German discusses use of IO access and its multiple applications, focusing on the EZ-IO Infusion System.

Olaussen A. Best evidence topic reports: which intraosseous device is best in the prehospital setting? *Emerg Med J* 2011;28(8):717-8. doi: 10.1136/emj.2010.108381

724

This article describes a literature review study with the objective of establishing which intraosseous device is best for prehospital use. This short review searched Medline 1950-2010, CINAHL 1982-2010 and EMBASE 1980-2010 and identified two studies meeting their evidence search criteria, one study compared the BIG vs. manual; the second compared EZ-IO vs. FAST-1. The clinical bottom line asserted by the author was traditional manual IO devices have faster, better success rates in the pre-hospital setting; but that more randomized trials are needed to determine the best device.

Australia

Reades R, Studneck J, Garrett J, Vandeventer S, Blackwell T. Comparison of first-attempt success between tibial and humeral intraosseous insertions during out-of-hospital cardiac arrest. *Prehosp Emerg Care* 2011;15(2):278-81. doi:10.3109/10903127.2010.545479

464

This article describes a pre-hospital clinical study comparing IO first-attempt success between humeral and tibial sites. Of 88 cardiac arrest patients analyzed, 58 and 30 IO access attempts were made in the tibia and humerus, respectively. Of those, there was a 90% first attempt success rate for the tibia, compared to 60% for the humerus. Of successful insertions, 6% of tibial insertions became displaced during transport, compared to 33% of humeral insertions. Investigators concluded that proximal tibial IO needle placement was associated with a significantly higher frequency of first-attempt success and lower incidence of needle dislodgements compared to humeral placements.

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The objective of this study was to determine the frequency of first-attempt success of humeral IO, tibial IO, and peripheral IV (PIV) insertions during out-of-hospital cardiac arrest. Patients were randomized to receive one of the 3 methods. There were 182 patients enrolled, 64 were assigned to tibial IO, 51 to humeral IO and 67 to PIV. Of all patients 130 (71%) were successful on first attempt with 17 (9%) needles dislodged. First attempt success within the treatment groups was 91% for tibial IO, 51% for humeral IO, and 43% for PIV.

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- This article is a response to the Taylor and Clarke 2011 report of two amputations required following development of compartment syndrome after IO infusion. The author notes that complications are possible with all methods of establishing IO access including manual, spring loaded and power driven needles and that it is not accurate to directly relate the adverse events to the power driven device only.

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This abstract presented at the 2010 ACEP Research Forum describes a study designed to compare Lidocaine's effect on pain during fluid infusion through the tibial and humeral IO routes. Authors concluded that, for adequate IO infusion rates with minimal and tolerable pain, 40mg of preservative-free Lidocaine may be needed; followed by a rapid normal saline syringe flush of at least 10mL and another 20mg of Lidocaine. Additional dosing and flushing may be required. For less overall pain due to IO infusion, and greater infusion flow rates, the proximal humerus should be strongly considered, using a longer IO needleset. This research was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.

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- The authors describe literature that support the use of IO access for administering anesthesia in the ICU, perioperative and operating room, including a study in which IO access was used successfully for providing intraoperative anesthesia for 106 of 109 patients. Among their conclusions, the authors reported that, even though rarely reported in anesthesia literature, IO access is a technique anyone providing care to children should consider when the patient has difficult IV access. They also concluded that IO access should be a part of an algorithm that includes numbers of attempts at peripheral access, feasibility of central access and the need for continued postoperative access; and that considering that IO access may be occasionally used in the perioperative setting in both emergent and nonemergent scenarios, it may be beneficial to have appropriate IO needles in the OR.

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- This letter to the editor discussed the experience of one ground emergency rescue service in Germany and their trial implementation of the EZ-IO, as compared to the David et al evaluation of the BIG by emergency physicians in which the rate of failure was 55%. Over a one year evaluation of the EZ-IO in the field, it was used in 20 patients, of which 19 were successfully placed (95%). The success of the field evaluation and a human cadaver study resulted in the addition of the EZ-IO to the receiving University Hospital emergency department.
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This article describes a study conducted at an urban Level I trauma center in Munich, Germany. Ten consecutive patients for whom PIV was difficult or impossible were simultaneously given a central line and an EZ-IO. Procedure times were measured and defined as the time the device package was taken off the shelf until the first drug or solution was administered. First attempt success rate was 90% for EZ-IO and 60% for CVC. The mean procedure times were 2.3 minutes for EZ-IO and 9.9 minutes for CVC, a clinically and statistically significant difference. Investigators concluded, because CVC was slower and less efficacious, IO may improve the safety of patients requiring resuscitation in the ED.
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This article describes a cadaver study to determine skill acquisition and performance by use of the EZ-IO system by novices. Overall success rate for the 99 operators was 97%, and mean insertion time was 6 seconds. All operators rated the device faster and easier than using a central line, and 99% expressed willingness to use the device for cardiac arrest patients.
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This article describes IO use in general, and the EZ-IO in particular. The author describes its use by the emergency staff at her hospital and how they became advocates for IO access in both emergent adult and pediatric patients. She found that its use improves the quality of our care by providing vascular access to our most critical patients.
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This abstract for a presentation at the 2009 ACEP Research Forum describes a swine study designed to determine the feasibility of inducing therapeutic hypothermia (TH) after resuscitation by giving an IO infusion of iced saline. Researchers concluded that rapid, large volume IO infusion of iced saline is as effective for lowering core body temperature after resuscitation as central access and peripheral IV. This research was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.
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- This article describes a prospective, observational study involving a convenience sample of 25 medical students, physicians and nursing staff recruited evaluate the EZIO powered drill device on a bone model. Twenty-three (92%) of the 25 study subjects required only one attempt at placing the EZ-IO. Investigators concluded that the device was easy to use with high success rates of insertion with inexperienced participants.
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- This article describes a case in which IO access, using the EZ-IO, was attempted in a patient with osteogenesis imperfecta. In each of 3 attempts, the needle became loose immediately after IO insertion. The author acknowledged that during emergencies it is difficult to assess and consider every possible contraindication for every intervention; and that IO access using the EZ-IO is the author's choice for emergency vascular access when peripheral access is difficult or has failed.
- Ong ME, Chan YH, Oh HH, Ngo AS. An observational prospective study comparing tibial and humeral intraosseous access using the EZ-IO. Am J Emerg Med 2009;27:8-15** 417
- Comparison of tibial and humeral IO use in 24 adults. Both sites suitable for IO infusion. This study was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.
- Ong ME, Ngo AS, Wijaya R. An observational prospective study to determine the ease of vascular access in adults using a novel intraosseous access device. Ann Acad Med Singapore 2009;38:121-4** 420
- This article describes a prospective, observational study involving a convenience sample of 25 medical students, physicians and nursing staff recruited evaluate the EZIO powered drill device on a bone model. Twenty-three (92%) of the 25 study subjects required only one attempt at placing the EZ-IO. Investigators concluded that the device was easy to use with high success rates of insertion with inexperienced participants. (Note: This study was also described in an earlier article published in American Journal of Emergency Medicine) This study was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.
- Ornato JP, Peberdy MA, Kurz MC. Abstract P134: A building block strategy for optimizing outcomes from out of hospital cardiac arrest. Circulation 2009;120:S1470-a** 404
- In this 1,598 patient case series, investigators studied the effects of serial standard of care changes in the EMS system over time. They concluded that IO access is an essential component for a proven algorithm for the management of OOH-CA.
- Paxton JH, Knuth TE, Klausner HA. Proximal humerus intraosseous infusion: a preferred emergency venous access. J Trauma 2009;67:606-11** 430
- This article describes the first clinical study that focuses on the proximal humerus as an IO site. It is also the first article describing a comparison between IO access and peripheral IV (PIV) and central venous catheters (CVC). They found that IO catheter placement was significantly faster than PIV or CVC placement, and concluded that IO access is life-saving when PIV or CVC is difficult or impossible. This study was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.
- Philbeck T, Miller L, Montez D. Pain management during intraosseous infusion through the proximal humerus. Ann Emerg Med 2009;54(3):S128** 413
- This abstract for a presentation at the 2009 ACEP Research Forum describes a volunteer study to determine the optimal Lidocaine dosing and sequencing for patients receiving fluids through the IO route and to determine if adequate fluid flow rates can be delivered through the proximal humerus IO site. Researchers concluded that for adequate IO infusion rates with minimal and tolerable pain, 40mg of preservative-free Lidocaine may be needed, followed by a rapid normal saline flush of 10ml. Additional dosing and flushing may be required. For humeral insertion, a longer IO needleset should be considered. This study was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.
- Plancade D, Ruttimann M, Boulland P, et al. [Evaluation d'un nouveau catheter pour perfusion intra-osseuse en OPEX]. La Revue du CARUM-Réanoxo 2009;25(2):49-50. French** 410
- This article describes an observational study performed by the French military air surgical team in Chad. There were 11 patients with no insertion failures. For 7 patients, the insertion site was the proximal tibia and for the remainder the site was the proximal humerus. The authors concluded that the EZ-IO is a device that is simple, reliable and which gives satisfaction for the administration of drugs.

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- Sarkar D, Philbeck T. The use of multiple intraosseous catheters in combat casualty resuscitation. *Mil Med* 2009;174:106-8** 418
This case study describes injuries sustained in Iraq by an American soldier, and the concurrent use of 4 IO devices to resuscitate and stabilize him.
- Schutt RC, Bowman B, Cevik C, et al. Intraosseous line placement does not improve outcome in adults with out-of-hospital cardiac arrest. *Prehosp Emerg Care* 2009;13(1):102** 417
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Authors of this article describe a pilot study designed to compare the success rate for insertion and ease-of-use of the Bone Injection Gun (BIG) spring-loaded device and the EZ-IO battery-powered device on a turkey bone model. Investigators concluded that the EZ-IO demonstrated higher success rates than the BIG (28/29 vs. 19/29, p=0.016), and the EZ-IO was the preferred device.
- Sunde GA, Thoresen A, Heltne J-K. [Intraossøs tilgang på kritisk syke pasienter - gammel teknikk får ny heder, eller kun for spesielt interessert]? *NAForum* 2009;22(1):33-7. German** 407
This article, in German, describes the technique of IO access, the introduction of two different IO devices (Cook and EZ-IO) and describes IO use in pediatric emergency care.
- Toursarkissian M, Schmidbauer W, Breckwoldt J, Spies C. [Präklinischer Einsatz von intraossären Zugängen beim Erwachsenen: Überblick und Anwendungsbeispiele] Preclinical use of intraosseous access (IO) in adults: Literature review and case reports. *Anesthesiol Intensivmed Notfallmed Schmerzther* 2009;44(1):22-7. German** 416
This review article in German describes intraosseous vascular access, and includes descriptions of the Waismed Bone Injection Gun, Vidacare EZ-IO, Jamshidi and Cook Medical IO devices.
- Truhlar A, Skulec R, Rozsival P, Cerny V. Efficient prehospital induction of therapeutic hypothermia via intraosseous infusion. *Resuscitation* 2010;81(2):262-3. doi: 10.1016/j.resuscitation.2009.10.029. Epub 2009 Dec 16** 442
This letter to the editor describes the first case reported in the clinical literature in which therapeutic hypothermia was administered using the intraosseous route. The patient, a 2-year-old boy who was found submerged in a cesspool and had been asystolic for 5-10 minutes, survived without neurological complications.
- Von Hoff DD, Kuhn JG, Burris HA, Miller LJ. La perfusion intraosseuse est-elle équivalente à la perfusion intraveineuse? *Urgence Pratique* 2009;36:36-40** 507
This French version of an article previously published in American Journal of Emergency Medicine describes a 25-patient clinical study that compared the pharmacokinetics of intraosseous using the Vidaport (a predecessor of the Vidacare EZ-IO) vs. intravenous administration of morphine sulfate in adults. Results showed no differences between IO and IV administration of morphine for nearly all pharmacokinetic parameters, including maximum plasma concentration, time to maximum plasma concentration, and area under plasma concentration-time curve. There was a significant difference in the volume of distribution in the central compartment, which investigators attributed to a minor deposition effect near the IO port or in the bone marrow. Investigators concluded that the results support the bioequivalence of IO and IV administration of morphine in adults.
- Weiss M, Henze G, Eich C, Neuhaus D. [Intraossäre infusion: Eine wichtige Technik auch für die Kinderanästhesie]. *Der Anaesthesist* 9 2009:863-75. Norwegian** 406
This article, in Norwegian, describes IO access and modern IO devices, including the Bone Injection Gun, FAST1, and EZ-IO.
- Weiss M, Henze G, Eich C, Neuhaus D. Intraossäre infusion: Eine wichtige Technik auch für die Kinderanästhesie [Intraosseous infusion: an important technique also for paediatric anaesthesia]. *Anaesthesist* 2009;58(9):863-75. doi: 10.1007/s00101-009-1605-1 German** 434
Discusses use of IO for pediatric anesthesia. Specifies importance of equipment, education, guidelines.
- Wright JK, Christy RJ, Tharp RV, Kalns JE. Evaluation of intraosseous delivery of factor VIIa during hemorrhagic shock in the pig. *Mil Med* 2009;174:119-23** 419
This swine study was designed to determine if intraosseous infusion is suitable to delivery recombinant human factor VIIa (rFVIIa) during hemorrhagic shock. Investigators concluded that administration of rFVIIa via IO infusion is a safe route for delivery and is likely to produce blood levels required to improve hemostasis during shock.

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YEAR: 2008

- Atanda A Jr, Statter MB. Compartment syndrome of the leg after intraosseous infusion: guidelines for prevention, early detection, and treatment. Am J Orthop 2008;37:E198-200** 413
- This article discusses the importance of proper technique, attention to detail, and serial monitoring of limb involved when using IO vascular access to avoid potential compartment syndrome and other complications. The author reports the case of a 2-year-old boy who suffered compartment syndrome of the lower limb following use of IO infusion for resuscitation. Early detection of and response to changes in the affected limb resulted in the patient's successful recovery
- Borron S, Arias J, Sanchez M Bauer C. Hemodynamics following intraosseous administration of hydroxocobalamin in the goat. Ann Emerg Med 2008;52(4):S96** 421
- Animal (goat) study to determine if IO administration of hydroxocobalamin for antidotal treatment for exposure to cyanide and other poison agents would be faster and require less fine motor coordination and sensitivity; and would result in similar hemodynamic changes compared to IV administration. Using the EZ-IO device, researchers concluded that hemodynamic effects of hydroxocobalamin given by the IO route in non-poisoned goats are mild and similar in magnitude to those of saline control animals.
- Borron S, Arias J, Sanchez M, et al. Intraosseous line placement by hazardous materials responders and receivers for hydroxocobalamin administration. Ann Emerg Med 2008;52(4):S97** 420
- Animal (goat) study to determine the capacity and time required for protected hazardous materials responders and receivers to accomplish vascular access and hydroxocobalamin administration for antidotal treatment for exposure to cyanide and other poison agents. Using the EZ-IO device, researchers concluded that the time required for IO administration of the drug was shorter than intravenous administration; and that IO placement is readily accomplished wearing all levels of chemical protective garments and equipment.
- Brenner T, Bernhard M, Helm M, et al. Comparison of two intraosseous infusion systems for adult emergency medical use. Resuscitation 2008;78(3):314-9** 380
- Study comparing manual intraosseous insertion with EZ-IO using adult human cadavers as a model. No significant difference in insertion time between 39 manual insertions and 45 EZ-IO insertions. Found a difference in the success rate (manual, 79.5% vs. EZ-IO 97.8%, $p < 0.01$). The EZ-IO had fewer complications (manual, 15.4% vs. EZ-IO 0.0%, $p < 0.01$) and scored higher on user friendliness (school grading system: manual, 1.9 ± 0.7 vs. EZ-IO 1.2 ± 0.4 , $p < 0.01$).
- de Caen AR, Reis A, Bhutta A. Vascular access and drug therapy in pediatric resuscitation. Pediatr Clin N Am 2008;55:909-27** 363
- Describes common drugs used in pediatric resuscitation and evidence supporting their use. Also describes routes of administration including intravenous, intraosseous, and intratracheal. Describes IO systems including Bone Injection Gun, FAST-1, and EZ-IO.
- DeBoer S, Russell T, Seaver M, Vardi A. Infant intraosseous infusion. Neonatal Network 2008;27:25-32** 403
- This article describes IO infusion devices - including Jamshidi, Cook, WaisMed, and Vidacare devices - and placement sites. It also addresses assessment and care of the infant receiving fluids and medications through the IO route.
- Fowler RL, Pierce A, Nazeer S, Philbeck TE, Miller LJ. 1,199 case series: Powered intraosseous insertion provides safe and effective vascular access for emergency patients. Ann Emerg Med 2008;52(4):S152** 418
- Large retrospective study of patients for whom emergency vascular access was obtained using the Vidacare EZ-IO intraosseous system. Insertion success was 92% and within 10 seconds for 84% of the one-attempt successful cases. Complication rate was low (4.8%), none were serious, and extravasation was the most frequent (0.8%). The device was rated easy to use 72% of the time, and researchers concluded that the powered IO device is safe and effective for achieving vascular access in the resuscitation and stabilization of emergency patients. This study was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.
- Horton MA, Beamer C. Powered intraosseous insertion provides safe and effective vascular access for pediatric emergency patients. Pediatr Emerg Care 2008;24(6):347-50** 381
- A retrospective clinical study was conducted to demonstrate the safety and effectiveness of the EZ-IO intraosseous access device for pediatric patients. For the 95 eligible patients in the study, successful insertion and infusion was achieved in 94% of the patients. Insertion time was 10 seconds or less in 77% of the one-attempt successful cases reporting time to insertion. There were 4 minor complications (4%), but none significant. The results of this study support the use of the EZ-IO for children in emergency situations. The complication rate suggests that the powered IO device is safe and effective for the resuscitation and stabilization of pediatric patients. This study was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.

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- Leidel BA, Kirchoff C. [Intraossäre infusion beim erwachsenen]. Der Chirurg 2008; 4:315-26. German** 402
Article describing IO access.
- Paxton JH, Knuth TE, Klausner HA. Humeral head intraosseous insertion: The preferred emergency venous access. Ann Emerg Med 2008;52(4):S58** 419
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- Pointer JE, Vultaggio D, Schnepf R, Kleveno A. Fast or easy? Comparing two adult IO infusion devices. JEMS.com 2008** 382
This article describes an observational study in which two intraosseous devices were compared: the Pyng Medical F.A.S.T.1 and the Vidacare EZ-IO. For the 117 patients on which the F.A.S.T.1 was used, there was an 84% success; compared to a 97% success rate for the EZ-IO (n=71).
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- Von Hoff DD, Kuhn JG, Burris HA, Miller LJ. Does intraosseous equal intravenous? A pharmacokinetic study. Am J Emerg Med 2008; 26: 31-8** 387
This article describes a 25-patient clinical study that compared the pharmacokinetics of intraosseous vs. intravenous administration of morphine sulfate in adults. Results showed no differences between IO and IV administration of morphine sulfate for nearly all pharmacokinetic parameters. Investigators concluded that the results support the bioequivalence of IO and IV administration of morphine in adults.
- Woosley CR, Mayes TC. The pediatric patient and thoracic trauma. Thor Cardiovasc Surg 2008;20:58-63** 399
This article describes thoracic trauma in the pediatric population. Includes a review of the assessment of pediatric patients. Circulation section of the article strongly recommends rapid intravascular volume expansion by the intraosseous route, and recommends the EZ-IO for "...quick and reliable vascular access during resuscitation ...".
- YEAR: 2007**
- Beamer CL, Horton M. Powered needle insertion provides safe and effective vascular access for pediatric emergency patients. Ann Emerg Med 2007;50(3):S40** 395
This abstract for a presentation at the 2007 American College of Emergency Physicians Research Forum describes an observational study in which the EZ-IO was used to provide emergency vascular access for 95 pediatric patients. Successful insertion and infusion was achieved in 94% of the patients, and insertion time was within 10 seconds for 81% of the placements. There were four minor and no serious complications.
- Buck ML, Wiggins BS, Sesler JM. Intraosseous drug administration in children and adults during cardiopulmonary resuscitation. Ann Pharmacother 2007;41:1679-86** 374
This article reviews and assesses the literature on the use of IO drug administration during cardiopulmonary resuscitation. It addresses the risks and benefits of using IO in adults and children. The article describes the FDA-cleared devices available for use including the Pyng F.A.S.T.1, Waismed Bone Injection Gun and the Vidacare EZ-IO.
- Cooper BR, Mahoney PF, Hodgetts TJ, Mellor A. Intra-osseous access (EZ-IO®) for resuscitation: UK military combat experience. J R Army Med Corps 2007;153(4):314-6** 379
Describes the experience of the UK Defence Medical Service using the EZ-IO for emergency vascular access in Afghanistan. They used the device for 26 patients, including 10 children. Of the 26 EZ-IO placements, 23 were made in the emergency department. There was a 97% insertion success rate with no infection. Significant infusion pain was felt by three patients.
- de Caen A. Venous access in the critically ill child. Pediatr Emerg Care 2007;23:422-4** 372
This review article states the availability of intraosseous (IO) needles for pediatric patients, outlines the limitations of traditional venous access, and discusses the various IO devices currently available, including the Vidacare EZ-IO®.

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- DeBoer S, Andrews D. Infant venous access: 'Counting fingers' and 'playing baseball'. *Australasian Emerg Nurs J* 2007; 10: 46-51** 356
This article summarized the challenges and methods of providing vascular access for infants. It describes IO techniques and devices, including the Jamshidi, Cook, EZ-IO® and Bone Injection Gun (BIG) devices.
- Fowler R, Gallagher JV, Isaacs SM, Ossman E, Pepe P, Wayne W. The role of intraosseous vascular access in the out-of-hospital environment (resource document to NAEMSP position statement). *Prehosp Emerg Care* 2007;11:63-6** 355
Article calls for EMS medical directors to consider and use the intraosseous route for adult patients requiring immediate vascular access. Provides evidence in support of position statement by the National Association of EMS Physicians on IO use.
http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=17169880
- Fowler RL. Prehospital intraosseous access: elemental to the field? *JEMS* 2007; doi:<http://jems.com/print/9198>** 543
Discussion of the role intraosseous vascular access can play in the prehospital setting where vascular access is often difficult or impossible to establish. The EZ-IO is named as a new IO device along with descriptions of Jamshidi, Pyng Fast 1, and BIG needles.
- Frascone RJ, Jensen JP, Kaye K, Salzman JG. Consecutive field trials using two different intraosseous devices. *Prehosp Emerg Care* 2007;11(2):164-71** 357
This article describes authors' evaluation of provider performance using two IO devices; the Pyng Medical F.A.S.T.1™ and the Vidacare EZ-IO®. Of 89 insertions with each device, success rate for 72% for the F.A.S.T.1 and 87% for the EZ-IO, a significant difference (p=0.009). The time to fluid insertion for the EZ-IO was also faster (p=0.02). Authors noted that the EZ-IO is unique and much more useful than the F.A.S.T.1.
- Gagliardi P, Purrone G. [Il potere di salvare vite: l'infusione di liquidi e farmaci in emergenza con accesso venoso non reperibile]. *N & A Mensile Italiano del Soccorso* 2007; 177: 20-3. Italian** 376
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- Harrington LL, Rehbolz C, Mitchell PM, Dyer KS, King K, Moyer P. Out-of-hospital placement of adult intraosseous access using the EZ-IO device. *Ann Emerg Med* 2007;50(3):S81-2** 396
This abstract for a presentation at the 2007 American College of Emergency Physicians Research Forum describes an observational study done at Boston Medical Center in which the Vidacare EZ-IO was used to provide emergency vascular access for 50 critically-ill adult patients. Successful insertion was achieved in 92% of the patients; with 90% success on the first attempt. There was one immediate complication—a dislodgement during transport. Investigators concluded that the device is a safe and feasible device for adult patients requiring out-of-hospital vascular care.
- Hoskins SL, Zachariah BS, Copper N, Kramer GC. Comparison of intraosseous proximal humerus and sternal routes for drug delivery during CPR. *Circulation* 2007;116:II_993** 386
Results from this, study which sought to compare drug delivery time using the proximal humerus IO route to delivery time using the sternal IO route, suggest that IO proximal humerus is comparable to IO sternal for prompt drug delivery during CPR.
- Landes AH. Intra-osseous infusions: the current status. *Care of the Critically Ill* 2007; 23: 53-8** 361
Overview of IO access. Includes historical aspects, current status, indications for use, advantages and disadvantages, IO kinetics, insertion sites, complications and contraindications and description of available IO devices, including EZ-IO®.
- Mathew N, McGinnis-Hainsworth D, Megargel R, Cleary A, O'Connor R. Trends in the usage of intraosseous access in the prehospital setting. *Prehosp Emerg Care* 2007;11(1):130** 362
In this study, presented at the NAEMSP 2007 annual meeting, authors compared the success rate of conventional IO access with the EZ-IO during 245 cases in the prehospital setting. They concluded that using EZ-IO® results in a statistically significant increase in IO success rate, compared to conventional IO methods.
Abstract

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Arrow® EZ-IO®

- Myers BJ, Lewis R. Induced cooling by EMS (ICE): year one in Raleigh/Wake County. JEMS 2007;32:s13-5** 398
This article describes the experience of the Wake County (NC) EMS System in inducing hypothermia for patients with return of spontaneous circulation after cardiac arrest. Authors describe their use of the Vidacare EZ-IO (now Arrow® EZ-IO Intraosseous Vascular Access System) for the administration of chilled saline. In this report 56% of vascular access cooling was done utilizing the IO device and an additional 18 % utilized a combination of IO and IV induced cooling. The overall EZ-IO use in this program for all insertions were 414 with an insertion success rate of 94%.
- Potyka JS, Gordon DJ. Stories behind the numbers: IO experiences in providers' own words. JEMS 2007;32:s30-1** 400
Qualitative study focuses on EMS caregivers' experiences with Vidacare's EZ-IO device and personal opinions. The study used a narrative approach to gain insight from EMS practitioners working with an IO access device under real field conditions.
- Pye D. NY Paramedics get the EZ-IO. JEMS 2007; doi: <http://www.jems.com/print/5184>** 550
This article in JEMS discusses an EMS system in New York following their adoption of the EZ-IO, and the advantages.
- Scheres M. [Nieuw hulpmiddel voor intra-ossale toegang]. Vakblad V & VN Ambulancezorg 2007;1:16-7. Dutch** 373
Article in Dutch describing IO access and EZ-IO.
- Stouffer JA, Jui J, Acebo J, Hawks RW. The Portland IO experience: results of an adult intraosseous infusion protocol. JEMS 2007;32:S27-8** 397
The article describes a prospective observational study conducted by several EMS agencies in Portland, OR to determine the safety, efficacy and benefits of using the Vidacare EZ-IO in the prehospital environment. The IO device was successfully placed in 95% of the 280 cases. In 98% of the cases, placement was made within six seconds.
- Suyama J, Knutsen C, Northington W, Hahn M, Hostler D. Intraosseous vs. intravenous access while wearing personal protective equipment in a simulated HazMat scenario. Acad Emerg Med 2007;14(5):s128** 360
Study investigating time difference in obtaining IO vs. IV access while wearing personal protective equipment (PPE) in simulated HazMat scenarios. With provider in PPE and mannequin not in PPE, vascular access was faster with IO (14 seconds vs. 46 seconds; p<0.001); also, fluid infusion time (28 seconds vs. 46 seconds; p<0.001). With provider and mannequin in PPE, all the following favored IO: needle to skin time (13 seconds vs. 25 seconds, p<0.001), vascular access time (17 seconds vs. 63 seconds; p<0.001), and fluid infusion time (30 seconds vs. 66 seconds; p<0.001). Investigators conclude that EZ-IO under HazMat conditions provides vascular access and fluid more quickly than IV access.
- Suyama J, Knutsen CC, Northington WE, Hahn M, Hostler D. IO versus IV access while wearing personal protective equipment in a HazMat scenario. Prehosp Emerg Care 2007;11(4):467-72** 401
Article describes a controlled study in which the time difference between IV and IO access was compared while providers and simulated patients (mannequins) were wearing personal protective equipment (PPE). Twenty-two EMT-P providers measured the times to skin access, vascular access and fluid infusion in three scenarios: no PPE for providers or mannequins; providers only in PPE; and both providers and mannequins in PPE. In all scenarios, there was a statistically significant difference in vascular access and fluid infusion time, in favor of the EZ-IO. Investigators concluded that, overall, the EZ-IO provides vascular access and fluid more quickly than standard IV access, and that donning PPE does not hinder providers' use of the EZ-IO.
- Wayne MA. Intraosseous vascular access: devices, sites and rationale for IO use. JEMS 2007;32:s23-5** 375
This article reviews intraosseous vascular access in general, and summarizes the various devices available. These include the Waismed B.I.G., the Vidacare EZ-IO, and Pyng F.A.S.T.1.
- Weiss M, Gächter-Angehrn J, Neuhaus D. [Intraossäre infusionstechnik]. German Interdisciplinary Journal of Emergency Medicine 2007; 10: 99-116. German** 358
This article in German (with abstract in English) describes IO infusion in detail. It includes techniques, indications, complications, and recommendations. Also describes the various devices available, including Cook, Bone Injection Gun (BIG), First Access for Shock and Trauma (F.A.S.T.1), and the EZ-IO®.

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Arrow® EZ-IO®

YEAR: 2006

Frascone RJ, Jensen J, Salzman J, Kaye K. EZ-IO: A field trial. *Prehosp Emerg Care* 2006;10(1):123-4 354

In this study, presented at the NAEMSP 2006 annual meeting, investigators reported the results of a study that evaluated the performance of the EZ-IO® compared to an earlier evaluation of the Pyng F.A.S.T.1 system. There was a statistically significant higher success rate using the EZ-IO® compared to Pyng system, and investigators concluded that the EZ-IO® appears to be a superior device with regard to insertion success.

Guyette FX, Rittenberger JC, Platt T, Suffoletto B, Hostler D, Wang HE. Feasibility of basic emergency medical technicians to perform selected advanced life support interventions. *Prehosp Emerg Care* 2006;10(4):518-21 353

Prospective observational study evaluating EMT-B ability to provide care in out-of-hospital cardiac arrests. Found that EMT-Bs were able to place the EZ-IO with a 94% success rate. Median time to placement was 72 seconds.

Hoskins SL, Kramer GC, Stephens CT, Zachariah BS. Abstract 79: Efficacy of epinephrine delivery via the intraosseous humeral head route during CPR. *Circulation* 2006;114:II_1204 422

Results from this study which sought to determine the efficacy of intraosseous drug delivery using the proximal humerus during CPR in swine showed that the humeral route generated higher mean arterial pressures than central venous or endotracheal delivery.

Wayne M. [Perfusion intra osseuse chez l'adulte: il est temps d'y penser]. *Urgence Pratique* 2006; 77: 47-9. French 371

Article in French describes IO access and IO devices, including B.I.G., F.A.S.T.1 and EZ-IO®.

Wayne MA. Adult intraosseous access: an idea whose time has come. *Israeli J Emerg Med* 2006;6(2):41-5 638

The author provides an overview of intraosseous vascular access discussing evolution of the practice, equipment, treatment options and contraindications.

YEAR: 2005

Davidoff J, Fowler R, Gordon D, Klein G, Kovar J, Lozano M, Potkya J, Racht E, Saussy J, Swanson E, Yamada R, Miller L. Clinical evaluation of a novel intraosseous device for adults: prospective, 250-patient, multi-center trial. *JEMS* 2005;30(10):s20-3 352

Observational study evaluating use of the EZ-IO®. Found 97% success rate for insertion and infusion into the IO space by paramedics, nurses, physicians and other EMS personnel in using the device for emergency vascular access. No serious complications reported. This study was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.

DeBoer S, Seaver M, Morissette C. Intraosseous infusion: not just for kids anymore. *Emerg Med Serv* 2005;34(54):56-63 331

Article describes intraosseous access for adults and pediatrics. Describes and discusses IO devices available including Jamshidi, Bone Injection Gun, F.A.S.T.1, and EZ-IO®.

Gillum L, Kovar J. Powered intraosseous access in the prehospital setting: MCHD EMS puts the EZ-IO to the test. *JEMS* 2005;30(10):s24-6 327

Observational study of initial use of the EZ-IO® in 125 patients by EMS providers. Found 94% success rate for insertion and infusion into the IO space. No complications reported. This study was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.

Heightman AJ. The rebirth of adult IO: a first-hand account of recent advances in intraosseous infusion for adults, drawn from a scientific workshop and practical lab experience. *JEMS* 2005;30(10):s4-7 337

Editorial article highlighting recent advances in intraosseous (IO) infusion and IO devices based on the author's experience at a scientific seminar hosted by Vidacare. Makes recommendations on the efficiency and safety of the devices.

Hoskins S, Nascimento P, Espana J, Kramer G. Pharmacokinetics of intraosseous drug delivery during CPR. *Shock* 2005;23:35 423

This animal study compared IO drug delivery in the tibia versus the sternum during CPR. Researchers concluded that during CPR IO infusions delivered via both sites were effective—although sternal delivery was faster; and that IO sternum access is comparable to IV access for drug delivery during CPR.

Intraosseous Vascular Access Bibliography

Arrow® EZ-IO®

Hoskins S, Stephens C, Kramer G. Efficacy of intraosseous drug delivery during cardiopulmonary resuscitation in swine. Paper presented at the annual meeting of the National Association of EMS Physicians, Registry Resort, Naples, FL. 2009-05-25 from http://www.allacademic.com/meta/p64887_index.html 506

This study abstract discusses use of the EZ-IO to determine the pharmacokinetics (PK) and efficacy of tibial IO drug delivery during treatment of cardiac arrest in the swine model, as compared to IV access. Results showed that PK analysis of IO drug delivery via the tibial route showed a delay of 20-50 seconds compared to IV; however, physiologically significant levels of epinephrine were reached as MAP. This research was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.

Kramer GC, Hoskins SL, Espana J, do Nascimento P. Intraosseous drug delivery during cardiopulmonary resuscitation: relative dose delivery via the sternal and tibial routes. Acad Emerg Med 2005;12:s6. 332

Animal study compared the sternal and tibial routes for IO drug delivery during CPR. Investigators concluded that both the sternal and tibial routes can effectively deliver near equivalent doses during CPR in swine.

http://www.aemj.org/cgi/content/abstract/12/5_suppl_1/67

Miller LJ, Kramer GC, Bolleter S. Rescue access made easy: Intraosseous infusion, once limited to use in children, is now becoming a reliable access site for adults. JEMS 2005;30(10):Suppl 8-18 345

Overview of IO therapy. Includes 10 Myths about Adult IO and description of available IO devices, including the EZ-IO®.

YEAR: 1922

Drinker C, Drinker K, Lund C. The circulation in the mammalian bone marrow. Am J Physiol 1922;62(1):1-92 1

Seminal article on blood circulation in the IO space. Demonstrates movement of red blood cells from the bone marrow into the circulating blood by perfusion of the tibia of the dog and by injections into the bone marrow in the rabbit and cat.

Intraosseous Vascular Access Bibliography

Guidelines

YEAR: 2018

Nishida O, Ogura H, Egi M, et al. The Japanese clinical practice guidelines for management of sepsis and septic shock 2016 (J-SSCG 2016). *Acute Med Surg* 2018;5(1):3-89. doi: 10.1002/ams2.322 1059

These guidelines are a Japanese-specific set of guidelines for sepsis and septic shock created by the Japanese Society of Intensive Care Medicine and the Japanese Association for Acute Medicine. The IO route for administration of fluid resuscitation and circulatory inotropes when treating septic shock in pediatric patients is discussed. The authors conclude there is insufficient evidence to make a recommendation for this use.

YEAR: 2017

Battaloglu E, Porter K. Management of pregnancy and obstetric complications in prehospital trauma care: Faculty of prehospital care consensus guidelines. *Emerg Med J* 2017;34(5):318-25. doi: 10.1136/emermed-2016-205978 1043

This paper is a consensus statement seeking to provide clear guidance for the management of pregnant trauma patients in the pre-hospital setting in the UK. IO access is recommended as an alternative to gain vascular access in pregnant trauma patients when IV access cannot be easily or quickly established. If possible, it is recommended that IO access be placed in the right humeral head in order to facilitate left tilt/left lateral positioning of the pregnant patient.

Faudeux C, Tran A, Dupont A, et al. Development of reliable and validated tools to evaluate technical resuscitation skills in a pediatric simulation setting: resuscitation and emergency simulation checklist for assessment in pediatrics. *J Pediatr* 2017;188:252-57. doi:10.1016/j.jpeds.2017.03.055 920

This study addresses the need for the development of a reliable and validated tool to evaluate technical resuscitation skills in a pediatric simulation setting. The authors created four resuscitation and emergency simulation checklist and evaluation tools were created, (RESCAPE). Study found that use of the RESCAPE tools are reliable and validated tools for evaluation of resuscitation skills in pediatric simulation-based educational programs.

Pamplin J, Fisher AD, Penny A, et al. Analgesia and sedation management during prolonged field care. *J Spec Oper Med* 2017;17(1):106-20 1009

These are guidelines for prolonged field care (PFC) intended to be used after Tactical Combat Casualty Care (TCCC) when evacuation to higher level of care is not immediately possible. The intent of these guidelines is to identify potential issues to consider when providing analgesia with or without sedation for an extended time period (4-72 hours). IO is listed as an optional route of administration.

Rhodes A, Evans LE, Alhazzani W, et al. Surviving sepsis campaign: International guidelines for management of sepsis and septic shock. *Intensive Care Med* 2017;1-74. doi:10.1007/s00134-017-4683-6 895

Within the updated 2016 Surviving Sepsis Campaign Guidelines noted that intraosseous (IO) access can be "quickly and reliably established" which will make following the guidelines for fluid therapy and early antibiotics an easier task.

U.S. Army, CoTCCC, TCCC Working Group. Tactical combat casualty care: Lessons and best practices. *Tactical combat casualty care (TCCC): Lessons and best practices. Handbook. No. 17-13: Version 5. May 2017* 1072

The CoTCCC handbook was created as a guide to best practices created by the Committee on Tactical Combat Casualty Care (CoTCCC) which includes representatives from all the U.S. Armed Services that are part of the Tactical Combat Casualty Care (TCCC) Working Group. The recommendations are based on input from the battlefield as well as evidence in the civilian literature, examined and put together to provide guidelines for care. The recommendations and required skill sets include IO access as an alternative to IV access in multiple sections. The TCCC- Medical provider skill set specifically includes the ability to demonstrate the use of IV/IO blood product administration (medical officers and operating room special operations medics) and the use of IV/IO tranexamic acid (TXA).

YEAR: 2016

Bodenham A, Babu S, Bennett J, et al. Association of Great Britain and Ireland: Safe vascular access 2016 guidelines. *Anaesthesia* 2016;71:573-85. doi:10.1111/anae.13360 937

This consensus document was created by a working group of the Association of Anaesthetists of Great Britain and Ireland and based upon an up to date review of the literature, practice and expert opinion. The recommendations focus on safety in relation to insertion, care and removal of vascular access devices. IO access is recommended as useful for emergencies in cases of difficult vascular access; and clinicians providing acute care should have IO devices accessible and be trained in IO access techniques.

Denton A, Bodenham A, Conquest A, et al. Standards for infusion therapy (4th edition). London: Royal College of Nursing 2016:47-8 891

This 2016 publication by the Royal College of Nursing (RCN) was intended to support clinical practice for adult patients undergoing infusion therapies, including intraosseous (IO) access. The chapters begin with a general statement followed by the "standard" set by RCN and then guidelines relating to that intervention. The section on IO access states IO access "should be obtained for emergency or short-term treatment when access by the vascular route is difficult" and the "patient's condition is considered life-threatening".

Intraosseous Vascular Access Bibliography

Guidelines

National Clinical Guideline Centre. Major trauma: Assessment and initial management. London: National Institute for Health and Care Excellence (UK); 2016 Feb. (NICE Guideline, No. 39.):7. PMID:26913320. <http://nice.org.uk/guidance/ng39> (Accessed: 12/15/17)

894

This section of the 2016 National Institute for Health and Care Excellence (NICE) guidelines addressed assessment and initial management of trauma patients. In the prehospital setting for major trauma, intraosseous (IO) access is recommended if intravenous access fails; and should be considered for first line access in patients ≤ 16 years old. In the hospital setting, if peripheral intravenous access fails, consider IO access while central venous access is being achieved.

YEAR: 2015

Hazinski MF, Shuster M, Donnino MW, et al. The AHA guidelines highlights project team. Highlights of the 2015 AHA guidelines update for CPR and ECC. American Heart Association 2015. AHA. Available at: <https://eccguidelines.heart.org/wp-content/uploads/2015/10/2015-AHA-Guidelines-Highlights-English.pdf>

893

This publication was created for providers and instructors to summarize the key issues and changes affecting practice in the 2015 American Heart Association (AHA) Guidelines Update for Cardiopulmonary Resuscitation (CPR) and Emergency Cardiovascular Care (ECC). No changes specific to intraosseous access were mentioned. Intranasal administration of naloxone for overdose management was added as a reasonable intervention.

Link MS Berkow LC, Kudenchuk PJ, et al. Part 7: Adult advanced cardiovascular life support 2015 American Heart Association guidelines update for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care Circulation 2015;132(Suppl 2):S444-S464. DOI: 10.1161/CIR.0000000000000261

950

The 2015 updated ACLS guidelines considered a number of issues regarding cardiovascular life support; however there were no changes to those recommendations made in the 2010 guidelines in regard to intraosseous access. The 2010 guidelines stated in regard to IO drug delivery, "it is reasonable for providers to establish IO access if IV access is not readily available (Class IIa, LOE C)."

Monsieurs KG, Nolan JP, Bossaert LL, et al. European Resuscitation Council Guidelines for Resuscitation 2015 Section 1. Executive summary. Resuscitation 2015;95: 1-80

952

This article summarizes the main updates to the 2015 ERC Guidelines for Resuscitation of adults and pediatric patients. In reference to intraosseous (IO) vascular access, the guidelines state: IO access is a "rapid, safe, and effective route to give drugs, fluids and blood products"; and recommend consideration of the IO route when peripheral venous access is difficult.

Seghatchian J, Putter JS. Advances in transfusion science for shock-trauma: optimizing the clinical management of acute haemorrhage. Transfus Apher Sci 2015;53(3):412-22. <http://dx.doi.org/10.1016/j.transci.2015.11.012>

852

This review article describes various protocols for haemorrhage control, specifying routes of access, including intraosseous vascular access infusion rates and volumes of various transfusion fluids.

Soar J, Nolan JP, Böttiger BW, et al. European resuscitation council guidelines for resuscitation 2015, Section 3. Adult advanced life support. Resuscitation 2015;95:100-47. [doi.org/10.1016/j.resuscitation.2015.07.016](http://dx.doi.org/10.1016/j.resuscitation.2015.07.016)

892

This publication was created for providers and instructors to summarize the key issues and changes affecting practice in the 2015 American Heart Association (AHA) Guidelines Update for Cardiopulmonary Resuscitation (CPR) and Emergency Cardiovascular Care (ECC). No changes specific to intraosseous access were mentioned. Intranasal administration of naloxone for overdose management was added as a reasonable intervention.

YEAR: 2014

Cheung WJ, Rosenberg H, Vaillancourt C. Barriers and facilitators to intraosseous access in adult resuscitations when peripheral intravenous access is not achievable. Acad Emerg Med 2014;21:250-6. [doi:10.1111/acem.12329](http://dx.doi.org/10.1111/acem.12329)

705

This survey study sought to identify the barriers and facilitators to use of intraosseous vascular access for adult resuscitations when peripheral IV (PIV) access is not available, among physicians from various clinical care settings in 3 teaching hospitals in Ottawa, Ontario. Completed survey responses were received from 205 physicians; results suggest that to increase IO use educational interventions need to address their attitudinal, normative, and control beliefs. Specific beliefs that act as barriers are described.

Canada

Egyptian Pediatric Association Gazette. Hot topics in neonatology: Lecture given at the EPA's national conference-1.1.10. Vascular access. Egypt Pediatr Assoc Gazette 2013;61:92-5. <http://dx.doi.org/10.1016/j.epag.2013.11.007>

707

This article identifies new concepts and changes in neonatal resuscitation discussed at the Egyptian Pediatric Association national conference. Intraosseous vascular access is included stating, "temporary intraosseous access to provide fluids and medication to resuscitate critically ill neonates may be indicated following unsuccessful attempts to establish intravenous vascular access or when caregivers are more skilled at securing intraosseous access."

Egypt

Intraosseous Vascular Access Bibliography

Guidelines

- Khilani A, Mazwi M, Paquette ET. Pediatric sepsis in the global setting. Clin Pediatr Emerg Med 2014;15(2):193-203** 725
This discussion of pediatric sepsis focuses on the "global setting" making note of inherent differences in policies, diagnostics, causes and management approach between regions. A review of basic assessment, treatment, follow-up and prevention strategies applicable regardless of resources is offered. Goal directed therapy within the first 5 minutes includes establishment of IV/IO access.
- Lewis P, Wright C. Saving the critically injured trauma patient: a retrospective analysis of 1000 uses of intraosseous access. Emerg Med J 2014;31(9):784. doi:10.1136/emmermed-2014-203588** 714
This retrospective study reported IO use over a 7-year period during combat operations in Afghanistan by the UK Defence Medical Services. The EZ-IO and FAST1 IO devices were available for use; IO use data was collected from the front line, during helicopter evacuation and at the combat hospital. A total of 1014 IO devices were inserted into 830 adult patients; various medications infused via IO access are listed. Across all cases there were no serious IO complications and 14 minor complications. The author concluded that in the pre-hospital setting in particular and in severely injured trauma patients, IO access should be considered a primary method of obtaining vascular access.
- Neuhaus D. Intraosseous Infusion in elective and emergency pediatric anesthesia: when should we use it? Curr Opin Anaesthesiol 2014;27(3):282-7. DOI: 10.1097/ACO.0000000000000069** 723
General review of IO access, with particular attention to perioperative setting and includes published guidelines of the German Scientific Working Group for Pediatric Anesthesia for use of intraosseous access. The author recommends that for children with known difficult venous access physicians discuss the possibility of IO access preoperatively with the family.
Switzerland
- Pasley J, Miller C, Dubose J, et al. Intraosseous infusion rates under high pressure: a cadaveric comparison of anatomic sites. 2014 Annual Scientific Assembly for the Eastern Assoc for the Surgery of Trauma meeting. http://www.dtic.mil/cgi-bin/GetTRDoc?AD=ADA597324. Published January 2014. Accessed May 12, 2014** 728
This report describes a study conducted by the Air Force Research Laboratory comparing intraosseous infusion rates between IO sites in a cadaveric model to determine if there is a site that is most effective for volume resuscitation. Using 16 cadavers procured within 72 hours of death, IO access was established in the proximal tibia and proximal humerus using the EZ-IO and in the sternum using the FAST1. Results showed the mean flow rate in the sternum was 1.6 times greater than the humerus and 3.1 times greater than the tibia. An abstract describing this report was presented by oral presentation at the 2014 annual scientific assembly for the Eastern Association for the Surgery of Trauma meeting.
- Polat O, Oguz AB, Comert A, Demirkan A, Gunalp M, Tuccar E. Intraosseous access learning curve; is it really practical? Am J Emerg Med 2014; 32(12):1543-4.doi: 10.1016/j.ajem.2014.09.018** 747
This letter to the editor describes a cadaver study performed by 50 interns who had never performed IO insertion, to determine if there is a learning curve associated with use of the EZ-IO for establishing IO vascular access in the proximal tibia. Following training each intern performed 10 IO insertions and were timed. The results showed a difference between the first and the eighth attempts resulting in a decrease in time to insertion by half. The authors concluded that practice insertions are necessary to become comfortable with the device.
Turkey
- Rush S, D'Amore J, Boccio E. A review of the evolution of intraosseous access in tactical settings and a feasibility study of a human cadaver model for a humeral head approach. Mil Med 2014;179(8 Suppl):24-8. doi: 10.7205/MILMED-D-13-00484** 726
This article explores use of IO vascular access in combat and tactical settings through a brief review of the literature describing this practice. A small feasibility study is discussed that evaluated the use of cadavers for training 26 U.S. Air Force Pararescuemen (PJs) on establishing IO access in the humeral head (proximal humerus is the descriptor used by EZ-IO for this site) using the EZ-IO powered driver and needle set system (pictured in the article) and needles inserted with a manual driver without power. First attempt placement success with the EZ-IO powered driver system was achieved in 25 of 26 attempts; first attempt placement success using the manual driver and needle set occurred in 19 of 21 attempts. The authors concluded that the humeral head (proximal humerus) IO site is the most appropriate site within the tactical setting; and that use of a human cadaver model for training is an appropriate model.
- YEAR: 2013**
- American Academy of Pediatrics. Joint policy statement - guidelines for care of children in the emergency department. J Emerg Nurs 2013;39(2):116-27** 648
Reprint article of policy statement originally published 2009, endorsed by multiple professional societies providing guidelines for care of children in the emergency department. A recommendation for IO equipment in adult and pediatric sizes is included.
- Cleugh FM, Maconochie IK. Management of the multiply injured child. Paediatrics and Child Health 2013;23(5):194-9** 659
General overview of care of a child with multiple trauma. IO vascular access is mentioned as a treatment option after 90 seconds or 3 failed PIV attempts. The B.I.G. is cited as an option along with the manual needles.

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Guidelines

- Hunsaker S, Hillis D. Intraosseous vascular access for alert patients. *Am J Nurs* 2013;113(11):34-9** 672
This article presents an overview of IO access focused on nurses' use of the technique. A list of available devices, history and support for use and possible complications are included.
- Lewis GC, Crapo SA, William JG. Critical skills and procedures in emergency medicine- vascular access skills and procedures. *Emerg Med Clin N Am* 2013;31(1):59-86. doi: 10.1016/j.emc.2012.09.006** 631
This article provides an overview of various vascular access modalities in emergency medicine including peripheral IV, venous cut-down, central venous catheter, intraosseous access, umbilical vessel access, and arterial access. The anatomy and physiology, indications and contraindications, procedure steps and special considerations are outlined for each access methods discussed.
- Lyon RM, Donald M. Intraosseous access in the prehospital setting-Ideal first-line option or best bailout? *Resuscitation* 2013;84:405-406. <http://dx.doi.org/10.1016/j.resuscitation.2013.01.027>** 615
Editorial reviewing a case series of EZ-IO use in the pre-hospital setting in Switzerland by Santos et al., combined with a literature review. The authors conclude IO access should probably be used selectively and training on its use improved, insertion sites should be compared and further investigation of use of the EZ-IO in major trauma patients, infusing blood components, use in infants, and application of training warrant further investigation.
- Manrique Martinez I, Pons Morales S, Casal Angulo C, Garcia Aracil N, Castejon de la Encina ME. Accesos intraoseos: revision y manejo. *An Pediatr Contin* 2013;11(3):167-73** 627
This article in Spanish provides an overview of intraosseous vascular access.
Article in Spanish
- Mills A, Pappin D, Field V, Thorp-Jones D. Intraosseous access in the peripartum patient: is your needle long enough? *Int J Obstet Anesth* 2013;22(1):S30** 675
This abstract describes a study in which the investigators sought to determine the approximate patient population in which the 25mm EZ-IO needle set was sufficient length to establish IO access in peripartum patients. Ultrasound was used to determine the tissue depth at four insertion sites. Twenty-six women were recruited with a median gestation of 34 weeks. In 88% of patients with a BMI<40 kg/m² the 25mm needle is sufficient to reach the bone marrow at both tibial sites. For the humeral site, IO placement may be more difficult for patients with a BMI>25 kg/m².
UK
- Plancade D, Ruttimann M, Wagnon G, et al.. La perfusion intraosseuse chez l'adulte. *Annales Francaises d'Anesthesie et de Reanimation* 2013;<http://dx.doi.org/10.1016/j.annfar.2013.02.024>. French** 617
This article in French gives an overview of intraosseous vascular access including the physiology of IO infusion, insertion sites, indications, and complications. Available IO devices on the market are described including, time to insertion, success rate and cost.
- Soto F, Murphy A, Heaton H. Critical procedures in pediatric emergency medicine. *Emerg Med Clin N Am* 2013;31:335-76. <http://dx.doi.org/10.1016/j.emc.2012.09.003>** 623
An overview of pediatric emergency medicine and critical procedures. One of the key points noted: intraosseous vascular access can be used in all ages.
- Souchtchenko SS, Benner JP, Allen JL, Brady WJ. A review of chest compression interruptions during out-of-hospital cardiac arrest and strategies for the future. *J Emerg Med* 2013. <http://dx.doi.org/10.1016/j.jemermed.2013.01.023>** 624
This article reviews the clinical effects of both high-quality chest compressions and the effects that interruptions during chest compressions have clinically on patient outcomes. The authors indicate intraosseous vascular access should be heavily considered as the first or at least second-line method used to help prevent prolonged compression interruptions for the purpose of establishing vascular access. The authors note that when using the EZ-IO this method of access is fast, effective, can handle all resuscitation fluids, and can minimize no flow time when used properly.
- YEAR: 2012**
- Crowley M, Brim C, Proehl J, et al. Emergency nursing resource: difficult intravenous access. *J of Emerg Nursing* 2012;38(4):335-43** 602
Manuscript of a literature review and critical analysis done to develop the Emergency Nurse's Association (ENA) December 2011 Emergency Nursing Resource (ENR) which focused on the clinical issue of difficult IV access. Graded recommendations and decision options are provided for alternatives to IV access, including IO.
- Dandele LM, Ohler KH. Pharmacotherapy of pediatric advanced life support and toxicological emergencies. *AACN Adv Crit Care* 2012;23(4):398-412. doi:10.1097/NCI.0b013e31826b4c70** 635
PALS 2012 guidelines on pharmacotherapy and toxicological emergencies.

Intraosseous Vascular Access Bibliography

Guidelines

- Hallas P, Brabrand M, Folkestad L. Reasons for not using intraosseous access in critical illness. *Emerg Med J* 2012;29(6):506-7. doi:10.1136/emj.2010.094011** 438
- This article describes a questionnaire study in which members of selected Scandinavian medical societies were surveyed to identify reasons for not using IO access during resuscitation when IV access is difficult. There were 759 evaluable responses from doctors, nurses, and ambulance staff. Of the respondents, 178 (23.5%) had experienced at least one situation where there was an indication for IO but it was not attempted. The most common reason for not using IO was unavailability of equipment (n=86) and lack of training. The author concluded that increased training in IO use and greater availability of IO equipment for front-line staff should be implemented.
- Ibrahim M, Cairney K. Intraosseous (IO) infusion as a means of vascular access. *Br J Resuscitation* 2012;Autumn:23-6** 599
- This article provides an overview of intraosseous vascular access, including applicable patient population, IO access sites, pain management, IO education and compares IO access to central venous access.
- Kerby JD, Cusick MV. Prehospital emergency trauma care and management. *Surg Clin N Am* 2012;92:823-41. doi:10.1016/j.suc.2012.04.009** 591
- An overview of pre-hospital trauma care. Endotracheal intubation, use of tourniquets, identification of shock, and clinical research in the pre-hospital setting are specifically addressed. Intraosseous vascular access is generally mentioned in relation to resuscitation.
- Oriot D, Darrieux E, Boureau-Voultoury A, Ragot S, Scepti M. Validation of a performance assessment scale for simulated intraosseous access. *Simul Healthc* 2012;7(3):171-5. doi:10.1097/SIH.0b013e31824a5c20** 581
- This article describes the validation testing of a newly developed performance assessment scale for evaluating the intraosseous manual insertion process in the proximal tibia during simulated procedures. The authors concluded that the scale was a reliable tool to assess the overall IO insertion procedure and that with modifications this scale may be used with other IO devices and in the clinical setting.
- Paxton JH. Intraosseous vascular access: A review. *Trauma* 2012;14(3):195-232. DOI:10.1177/1460408611430175** 690
- An overview of IO vascular access including a review of currently available literature. The author discusses various IO devices available and their performance metrics, IO access sites, flow rates, advantages and disadvantages of IO access compared to conventional access methods, complications and recommendations on use of the approach. The author concludes that while IO access may not be appropriate for all patients, it deserves a place in the modern provider's armamentarium.
- Ribiero de Sa RA, Melo CL, Dantas RB, Delfim LVV. Vascular access through the intraosseous route in pediatric emergencies. *Rev Bras Ter Intensiva* 2012;24(4):407-14** 716
- The authors evaluated use of IO access in pediatric emergencies through a literature review. The objective was to describe the techniques, professional responsibilities, and care related to obtaining IO access.
- Brazil*
- Rose EC. The evidence-based use of intraosseous lines in pediatric patients. *Pediatr Emerg Med Pract* 2012;9(6):1-12. www.edmedicine.net** 585
- This article presents a general overview of intraosseous (IO) vascular access in the pediatric population through an IO literature review. Available IO devices were discussed.
- Voigt J, Waltzman M, Lottenberg L. Intraosseous vascular access for in-hospital emergency use: A systematic clinical review of the literature and analysis. *Pediatr Emerg Care* 2012;28(2):185-99** 562
- In this article the authors review the evidence supporting the use of IO access; determine the utilization IO access as described in the literature; and assess the level of specialty society support. Various IO devices are mentioned including the EZ-IO
- Winters ME, Mallemat H, Brady WJ. The critical care literature 2011. *Am J Emerg Med* 2013;31(3):593-6. http://dx.doi.org/10.1016/j.ajem.2012.09.018** 622
- A critical care literature review article that addressed cardiac arrest, trauma, ultrasound, pediatrics, and boarding. Intraosseous vascular access is noted as a method for obtaining vascular access.
- YEAR: 2011**
- de Vogel J, Heydanus R, Mulders AGM, Smalbrakk DJC, Papatsonis DNM, Gerritse BM. Lifesaving intraosseous access in a patient with a massive obstetric hemorrhage. *Am J Perinatol Rep* 2011;1(2):119-122. doi: http://dx.doi.org/10.1055/s-0031-1293514** 541
- Case study of a 42 year-old woman with massive obstetric hemorrhage ultimately resulting in postpartum hysterectomy. Massive blood loss and inability to stop bleed prevented sufficient resuscitation via established PIV lines. IO access was established with the EZ-IO and used for fluid replacement and administration of cardiac resuscitation drugs. Fluid administered through IO access was 75% of the total infusion volume.

Intraosseous Vascular Access Bibliography

Guidelines

- Eich C, Weiss M, Neuhaus D, et al. Handlungsempfehlung zur intraossären Infusion in der Kinderanästhesie [Recommended action for intraosseous infusion in children's anesthesia]. *Anästh Intensivmed* 2011;52:S46-52. German** 770
- German Society of Anaesthesiology and Intensivmedizin eV (DGAI), includes a general discussion of intraosseous (IO) as vascular access, overview of devices and recommendations for pediatric anesthesia with indications for intraosseous infusion in pediatric anesthesia and perioperative care in children. Early or primary IO indications are respiratory and circulatory arrest; critical hemodynamic instability before or during anesthesia introduction; severe laryngospasm; anesthesia induction in respiratory bleeding. Urgent indications (decision based on each case is necessary) include urgent induction of anesthesia in non-fasted children (Ileus, RSI); induction of anesthesia in children with unstable circulation or severe cardiac insufficiency. Semi-elective indications (decision based on each case is necessary) after mask induction of anaesthesia (if vascular access required); mandatory induction of "intravenous" anaesthesia (as in malignant hyperthermia). This article is in German.
- Emergency Nurses Association (ENA). Emergency nursing resource: Difficult intravenous access. Des Plaines, IL: Emergency Nurses Association; December 2011** 603
- The Emergency Nurse's Association (ENA) published a series of Emergency Nursing Resources with emphasis on clinical or practice based issues. This issue focused on difficult IV access and provides a summary of the literature review, with graded recommendations and decision options for practice for IO access, ultrasound guidance, subcutaneous rehydration therapy and several other alternatives. IO access is graded as having a high level of evidence supporting use of IO access when difficult IV access is known or suspected for high success rates and rapid time to insertion.
- Friedman JN. Emergency management of the paediatric patient with generalized convulsive status epilepticus. *Paediatr Child Health* 2011;16(2):91-97** 1073
- This Canadian Paediatric Society paper provides guidelines for the "emergency management of generalized convulsive status epilepticus (CSE) in children and infants older than one month of age". Use of IO access is included for medication administration when IV access is not possible.
- Hafeez W, Ronca LT, Maldonado TE. Pediatric advanced life support update for the emergency physician: Review of 2010 guideline changes. *Clin Pediatr Emerg Med* 2011;12(4):255-65** 525
- General overview of PALS updates. Various IO devices were specifically mentioned in the vascular access section, including the EZ-IO.
- Hallas P, Folkestad L, Brabrand M. How many training modalities are needed to obtain procedural confidence in intraosseous access? A questionnaire study. *Eur J Emerg Med* 2011; 18(6):360-2. doi:10.1097/MEJ.0b013e328349ecd** 460
- An online questionnaire was distributed to members of emergency medicine, pediatric and anesthesiology societies in Scandinavia regarding the amount of training they have received on IO vascular access and evaluate their level of confidence. A total of 322 responses were received and categorized as confident or not confident. The author concluded that confidence with IO increases with the number of learning modalities, and that hands-on experience as a single training modality seems as effective as having a combination of two non-hands-on modalities.
- Kehrl T, Broderick E. Relationship of body mass index and increased difficulty with intraosseous needle placement: assessment of tissue depth using ultrasound. *Ann Emerg Med* 2011;54(4s):S263** 531
- In this abstract the authors attempted to establish a relationship in obese patients (BMI >30) between BMI, ability to palpate the tibial tubercle, and tissue depth at the IO insertion sites. Results showed that in obese patients, IO placement with a 25mm catheter is feasible at the proximal and distal tibial sites if the tibial tubercle is palpable and that insertion into the proximal humerus in this population is not recommended.
- Abstract only*
- Khan LAK, Anakwe RE, Murray A, Godwin Y. A severe complication following intraosseous infusion used during resuscitation of a child. *Inj Extra* 2011;doi:10.1016/j.injury.2011.05.015** 485
- This article describes the case of an 11-year-old boy who suffered compartment syndrome of the lower leg following use of the EZ-IO for resuscitation and 24 hours of intraosseous infusion of adrenaline, calcium and potassium. The author concluded that further work is needed to develop recommendations for maximum duration, dose, volume and rates for intraosseous infusion.
- Mikrogianakis A, Kam A, Silver S, et al. Telesimulation: An innovative and effective tool for teaching novel intraosseous insertion techniques in developing countries. *Acad Emerg Med* 2011;18(4):420-7. doi:10.1111/j.1553-2712.2011.01038.x** 440
- This study evaluated the use of telesimulation by Canadian pediatricians to teach a relatively new IO insertion technique (EZ-IO System) to physicians in Africa. Self-assessment questionnaires were completed before and after training, multiple-choice tests were given and a demonstration of competency was done within 3 training sessions. Twenty-two physicians participated; the sessions improved physicians' knowledge, self-reported confidence, and comfort level in inserting the IO needle. The author concluded that telesimulation offers potential for teaching other procedural skills over distances.

Intraosseous Vascular Access Bibliography

Guidelines

Miller LJ, Philbeck TE, Puga TA, Montez DF, Escobar GP. A pre-clinical study to determine the time to bone sealing and healing following intraosseous vascular access. *Ann Emerg Med* 2011;58(4S):S240 475

The objectives of this study were to evaluate the amount of time necessary following IO insertion and infusion for the bone to heal such that a second IO catheter can be placed in the same bone without the risk of extravasation from the first hole; and to determine the length of time required to show radiological evidence of closure. Four anesthetized goats were used for the study. Twenty-four hours post insertion, extravasation was observed in 2 of 4 tibial sites with no extravasation in 4 humeral sites. Forty-eight hours post insertion, no extravasation was observed in tibial or humeral sites. Authors concluded that IO infusion should not be attempted in the same bone as a previous IO insertion within 48 hours of removal of the first IO catheter. Radiological examination showed evidence of bone healing as early as 6 days post IO placement. This research was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.

Nagler J, Krauss B. Intraosseous catheter placement in children. *NEJM* 2011;364(8):e14-8 491

This article provides an overview of intraosseous vascular access for pediatrics and discusses general indications, contraindications, complications, and intraosseous devices.

Schexnayder SM, Storm EA, Stroud MD, et al. Chapter 15-Pediatric vascular access and centeses. *Pediatric Critical Care* 2011;4th ed:139-63. ISBN: 978-0-323-07307-3 680

This document addresses pediatric vascular access and includes an overview of intraosseous vascular access. Indications, contraindications, supplies and equipment, technique, complications and maintenance are discussed.

Taylor CC. Amputation and intraosseous access in infants. *BMJ* 2011;342:d2778. doi:10.1136/bmj.d2778 484

This article describes two cases of leg amputation after intraosseous infusion in a 5-month-old girl and a 17-month-old boy. The author concluded that fluid extravasation, exacerbated by tibial fracture and needle dislodgement during transportation, caused limb ischemia in these two patients, and that adherence to the principles of careful needle placement, splinting/securing the catheter and limb, limited length of infusion and repeated monitoring of the limb will help avoid this devastating complication.

YEAR: 2010

Alexandrou E, Spencer T, Frost SA, Parr M, Davidson PM, Hillman KM. Establishing a nurse-led central venous catheter insertion service. *JAVA* 2010;15(1):21-7. doi:10.2309/java.15-1-5 436

This paper describes the process of establishing a nurse-led central venous catheter insertion service in a university affiliated hospital using a process evaluation method. Introduction discusses CVC adverse events rate and mortality.

Fenwick R. Intraosseous approach to vascular access in adult resuscitation. *Emerg Nurse* 2010;18(4):22-5 456

This article reviews intraosseous vascular access and its increased use in adult resuscitation. The IO route is described, including indications, contraindications, insertion sites and devices.

Gillum L. All access pass: mastering the use of IO devices. *JEMS* 2010;35(6):30, 32. doi: 10.1016/S0197-2510(10)70142-X 466

This article discusses training methodology and applies the concept to the implementation of the EZ-IO in the Montgomery County Hospital District EMS, a participant in the EZ-IO beta test.

Kleinman ME, Chameides L, Schexnayder SM, et al.. Part 14: Pediatric advanced life support: 2010 American Heart Association guidelines for cardiopulmonary resuscitation and emergency cardiovascular care. *Circulation* 2010;122(Suppl 3):S876-S908. doi: 10.1161/CIRCULATIONAHA.110.971101 947

Part 14 of the 2010 PALS update supports IO vascular access as easy and quick to establish, useful for first line access in cardiac arrest and equivalent for many medications.

Luck RP, Haines C, Mull CC. Intraosseous access. *J Emerg Med* 2010;39(4):468-75. doi:10.1016/j.jemermed.2009.04.054 492

This article provides an overview of intraosseous vascular access and discusses general indications, contraindications, complications, and intraosseous devices.

Miller L, Philbeck T, Montez D, Puga T. Volunteer studies of pain management during intraosseous infusion. *Ann Emerg Med* 2010;56(3):S141 499

This abstract presented at the 2010 ACEP Research Forum describes a study designed to compare Lidocaine's effect on pain during fluid infusion through the tibial and humeral IO routes. Authors concluded that, for adequate IO infusion rates with minimal and tolerable pain, 40mg of preservative-free Lidocaine may be needed; followed by a rapid normal saline syringe flush of at least 10mL and another 20mg of Lidocaine. Additional dosing and flushing may be required. For less overall pain due to IO infusion, and greater infusion flow rates, the proximal humerus should be strongly considered, using a longer IO needleset. This research was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.

Intraosseous Vascular Access Bibliography

Guidelines

- Neumar RW, Otto CW, Link MS, et al. Adult advanced cardiovascular life support. 2010 American heart association guidelines for cardiopulmonary resuscitation and emergency cardiovascular care. Circulation 2010;122(18)[Suppl 3]:S729-67.** 688
<https://doi.org/10.1161/CIRCULATIONAHA.110.970988>
 The 2010 American Heart Association Guidelines for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care. IO access is discussed as a preferred route when IV access cannot be established. The guidelines however do address the lack of clinical information regarding IO drug delivery during CPR but affirm it is reasonable for providers to establish IO access if IV access is not readily available.
- Nolan JP, Soar J, Zideman DA, et al. European resuscitation council guidelines for resuscitation 2010 Section 1. Executive summary. Resuscitation 2010;81(10):1219-76** 689
 2010 updated guidelines for resuscitation by the European Resuscitation Council. This update notes IO access as the preferred mode of vascular access for drug administration, over endotracheal administration, when IV access is unavailable. IO blood is also noted as useful for typing and evaluating laboratory values.
 European Union
- Phillips L, Brown L, Campbell T, Miller J, Proehl J, Youngberg B. Recommendations for the use of intraosseous vascular access for emergent and nonemergent situations in various healthcare settings: a consensus paper. J Emerg Nurs 2010;36(6):551-6.** 458
[doi:10.1016/j.jen.2010.09.001](https://doi.org/10.1016/j.jen.2010.09.001)
 This article discusses use of IO access within the hospital setting in the emergent and non-emergent patient populations. The history of IO access, clinical situations in which IO access may be considered, devices, contraindications, and complications are discussed. Additionally, pain management, economics, education and training and risk management are explored. This article is co-published in Journal of Infusion Nursing, the Journal of Pediatric Nursing, and Critical Care Nurse and was produced by the Consortium on Intraosseous Vascular Access in Healthcare Practice.
- Shah MI. Prehospital management of pediatric trauma. Clin Pediatr Emerg Med 2010;11(1):10-7** 626
 This article provides an overview of pediatric trauma care in the pre-hospital setting by using a literature review to evaluate the risks and benefits of various aspects of care. Topics discussed include: pre-hospital care time, pre-hospital triage and transport, airway management, intravenous (IV) and intraosseous (IO) vascular access and infusions, cervical spine immobilization, traumatic brain injury, and pain assessment and management.
- Vegunta RK. Chapter 8-Vascular access. Ashcraft's Pediatric Surgery 2010;5th ed:110-6** 681
 This document discusses various vascular access methods available for pediatric and neonate patients, including intraosseous access.
- Vizcarra C, Clum S. Intraosseous route as alternative access for infusion therapy. J Infus Nurs 2010;33(3):162-74** 482
 This article provides an overview of IO anatomy and physiology, IO access indications, care, and management; describes therapies administered via IO access; and discusses the expanding use of IO access into areas within hospitals during nonemergency clinical situations. It also includes a table addressing indications for IO access in the hospital, as well as a table addressing the general insertion procedure for IO access.
- World Health Organization. Guidelines for the prevention and clinical management of snakebite in Africa. World Health Organization 2010. WHO Regional Office for Africa, Brazzaville. (Document Reference WHO/AFR/ EDM/EDP/10.01).** 1032
<http://www.afro.who.int/> <http://www.afro.who.int/en/divisions-a-programmes/dsd/essential-medicines/highlights.html>
 These are the WHO guidelines for the prevention and clinical management of snakebite in Africa. Intraosseous access is presented as an option for volume resuscitation in the event of circulatory failure or shock. Intraosseous injection of antivenom in children is acceptable when intravenous administration is not possible
- YEAR: 2009**
- Barrett J. Adult Intraosseous infusion: "Good to the bone!" Response 2009;36(3):19-21** 461
 This article addresses adult IO infusion, primarily in the pre-hospital setting, with regard to the history of IO, anatomy and physiology, training considerations, clinical guidelines and contraindications, and financial considerations.
- Bell MK, Lowe C .. Push hard and push fast: The who, how, and why of pediatric advanced life support (PALS). Pediatr Emerg Med Pract 2009;6(11):1-30** 958
 This is a continuing medical education (CME) document discussing pediatric advanced life support guidelines. It is geared toward pediatric emergency medicine physicians. IO is a preferred route of drug administration.
- Bullard-Berent J. Intraosseous infusion: a instructional program for healthcare providers, revised edition (CD-ROM). Prehosp Emerg Care 2009;13:266** 422
 Instructional program on IO.

Intraosseous Vascular Access Bibliography

Guidelines

Cotton BA, Jerome R, Collier BR, et al. Guidelines for prehospital fluid resuscitation in the injured patient. J Trauma 2009;67(2):389-402 doi:10.1097/TA.0b013e3181a8b26f 538

Guidelines for prehospital fluid resuscitation addressing when vascular access should be attempted and how; and if fluids should be administered, which should be given and at what rate.

Infusion Nurses Society. The role of the registered nurse in the insertion of intraosseous access devices. J Infus Nurs 2009;32(4):187-8 427

Report from task force from Infusion Nurses Society advocating role for properly trained nurses in IO use.

YEAR: 2008

Atanda A Jr, Statter MB. Compartment syndrome of the leg after intraosseous infusion: guidelines for prevention, early detection, and treatment. Am J Orthop 2008;37:E198-200 413

This article discusses the importance of proper technique, attention to detail, and serial monitoring of limb involved when using IO vascular access to avoid potential compartment syndrome and other complications. The author reports the case of a 2-year-old boy who suffered compartment syndrome of the lower limb following use of IO infusion for resuscitation. Early detection of and response to changes in the affected limb resulted in the patient's successful recovery

Gorski LA (Infusion Nurses Society). Standard 63: Intraosseous Access Devices. J Inf Nurs 2008; 31: 146-7 391

Infusion Nurses Society's guidelines and standards for using IO devices.

Horton MA, Beamer C. Powered intraosseous insertion provides safe and effective vascular access for pediatric emergency patients. Pediatr Emerg Care 2008;24(6):347-50 381

A retrospective clinical study was conducted to demonstrate the safety and effectiveness of the EZ-IO intraosseous access device for pediatric patients. For the 95 eligible patients in the study, successful insertion and infusion was achieved in 94% of the patients. Insertion time was 10 seconds or less in 77% of the one-attempt successful cases reporting time to insertion. There were 4 minor complications (4%), but none significant. The results of this study support the use of the EZ-IO for children in emergency situations. The complication rate suggests that the powered IO device is safe and effective for the resuscitation and stabilization of pediatric patients. This study was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.

Pfister CA, Egger L, Wirthmoller B, Grief R. Structured training in intraosseous infusion to improve potentially life saving skills in pediatric emergencies: results of an open prospective national quality development project over 3 years. Paediatr Anaesth 2008;26:31-8 409

Three-year study of IO training and use in 28 hospital and ambulance services in Switzerland. Standardized training improved IO success rate to 100%.

Abstract only

YEAR: 2007

Beekley AC, Starnes BW, Sebesta JA. Lessons learned from modern military surgery. Surg Clin N Am 2007;87:157-84 650

Data from the largest combat trauma database was analyzed to identify how new or improved devices, dressings or drugs have impacted prehospital casualty care, how guidelines and resuscitation strategy have changed, and discusses lessons learned and how concepts have crossed back into the civilian practice. Intraosseous access, particularly the sternal site, is identified as one of the advances for vascular access in combat medicine.

Fowler R, Gallagher JV, Isaacs SM, Ossman E, Pepe P, Wayne W. The role of intraosseous vascular access in the out-of-hospital environment (resource document to NAEMSP position statement). Prehosp Emerg Care 2007;11:63-6 355

Article calls for EMS medical directors to consider and use the intraosseous route for adult patients requiring immediate vascular access. Provides evidence in support of position statement by the National Association of EMS Physicians on IO use.

http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=Pubmed&dopt=Abstract&list_uids=17169880

YEAR: 2006

King Edward Memorial/Princess Margaret Hospitals. Venous and arterial access and line management. King Edward Memorial/Princess Margaret Hospitals NCCU Clinical Guidelines Section: 5 2006; 1-3 390

Includes section on "Insertion of Intraosseous Needles and Care." Provides guidelines including Key Points, Equipment, Complications, Procedure, and Documentation.

Intraosseous Vascular Access Bibliography

Guidelines

- La May G, Friese G. Pediatric fluid resuscitation and airway management - a primer on volume replacement in pediatric patients. EMS 2006;May:65-72** 636
An overview of managing pediatric fluid resuscitation and airway management in the pre-hospital setting.
- YEAR: 2005**
- American Heart Association. Management of cardiac arrest. Circulation 2005; 112: IV-57-IV-66** 328
AHA guidelines for cardiac arrest recommending IO as first line alternative to IV access in adult cardiac arrest patients. Affirms that IO is a safe and effective way to access the central vascular system. Maintains that IO access is similar to central line access and results in fewer complications.
http://circ.ahajournals.org/cgi/content/full/112/24_suppl/IV-58
- Silverman AS, Wang VW. Shock: A common pathway for life-threatening pediatric illnesses and injuries [CME]. Pediatr Emerg Med Pract 2005;2(10):1-22** 1020
This is a continuing medical education (CME) document that provides an overview of shock and discusses management of shock in the pediatric patient. It is geared toward pediatric emergency medicine physicians. IO is a supported route for obtaining vascular access.
- Soar J, Deakin CD, Nolan JP, et al. European Resuscitation Council guidelines for resuscitation 2005. Section 7. Cardiac arrest in special circumstances. Resuscitation 2005; 67:S135-70** 392
European Resuscitation guidelines for cardiac arrest in special circumstances, e.g. life-threatening electrolyte disorders, poisoning, drowning, etc.
- YEAR: 2002**
- Dries DJ, Sample MA. Recent advances in emergency life support. Nurs Clin North Am 2002; 37:1-10** 290
Review article for a nursing audience outlining recent changes in emergency life support in the most recent Advanced Cardiac Life Support (ACLS) guidelines from the American Heart Association with specific emphasis on new technologies for vascular access and emergency airway management.
- YEAR: 2001**
- Atkins DL, Chameides L, Fallat ME, et al. Resuscitation science of pediatrics. Ann Emerg Med 2001;37(4):S41-8** 277
Review article on resuscitation in pediatrics outlining American Heart Association's 1992 changes in guidelines on automatic external defibrillators, vagal maneuvers for treatment of supraventricular tachycardia, validity of capillary refill to assess shock, IO vascular access, and ethical issues.
- Cain BS, Shannon-Cain J. Vasopressin in advanced cardiac life support? Crit Care Med 2001; 29: 1649** 281
Critical care article advocating use of vasopressin when standard or high dose epinephrine fails in a salvageable patient.
- YEAR: 1996**
- Wietlisbach M, Schupfer G. [Venous access and methods of drug application in ACLS (Advanced Cardiac Life Support)]. Ther Umsch 1996; 53: 630-3. German. Abstract** 214
Article in German
- YEAR: 1992**
- American Heart Association. Guidelines for cardiopulmonary resuscitation and emergency cardiac care: chain of survival. JAMA 1992; 268: 2171-2302** 130
Evaluation of the chain of survival from cardiac arrest using standard measurements of performance.
- YEAR: 1988**
- Mofenson HC, Tascone A, Caraccio TR. Guidelines for intraosseous infusions. J Emerg Med 1988;6:143-6** 68
Guidelines for IO in pediatric patients.

Intraosseous Vascular Access Bibliography

Guidelines

YEAR: 1986

Melker RJ. Intraosseous infusions. *Am J Emerg Med* 1986;4:490

46

Letter to the editor discussing guidelines for IO in Standards and Guidelines for Cardiopulmonary Resuscitation and Emergency Cardiac Care, and in the chapter on Intravenous and Intra-arterial Techniques for the Pediatric Advanced Life Support (PALS) textbook being completed by the Working Group on Pediatric Resuscitation of the American Heart Association.

Unger H, Spivey WH, McNamara RM, Lathers CM. Comparison of intraosseous and intravenous CBC and ASTRA 8 in swine. *Ann Emerg Med* 1986;15(5):198

561

This preclinical study compared CBCs and routine blood chemistries drawn from IO and IV blood. The authors concluded that IO blood chemistries reflected venous blood chemistries and may be used if venous blood cannot be obtained; CBC cannot be reliably obtained from IO blood.

YEAR: 1985

Hodge D. Intraosseous infusions: a review. *Pediatr Emerg Care* 1985;1(4):215-8

44

Review of IO insertion techniques of insertion, clinical indications, contraindications, and complications.

Intraosseous Vascular Access Bibliography

Infusion Devices

YEAR: 2018

Bjerkvig CK, Fosse TK, Apelseth TO, et al. Emergency sternal intraosseous access for warm fresh whole blood transfusion in damage control resuscitation. J Trauma Acute Care Surg 2018;84(6S):S120-4. doi:10.1097/TA.0000000000001850. (Norway) 962

This article describes a prospective, comparative, nonrandomized study to compare flow rates using the sternal IO route with two different devices (EZ-IO and Fast1) when transfusing warm fresh whole blood as well as measuring post-infusion hemolysis when compared to IV infusion. Post procedure blood samples from all patients were within normal ranges with no statistically significant differences between groups. This study had a high catheter insertion failure rate in the IO groups. This was most likely due to subjects, healthy Norwegian military volunteers, performing the procedures on each other. The results suggest that infusion of fresh whole blood via the IO route is safe and reliable.

Czyz R, Wudarczyk, Leskiewicz M, Czyz I. Current advances in intraosseous access - A review of presently available devices. J Ed Health Sport 2018;8(8):939-50. doi: 10.5281/zenodo.1406964 1049

This paper provides a brief overview of the following IO needles and devices: the Dieckmann Modified Needle, the EZ-IO Manual Needle Set, the EZ-IO T.A.L.O.N Needle Set, the Jamshidi Needle, the Bone Injection Gun (BIG), the New Intraosseous Device (NIO), the FAST Responder Sternal Intraosseous Device, and the EZ-IO Intraosseous Vascular Access System.

Fuchs Z, Scaal M, Haverkamp H, Koerber F, Persigehl T, Eifinger F. Anatomical investigations on intraosseous access in stillborns - Comparison of different devices and techniques. Resuscitation 2018;127:79-82 978

This article investigates the success rate of IO access in preterm and term stillborns using two different needles (21G butterfly and 15G EZ-IO) inserted manually and one battery-powered semi-automatic drill (EZ-IO). All insertions were performed on the tibia. Estimated success rates were 61.1% for the butterfly needle, 43.0% for the hand twisted EZ-IO, and 39.7% for the EZ-IO drill. The authors conclude that IO access in premature and term neonates is best achieved by manual access with a twisted butterfly needle.

Simsek P, Bayram SB, Gursoy A. İlaç uygulamaları için farklı bir yol: Intraosseöz ulaşım ve infüzyon [A different route for drug administration: Intraosseous access and infusion]. HEAD 2018;15(1):40-44. doi: 10.5222/HEAD2018.040. Turkish 1061

This is an article published in a Turkish nursing journal and written in Turkish. From the abstract, the IO route is described as an alternative approach to vascular access when venous access via a peripheral catheter cannot be obtained quickly. Complications of IO access and how to prevent them using nursing interventions are discussed. EZ-IO is discussed in the article.

Szarpak L, Ladny JR, Dabrowski M, et al. Comparison of 4 pediatric intraosseous access devices: A randomized simulation study. Pediatr Emerg Care 2018;00:1-5. doi:10.1097/PEC.0000000000001587. [Epub ahead of print] 1026

This study aimed to compare the success rates of 4 commonly used IO devices (NIO Pediatric, BIG Pediatric, EZ-IO, and a manual Jamshidi IO needle) in a pediatric model. Speed of insertion, ease of use, and complications were secondary outcomes. Seventy-five novice physicians from Warsaw, Poland participated in this study; none of whom had prior experience with IO devices. First attempt success rates were 43% (Jamshidi), 90% (BIG), 97% (EZ-IO), and 100% (NIO-P). Median time to achieve IO access was 18 seconds (NIO), 23 seconds (EZ-IO and BIG), and 34 seconds (Jamshidi). 39/68 participants preferred the NIO device, 18/68 preferred the EZ-IO device, 11/68 preferred the BIG device, and none of the participants preferred the Jamshidi needle.

YEAR: 2017

Elliott A, Dubé P, Cossette-Côté A, et al. Intraosseous administration of antidotes-a systematic review. Clin Toxicol 2017; 55(10):1025-54. doi:10.1080/15563650.2017.1337122 917

This study reviews current IO administration of antidotes for patients that have presented to the emergency department with serious poisoning and IV access is not available. The study concluded that the evidence supporting the use of IO route for administering antidotes for poisoning patients is rare. Most evidence of IO access administration of antidotes has occurred in animal studies and case reports. Per author, despite lack of evidence, IO access is a potential option for antidotal treatments for resuscitation for patients where IV access is not available.

Feinstein B, Stubbs B, Rea T, Kudenchuk P. Intraosseous compared to intravenous drug resuscitation in out-of-hospital cardiac arrest. Resuscitation 2017;117:91-6. doi:10.1016/j.resuscitation.2017.06.014 922

This retrospective cohort study evaluated emergency medical services (EMS) that treated adult patients with atraumatic out of hospital cardiac arrest (OHCA) in order to compare drug administration via intraosseous (IO) versus intravenous (IV) and the effectiveness. Study endpoints were survival to hospital discharge, return of spontaneous circulation (ROSC), and survival to hospital admission. The study included 1,800 patients, 1,525 of whom received IV access and 275 who received IO access. The practice for OHCA management in the EMS system from which the data was obtained was to attempt tibial IO access after failed IV attempts. The authors concluded that use of IO access was associated with a lower likelihood of ROSC and hospitalization; and acknowledged that further study of how vascular access routes affect OHCA patient outcomes is warranted.

Intraosseous Vascular Access Bibliography

Infusion Devices

Leutscher SA, Gerritse BM, van der Meer NJ, Schuitemaker FJ, Scohy TV. Need of intraosseous access in advanced life support in the in-hospital setting: Evaluation of difficult vascular access in cardiac arrest. *Resuscitation* 2017;112:e7 885

This letter to the editor states the usefulness of intraosseous access devices in out-of-hospital-cardiac-arrest (OHCA) settings.

YEAR: 2016

Adams TS, Blouin D, Johnson D. Effects of tibial and humerus intraosseous and intravenous vasopressin in porcine cardiac arrest model. *Am J Disaster Med* 2016;11(3):211-8. doi:10.5055/ajdm.2016.0241 896

This study compared maximum concentration time (Cmax) to maximum concentration mean (Tmax) of mean serum concentration of vasopressin, return of spontaneous circulation (ROSC), time to ROSC, with odds of survival to vasopressin administration by tibial intraosseous, proximal humerus intraosseous (PHIO), and intravenous (IV) routes in a cardiac arrest model. Authors concluded TIO and PHIO provide rapid and reliable access in administration of life-saving medications during cardiac arrest and may be faster due to IV difficulty.

Beaumont D, Baragchizadeh A, Johnson C, Johnson D. Effects of tibial and humerus intraosseous administration of epinephrine in a cardiac arrest swine model. *Am J Disaster Med* 2016;11(4):243-50. doi:10.5055/ajdm.2016.0246 898

This study examined the differences of pharmacokinetics and pharmacodynamics of epinephrine via of tibial intraosseous access and IV access. Interruptions in CPR in order to obtain vascular access reduces the flow of blood to vital organs. Study results showed that TIO access may be a faster alternative to IV access for delivery of vasoactive medications.

Blouin D, Gegel BT, Johnson D, Garcia-Blanco JC. Effects of intravenous, sternal, and humerus intraosseous administration of hexend on time of administration and hemodynamics in a hypovolemic swine model. *Am J Disaster Med* 2016;11(3):183-92. doi:10.5055/ajdm.2016.0238 900

This study was to determine if there were any significant differences between humerus intraosseous (PHIO), sternal intraosseous(SIO) and intravenous (IV) administration of Hexend on the hemodynamics or administration time in a hypovolemic swine model. Time of administration of the Hexend on effects on systolic and diastolic blood pressure, mean arterial pressure, heart rate, cardiac output and stroke volume. After administration of Hexend, data was collected every 2 minutes for 8 minutes total. Results found no significant difference in these measures among the PHIO, SIO or IV groups.

Burgert J. A primer on intraosseous access: History, clinical considerations, and current devices. *Am J Disaster Med* 2016;11(3):167-73. doi:10.5055/ajdm.2016.0236 901

This journal article literature review was written to provide information about the history, clinical considerations, and devices associated with intraosseous access to administer resuscitative drugs when IV access can't quickly or easily obtained.

Burgert J. Intraosseous vascular access in disasters and mass casualty events: A review of the literature. *Am J Disaster Med* 2016;11(3):149-66. doi:10.5055/ajdm.2016.0235 902

This literature review examined the increase in use of intraosseous access for administration of resuscitative fluids and drugs to patients where intravenous access could not quickly or easily obtained during disasters and mass casualty events. The review also included a comparison of IO route to other routes for establishing vascular access in patients that have been involved in mass casualty or disasters.

Celik T, Ozturk C, Balta S, Demirkol S, Iysoy A. A new route to life in patients with circulatory shock: Intraosseous route. *Am J Emerg Med* 2016;34(5):922-23. doi:10.1016/j.ajem.2016.02.035 906

In this letter to the editor authors discuss the importance of establishing access to circulatory system during CPR. The authors referenced the study "The effects of proximal and distal routes of intraosseous epinephrine administration on short-term resuscitative outcome measures in an adult swine model of ventricular fibrillation: a randomized controlled study" and the study "Intraosseous versus intravenous vascular access during out-of-hospital cardiac arrest: a randomized controlled trial". Authors concluded that intraosseous access seems reasonable for patients in cardiopulmonary arrest or severe shock that do not have available and quick IV access for administration of medications and fluids.

Lind T. Alternative access routes for fluid resuscitation. *Top Companion Anim Med* 2016;31(2):61-7. doi:10.1053/j.tcam.2016.08.005 886

This veterinary care article describes vascular access methods and devices used for small animal emergencies, including intraosseous devices.

Szarpak L, Czyzewski L, Woloszczuk-Gebicka B, Krajewski P, Fudalej M, Truszcowski Z. Comparison of NIO and EZ-IO intraosseous access devices in adult patients under resuscitation performed by paramedics: A randomized crossover manikin trial. *Am J Emerg Med* 2016;34(6):1166-7. doi:10.1016/j.ajem.2016.03.017. 774

This randomized crossover manikin trial compared the NIO and EZ-IO devices for time to placement and ease of use. For both parameters the NIO performed better.

Poland

Intraosseous Vascular Access Bibliography

Infusion Devices

Szarpak L, Truszewski Z, Smereka J, Krajewski P, Fudalej M. Ability of paramedics to perform intraosseous access. A randomized cadaver study comparing EZ-IO and NIO devices. Resuscitation 2016;104:e5-e6. doi:10.1016/j.resuscitation.2016.04.011

795

This letter to the editor describes a prospective, randomized, cross-over cadaveric study that evaluated use of the EZ-IO and NIO devices by novice paramedic device users. Following a brief in-service on use of both devices and practice insertions using a leg-trainer manikin, each participant attempted to establish IO access using each device in a resuscitation simulation with in an adult cadaver with CPR in progress. Results showed first attempt success rates of 97.4% with the NIO and 100% with the EZ-IO; and mean time to insertion was 16.8 seconds with the NIO and 42 seconds with the EZ-IO.

YEAR: 2015

Anson JA, Sinz EH, Swick JT. The versatility of intraosseous vascular access in perioperative medicine: a case series. J Clin Anesth 2015;27(1):63-7.http://dx.doi.org/10.1016/j.jclinane.2014.10.002

729

This article presents a 5-case series describing use of IO vascular access by anesthesiologists in the perioperative and critical care settings. All insertions were made in the proximal tibia and there were no adverse events reported. The devices cited as being used were the EZ-IO and the Cook Surfast manual needle. A proposed perioperative vascular access algorithm incorporating IO access is presented. The authors address key topics around IO access including use of same drug dosing as IV administered drugs, frequent palpation and monitoring of the insertion site for extravasation, low complication rate and actual risks associated with fat emboli and bone injury, pain and anxiety management in the awake patient and clinician-perceived pain. Administration of blood products, ACLS drugs, Lactated Ringer's solution and anesthetics are noted without complication. Use of IO aspirate for laboratory testing is noted, however use of the initial aspirate is indicated. Several patients in the case series were reported to find the discomfort of IO insertion preferable to multiple intravenous attempts. The authors concluded: IO lines can be placed quickly and safely in emergency situations or in elective surgical patients with difficult intravenous access; IO access can be useful in a wide variety of clinical settings; and is an important skill for anesthesiologist to learn.

Bradburn S, Gill S. Understanding and establishing intraosseous access (317). World Federation of Societies of Anaesthesiologists. June 26, 2015

955

This document is a tutorial provided by the World Federation of Anaesthesiologists geared at understanding and establishing intraosseous access. It provides an overview of venous blood drainage from bones as well as indications, contraindications, common access sites, advice for establishing access, an overview of device types, insertion techniques, and complications.

Hammer N, Möbius R, Gries A, Hossfeld B, Bechmann I, Bernhard M. Comparison of the fluid resuscitation rate with and without external pressure using two intraosseous infusion systems for adult emergencies, the CITRIN (comparison of intraosseous infusion systems in emergency medicine)- study. PLoS ONE 2015;10(12):e0143726. doi:10.1371/journal.pone.0143726

791

A cadaveric study performed by twenty-seven medical students, inexperienced with IO vascular access, that compared use of the EZ-IO for access in the proximal humerus and proximal tibia insertion sites and the FASTR for access in the sternum. First pass insertion success, insertion times, and one minute flow rates using external pressures from 0 to 300 mmHg were evaluated. The authors concluded that both the EZ-IO and FASTR devices may be effective IO devices and are likely suitable for fluid resuscitation using a pressure bag.

Pasley J, Miller CHT, DuBose J, et al. Intraosseous infusion rates under high pressure: a cadaveric comparison of anatomic sites. J Trauma Acute Care Surg 2015;78(2):295-9. DOI: 10.1097/TA.0000000000000516

750

A cadaveric study evaluating intraosseous (IO) vascular access insertion sites for attainable flow rates under 300 mmHg. The EZ-IO was used to establish IO access at the proximal humerus and proximal tibia sites; the FAST1 was used to establish sternal IO access. The total volume of fluid infused at the three IO access sites was 469 ± 190 mL for the sternum; 286 ± 218 mL for the humerus; and 154 ± 94 mL for the tibia. The mean flow rate infused at each site was as follows: 93.7 ± 37.9 mL/min for the sternum; 57.1 ± 43.5 mL/min for the humerus; and 30.7 ± 18.7 mL/min for the tibia. First attempt placement success was 100% for the sternum and proximal humerus and 81% for the tibia.

YEAR: 2014

Anson JA. Vascular access in resuscitation: Is there a role for the intraosseous route? Anesthesiology 2014;120(4):1015-31

695

Literature review through August 1, 2013 with primary aim to determine whether there is a role for intraosseous vascular access in the resuscitation of critically ill patients. Secondary aims were to investigate the evidence regarding clinical use, drug administration, and complications of IO access. The authors concluded that IO access can be achieved quickly and accurately in emergency situations and there is clearly a role for it in resuscitation of ill patients; anesthesiologists should become familiar with IO access.

Barnard EBG, Moy RJ, Kehoe AD, Bebarta VS, Smith JE. Rapid sequence induction of anesthesia via the intraosseous route: a prospective observational study. Emerg Med J 2014;32(6):449-52. doi:10.1136/emmermed-2014-203740

702

A prospective observational study that evaluated use of intraosseous vascular access for delivery of rapid sequence intubation (RSI) drugs. Data was collected between January and May 2012 at a combat hospital in Afghanistan. Thirty-four (34) patients underwent RSI with drug delivery via the IO route. Access was established in the proximal humerus and tibia using the EZ-IO and in the sternum using the FAST-1. All placements were successful on first attempt; first pass intubation success rate was 97%; a Cormack-Lehane (C-L) laryngoscopic grade view of 1 was reported 91%. Authors concluded that IO access is a safe and feasible route for delivery of anesthetic drugs for RSI.

Intraosseous Vascular Access Bibliography

Infusion Devices

Chansa E, Kansen K, Gustafsson B. [An intraosseous blood transfusion in a critically ill child] Une transfusion sanguine par voie intraosseuse chez un enfant gravement malade. Afr J Emerg Med 2014;4(2):83-5. <https://doi.org/10.1016/j.afjem.2013.05.003>

658

This article describes a case study of a 31-month old infant that suffered hypovolemic shock due to severe epistaxis. After several failed peripheral and central line attempts an 18g needle was inserted intraosseously through the proximal tibia. The child received 300 mL of Ringer's Lactate in one hour then 200 mL of blood via the IO route by syringe boluses resulting in improvement. Cloxacillin was also administered IO as prophylaxis for infection. Authors conclude an IO blood transfusion should be the immediate intervention in similar life-threatening situations.

Zambia

Demir OF, Aydin K, Akay H, Erbil B, Karcioğlu O, Gulalp B. Comparison of two intraosseous devices in adult patients in the emergency setting: a pilot study. Eur J Emerg Med 2014;DOI:10.1097/MEJ.0000000000000187

735

This was a prospective, randomized controlled clinical pilot study comparing the BIG and EZ-IO intraosseous (IO) vascular access devices in 52 adult patients admitted to an emergency department with difficult peripheral venous access. Twenty-six patients were randomized to each device; results were first attempt insertion success BIG 92.3%, EZ-IO 84.6% (P=0.668); procedure time: BIG 2.8 ± 1.2 seconds, EZ-IO 5.2 ± 2.2 seconds (P<0.001), significant; difficulty of use (with visual analogue scale): BIG 8.6 ± 6.4 mm, EZ-IO 25.4 ± 12.6 mm (P<0.001), significant. Authors concluded both EZ-IO and BIG are shown to be reliable and safe methods for insertion of intravascular access in emergency conditions. There were no adverse events or complications reported.

Turkey

Derikx HJGM, Gerritse BM, Gans R, vander Meer NJM. A randomized trial comparing two intraosseous access devices in intrahospital healthcare providers with a focus on retention of knowledge, skill, and self-efficacy. Eur J Trauma and Emerg Surg 2014;doi:10.1007/s00068-014-0385-8

706

This article describes a randomized trial comparing the retention knowledge, skill and self-efficacy among anesthesiologists and registered nurses of anesthesia with use of the EZ-IO and Bone Injection Gun (B.I.G.). Participants were randomized to be trained on one device and were tested at 0, 3, and 12 months post training. The authors concluded that training anesthesiologists on use of the EZ-IO with the educational tools provided by the manufacturer will ensure optimal performance for a period of one year.

The Netherlands

Dev SP, Stefan RA, Saun T, Lee S. Insertion of an intraosseous needle in adults. N Engl J Med 2014;370(24):e35(1)-e35(5). Doi:10.1056/NEJMc1211371

700

Text article that accompanies video featured in The New England Journal of Medicine on intraosseous access which provides a general overview of IO access and demonstration of IO insertion using the EZ-IO and one manual IO needle set.

Gurman P, Chi A, Hood T, et al. Prefilled devices for parenteral applications. Expert Rev Med Devices 2014;11(2):205-223

981

This review provides a comprehensive summary of pharmacologic therapies that utilize prefilled devices as a delivery mechanism for parenteral application. Six categories are described: endocrine, neurological, pain management, immune disorders, anaphylaxis, and emergency medicine. Within emergency medicine IO access is recommended as an alternative to IV access when IV access cannot be obtained. Various devices for IO access, including the EZ-IO device, are listed.

Kurowski A, Timler D, Evrin T, Szarpak T. Comparison of three different intraosseous access devices for adults during resuscitation: randomized cross-over manikin study. Am J Emerg Med 2014;32:1490-3. DOI: <http://dx.doi.org/10.1016/j.ajem.2014.09.007>

739

Manikin study conducted in Poland with 107 paramedic operators designed to investigate the success rate, time of insertion and perceived difficulty of intraosseous access devices during simulated resuscitation using the EZ-IO, Bone Injection Gun and Jamshidi needles. Results were first attempt success: B.I.G.: 91.59%; EZ-IO: 82.66%; Jamshidi: 47.66%; mean procedure time: B.I.G.: 2.0 min ± 0.7; EZ-IO: 3.1 min ± 0.9; Jamshidi: 4.2 min ± 1.0; and ease of use (1-very easy to 5-very hard): B.I.G.: 1.83; EZ-IO: 2.92; Jamshidi: 4.68.

Poland

Lewis P, Wright C. Saving the critically injured trauma patient: a retrospective analysis of 1000 uses of intraosseous access. Emerg Med J 2014;31(9):784. doi:10.1136/emmermed-2014-203588

714

This retrospective study reported IO use over a 7-year period during combat operations in Afghanistan by the UK Defence Medical Services. The EZ-IO and FAST1 IO devices were available for use; IO use data was collected from the front line, during helicopter evacuation and at the combat hospital. A total of 1014 IO devices were inserted into 830 adult patients; various medications infused via IO access are listed. Across all cases there were no serious IO complications and 14 minor complications. The author concluded that in the pre-hospital setting in particular and in severely injured trauma patients, IO access should be considered a primary method of obtaining vascular access.

Intraosseous Vascular Access Bibliography

Infusion Devices

- Nadler R, Gendler S, Chen J, Lending G, Abramovitch A, Glassberg E. The Israeli Defense Force experience with intraosseous access. *Military Medicine* 2014;179(11):1254-7** 740
- Retrospective study of the Israeli Defense Force (IDF) registry from January 1999 through October 2012 to identify all cases in which IO access was attempted. The Bone Injection Gun (B.I.G.) was the device used for IO access. A total 37 attempts were made in 30 patients. First attempt success was 53% with an overall success rate 49% when factoring subsequent attempts. Most frequent cause for failure related to providers skill level, and due to the device design allowing little room for error. This study prompted the IDF to seek an alternative for the B.I.G.
- Israel
- Pasley J, Miller C, Dubose J, et al. Intraosseous infusion rates under high pressure: a cadaveric comparison of anatomic sites. 2014 Annual Scientific Assembly for the Eastern Assoc for the Surgery of Trauma meeting. <http://www.dtic.mil/cgi-bin/GetTRDoc?AD=ADA597324>. Published January 2014. Accessed May 12, 2014** 728
- This report describes a study conducted by the Air Force Research Laboratory comparing intraosseous infusion rates between IO sites in a cadaveric model to determine if there is a site that is most effective for volume resuscitation. Using 16 cadavers procured within 72 hours of death, IO access was established in the proximal tibia and proximal humerus using the EZ-IO and in the sternum using the FAST1. Results showed the mean flow rate in the sternum was 1.6 times greater than the humerus and 3.1 times greater than the tibia. An abstract describing this report was presented by oral presentation at the 2014 annual scientific assembly for the Eastern Association for the Surgery of Trauma meeting.
- Vassallo J, Horne S, Smith JE. Intraosseous access in the military operational setting. *J R Nav Med Serv* 2014;100(1):36-9** 794
- This article describes a prospective, observational study conducted March – July 2011 at the emergency department, Camp Bastion, Afghanistan evaluating use of IO access in 117 patients established using the EZ-IO and the FAST1 devices (76% EZ-IO).
- West B, Jule M, Prescott N, Labond VA, Zettek K, Foland W. Out-of-hospital intraosseous versus intravenous access in return of spontaneous circulation. *Ann Emerg Med* 2014;64(4s):S70-1** 797
- Abstract reporting on retrospective prehospital study to evaluate the rate of out-of hospital return of spontaneous circulation (ROSC) in the cardiac arrest patient. The following were assessed and analyzed for direct or indirect correlation on ROSC; dispatch time to arrival, number of intravascular attempts per method (IV versus IO) and rate of success. Conclusions were that ROSC can be achieved more rapidly when IO access is used as the first attempt method in obtaining vascular access in prehospital cardiac arrest. There was a trend in shorter ROSC times among the first attempt IO group compared to the IV group; the difference did not reach statistical significance, most likely due to a lack of power from the smaller sample size of the IO group.
- YEAR: 2013**
- Barratt JW. Re: reasons for not using intraosseous access in critical illness. *Emerg Med J* 2013;30(6):516-7. doi:10.1136/emered-2012-202120** 703
- This article describes a questionnaire study that was given to UK Role One military clinicians deployed to Afghanistan to assess the level of experience and confidence rating with use of IO access, using the FAST-1 and EZ-IO, and IV access. Thirty-three responses were received; clinicians felt more confident with IV access over IO access; clinicians felt more confident with FAST-1 IO access than EZ-IO IO access.
- UK
- Bloch SA, Bloch AJ, Silva P. Adult intraosseous use in academic Eds and simulated comparison of emergent vascular access techniques. *Am J R Emerg Med* 2013. <http://dx.doi.org/10.1016/ajem.2012.11.021>** 652
- In a letter to the editor this study reports data collected (during a survey of one third of academic emergency medicine programs in the U.S.) regarding IO use in adults and comparing IO access with other vascular access techniques through simulation. Data suggest that IOs were used less than 5% of the time patients needed emergent access and a peripheral line was unobtainable. The EZ-IO was most often used IO device. Authors conclude IO use should be considered more frequently in critical, unstable patients. (This research was presented at the ACEP Research Forum in 2010).
- Cleugh FM, Maconochie IK. Management of the multiply injured child. *Paediatrics and Child Health* 2013;23(5):194-9** 659
- General overview of care of a child with multiple trauma. IO vascular access is mentioned as a treatment option after 90 seconds or 3 failed PIV attempts. The B.I.G. is cited as an option along with the manual needles.
- Cook LS. Infusion-related air embolism. *J Infus Nurs* 2013;36(1):26-36. Doi: 10.1097/NAN.0b013e318279a804** 613
- This article looks at various methods of vascular access including venous, arterial and intraosseous access and their potential to result in air embolism.

Intraosseous Vascular Access Bibliography

Infusion Devices

Dolister M, Miller S, Borron S, et al. Intraosseous vascular access is safe, effective and costs less than central venous catheters for patients in the hospital setting. J Vasc Access 2013;14(3):216-24. doi:10.5301/jva.5000130 583

An observational clinical study evaluating use of the EZ-IO in patients requiring urgent vascular access that would have otherwise received a central venous catheter due to a lack of other options. One hundred five (105) patients were enrolled across five hospitals. The authors concluded that use of IO access in place of CVCs provides time savings, safety, ease of use, and is effective at significant cost savings; IO access may be used as a bridge to CVC placement under optimal conditions; and IO access may be used to replace use of CVCs all together in selective patients. This study was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.

Erdmann L, Doll S, Ihle B, Kirsch J, Mutzbauer TS. Evaluation of the sternal intraosseous route as alternative emergency vascular access for the dental office: a manikin and cadaver model pilot study. Oral Surg Oral Med Oral Pathol Oral Radiol 2013;116(6):686-91 657

This article describes a mannequin and cadaver study that evaluated use of the EZ-IO sternal device and the Illinois needle to establish sternal IO vascular access by dental students. Results of the cadaver study showed two cases of perforation of the posterior sternal cortex when the Illinois needle was used and one EZ-IO insertion in the soft tissue without entering the IO space. The authors concluded use of the EZ-IO sternal device with the insertion site template and scalpel incision may be more efficient and less predisposed to complication than use of the Illinois needle.

Grossman V. Hot Topics: CT contrast and intraosseous lines: friends or enemies? J Radiol Nurs 2013; 32(1):41-4. http://dx.doi.org/10.1016/j.jradnu.2012.12.004 643

General discussion on use of the intraosseous vascular access route for infusion of CT contrast, with attention to clinical considerations pertinent to nurses working in the imaging suite. Author also reviews general IO principles and IO devices.

Hafner JW, Bryant A, Huang F, Swisher K. Effectiveness of a drill-assisted intraosseous catheter versus manual intraosseous catheter by resident physicians in a swine model. Western J Emerg Med 2013;XIV(6):629-32 668

This is a preclinical study comparing the EZ-IO and the Cook manual IO needle when used by 21 resident physicians to establish IO access in anesthetized swine. Results showed the drill-assisted needle was successfully placed 100% of attempts vs 76.2% successful placement with manual; time to placement and user preference also favored the EZ-IO. Technical issues reported included bending of the manual needle 33% of attempts.

Hallas P, Brabrand M, Folkestad L. Complication with intraosseous access: Scandinavian users' experience. West J Emerg Med 2013;14(5):440-3. doi:10.5811/westjem.2013.1.1200 669

A questionnaire study in which Scandinavian emergency physicians, anesthesiologist and pediatricians reported complications they have experienced with IO vascular access based on recollection alone. Complications were reported related to establishing IO access and using established IO access. Out of 1,802 IO cases reported by 386 responders, the most frequently reported complications included difficulty with periosteum penetration and bone marrow aspiration when establishing IO access; and slow infusion and needle displacement with established IO access. Osteomyelitis and compartment syndrome were reported with an occurrence of 0.4% and 0.6%. Researchers concluded that potential complications following IO insertion should be addressed during training. Devices discussed included the EZ-IO, BIG, Cook-Surfast, and other unidentified IO devices

Denmar

Hamed RK, Hartmans S, Gausche-Hill M. Anesthesia through an intraosseous line using an 18-gauge intravenous needle for emergency pediatric surgery. J Clin Anesth 2013;25(6):447-51;pii: S0952-8180(13)00202-X. doi: 10.1016/j.jclinane.2013.03.013.http://dx.doi.org/10.1016/j.jclinane.2013.03.013. Accessed September 3, 2013 670

This 30 pediatric patient case series describes use of IO access in the perioperative setting when peripheral and central venous access failed during anesthesia administration for emergency surgery. Due to unavailability of modern IO devices, a standard 18-gauge IV needle with a handmade IV extension set were used to establish IO access. The authors reported administering ketamine, succinylcholine, pancuronium, atracurium, halothane, neostigmine, atropine, blood products, fluids and hydrocortisone through the IO line without complication. The authors concluded that although it is not the first-line method for anesthesia, IO access should be considered by pediatric anesthesiologist when peripheral and central venous access has failed or is difficult.

Iraq

Helm M, Richter D, Schramm A, Lampl L, Hossfeld B.. Ist die intraossare punktion ein alternativer gefabzugang beim notfall in der zahnarztlichen praxis? Notfall Rettungsmed 2013;16:27-32. Doi:10.1007/s10049-012-1629-y. German 612

This article in German explores use of intraosseous access in a dental practice emergency. In a simulation study, dental students attempted to establish standard peripheral IV access and IO access using 3 different devices: EZ-IO, BIG, and manual IO. Results showed the manual was the fastest to insert, however, the EZ-IO had the highest first-attempt success rate as well as the lowest number of total attempts to IO access.

German

Intraosseous Vascular Access Bibliography

Infusion Devices

- Hunsaker S, Hillis D. Intraosseous vascular access for alert patients. *Am J Nurs* 2013;113(11):34-9** 672
This article presents an overview of IO access focused on nurses' use of the technique. A list of available devices, history and support for use and possible complications are included.
- Junkin R, Selfridge J, Litchfield. Intraosseous vascular access in obstetric emergencies: an OAA approved national survey. *Int J Obstet Anesth* 2013;22(1):S31** 673
This abstract describes the results of an online survey taken by members of the Obstetric Anaesthetists' Association, evaluating use of IO access in obstetric emergencies, and availability of IO equipment on UK labor wards. Results showed many members are trained on IO access, consider it a viable option during emergencies however have limited access to equipment.
UK
- Lewis GC, Crapo SA, William JG. Critical skills and procedures in emergency medicine- vascular access skills and procedures. *Emerg Med Clin N Am* 2013;31(1):59-86. doi: 10.1016/j.emc.2012.09.006** 631
This article provides an overview of various vascular access modalities in emergency medicine including peripheral IV, venous cut-down, central venous catheter, intraosseous access, umbilical vessel access, and arterial access. The anatomy and physiology, indications and contraindications, procedure steps and special considerations are outlined for each access methods discussed.
- Plancade D, Millot I, Fetissov H, et al.. Sternal perforation with an intraosseous device and hemomediastinum infusion *Ann Fr Anesth Reanim* 2013;<http://dx.doi.org/10.1016/j.annfar.2013.01.009>** 616
A 45-year-old woman in hemorrhagic shock with multiple injuries to the limbs, secondary to a war wound, received sternal IO access using the Jamshidi trocar (not specifically intended for sternal use). After initiating a blood transfusion through the IO line a contrast CT scan revealed sternal perforation and hemomediastinum, secondary to the transfusion, as well as drainage into the left pleural cavity. The catheter was removed, right thoracic drainage was performed, and the patient was released from ICU 48 hours later. The authors conclude this case report demonstrates the difficulty in selecting emergency insertion sites and the necessity of choosing an appropriate IO catheter.
- Plancade D, Ruttimann M, Wagnon G, et al.. La perfusion intraosseuse chez l'adulte. *Annales Francaises d'Anesthesie et de Reanimation* 2013;<http://dx.doi.org/10/1016/j.annfar.2013.02.024>. French** 617
This article in French gives an overview of intraosseous vascular access including the physiology of IO infusion, insertion sites, indications, and complications. Available IO devices on the market are described including, time to insertion, success rate and cost.
- Stranden G, Skogrand H, Spinella PC, Hervig T, Rein EB. Donor performance of combat readiness skills of special forces soldiers are maintained immediately after whole blood donation: A study to support the development of a prehospital fresh whole blood transfusion program. *Transfusion* 2013; 53(3):526-30. doi:10.1111/j.1537-2995.2012.03767.x** 570
This study conducted by the Norwegian Navy evaluated the ability of 25 soldiers to perform buddy transfusion by starting phlebotomy, establishing sternal IO access using the FAST1, and infusing 1 unit of whole blood. Physical performance was evaluated pre and post blood donation and lactate levels were recorded. The authors concluded that physical and combat performances are preserved within limits post whole blood donation and that soldiers are able to learn the phlebotomy and sternal reinfusion with only a short lecture on the procedure.
- YEAR: 2012**
- Cairney K, Matthew I. Options for intravascular access during resuscitation of adults. *Emerg Nurse* 2012;20(1):24-8** 536
This article discusses how IO access can be used to improve advanced life support therapy. The EZ-IO is described in this article; published comparative studies between other IO devices and peripheral IV access are cited, leading the author to conclude the EZ-IO is user friendly, and establishes intravascular access more quickly and more often on first attempt than other devices.
- Carness JM, Russell JL, Lima RM, Navarro LHC, Kramer GC. Fluid resuscitation using the intraosseous route: Infusion with lactated ringers and hetastarch. *Mil Med* 2012;177(2):222-8.** 529
This pre-clinical study evaluated IO flow rates obtainable with infusion of lactated Ringer's and hetastarch 6% through the proximal tibia and sternum IO insertion sites, using a swine model. The EZ-IO 25mm was used to facilitate tibial IO access; sternal access was established using a Jamshidi needle. Results showed that hetastarch flow rates were lower than lactated Ringer's flow rates at both insertion sites; sternal infusion of hetastarch is likely to provide greater estimated intravascular volume expansion than lactated Ringer's, despite the lower infusion rates; resuscitation using the IO rate is likely to benefit from pressure bag or high-pressure pump delivery. This study was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.

Intraosseous Vascular Access Bibliography

Infusion Devices

- Isayama K, Nakatani T, Tsuda M, Hirakawa A. Current status of establishing a venous line in CPA patients by emergency life-saving technicians in the prehospital setting in Japan and a proposal for intraosseous infusion. *Int J Emerg Med* 2012;5(1):2. doi:10.1186/1865-1380-5-2** 527
- This article discusses a retrospective review of Japanese prehospital system for intravenous infusion success rates in cardiopulmonary arrest (CPA) patients and a prospective simulation study. A nationwide database was reviewed for CPA records from 1 January 2005 to 31 December 2008 yielding 431,968 cases. Results showed the IV infusion success rate in adults increased annually, however the rate in pediatrics did not; and while the administration of adrenaline increased the 1-month survival rate did not. In the simulation study, 100 EMS technicians used the Bone Injection Gun (BIG) in simulator adult, pediatric and infant legs. There was no difference in the time to establish IO access between the simulation models. The authors concluded that IO access should be considered when IV access is difficult or impossible.
- Kalechstein S, Permual A, Cameron BM, et al. Evaluation of a new pediatric intraosseous needle insertion device for low-resource setting. *J Pediatr Surg* 2012;47(5):974-9. doi: 10.1016/j.pedsurg.2012.01.055** 546
- This article describes a study evaluating a new manual needle insertion device, the Near Needle Holder, which uses hollow-bore needles to establish IO access. In a comparative study, healthcare professionals attempted IO insertion in the proximal tibia insertion site of a mannequin using the NNH and a standard Cook manual IO needle. Participants then completed a questionnaire regarding their experience. The most reported complication was the plunging of the needle into the medullary space from the decrease in resistance once the cortex was penetrated. Other IO devices on the market are mentioned, including the EZ-IO.
- Lammers R, Byrwa M, Fales W. Root causes of errors in a simulated prehospital pediatric emergency. *Acad Emerg Med* 2012;19(1):37-47. doi: 10.1111/j.1553-2712.2011.01252.x** 590
- This simulation study evaluated the ability of 2 person EMS crews to manage a pediatric emergency and sought to determine root causes of errors made. Participating EMS crews used the BIG for IO access. The authors concluded that cognitive, procedural, affective, teamwork errors and error-producing conditions were identified as root causes for the errors made in the simulation. Authors also concluded that simulation followed by facilitated debriefing is an effective tool for identifying underlying causes of active and latent errors.
- Leidel BA, Kirchhoff C, Bogner V, Braunstein V, Biberthaler P, Kanz KG. Comparison of intraosseous versus central venous vascular access in adults under resuscitation in the emergency department with inaccessible peripheral veins. *Resuscitation* 2012;83(1):40-5. doi:10.1016/j.resuscitation.2011.08.017** 439
- This clinical trial evaluated the time required to establish IO access versus central venous catheter (CVC) in adults undergoing resuscitation, who had failed peripheral IV access (PIV) attempts. IO and CVC placement were performed simultaneously; two IO devices, the EZ-IO and the BIG, were used to facilitate IO access in randomized format. Forty (40) patients were enrolled, first attempt success for IO was 85% vs 60% for CVC placement; median procedure time was 2 minutes for IO vs 8 minutes for CVC. The author concluded that though IO access is safe, reliable and rapid during resuscitation, it cannot replace CVC but should be considered as a valuable bridging technique.
- Miller LJ, Montez DF, Puga TA, Philbeck TE. Intraosseous vascular access in the 21st century: improvements further reduce complication rates. *Ann Emerg Med* 2012;60(4S):S112** 597
- This abstract presented at the 2012 ACEP Research Forum discusses a literature review of intraosseous access publications since 1985 providing an updated safety profile for IO access. The search resulted in 192 articles describing IO access with 6 cases of osteomyelitis and 6 cases of compartment syndrome secondary to extravasation reported. Of the 192 articles identified, 140 described the EZ-IO. This study was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.
- Morehouse D. Fast combat and fast responder. *J of Spec Oper Med* 2012;12(4):126-8** 661
- This article highlights the FAST Combat™ IO device with improvements and as a replacement for the FAST1®. Anticipated FDA clearance: Spring 2013.
- Olaussen A, Williams B. Intraosseous access in the prehospital setting: literature review. *Prehosp Disaster Med* 2012;27(5):468-72. doi:10.1017/S1049023X12001124. http://journals.cambridge.org/abstract_S1049023X12001124** 582
- A literature review of articles describing intraosseous vascular access devices used in the pre-hospital setting. Twenty articles met the inclusion criteria and described the manual devices, BIG, Fast-1 and the EZ-IO. The authors concluded that the literature suggests that semiautomatic IO devices may be more effective than manual devices.
- Oriot D, Darrieux E, Boureau-Voultoury A, Ragot S, Scepti M. Validation of a performance assessment scale for simulated intraosseous access. *Simul Healthc* 2012;7(3):171-5. doi:10.1097/SIH.0b013e31824a5c20** 581
- This article describes the validation testing of a newly developed performance assessment scale for evaluating the intraosseous manual insertion process in the proximal tibia during simulated procedures. The authors concluded that the scale was a reliable tool to assess the overall IO insertion procedure and that with modifications this scale may be used with other IO devices and in the clinical setting.

Intraosseous Vascular Access Bibliography

Infusion Devices

- Page D. Intraosseous intrigue: Studies examine success rates on pediatric, adult & obese patients. JEMS January 2012;32-3** 515
In this article, the author discussed five recent studies on intraosseous access providing his opinion about the quality of each study.
- Paxton JH. Intraosseous vascular access: A review. Trauma 2012;14(3):195-232. DOI:10.1177/1460408611430175** 690
An overview of IO vascular access including a review of currently available literature. The author discusses various IO devices available and their performance metrics, IO access sites, flow rates, advantages and disadvantages of IO access compared to conventional access methods, complications and recommendations on use of the approach. The author concludes that while IO access may not be appropriate for all patients, it deserves a place in the modern provider's armamentarium.
- Plancade D, Nadaud J, Lapiere M, et al. Feasibility of a thoraco-abdominal CT with injection of iodinated contrast agent on sternal intraosseous catheter in an emergency department. Annales Francaises d'Anesthesie et de Reanimation 2012;http://dx.doi.org/10.1016/j.annfar.2012.10.009** 580
This letter to the editor describes a case in which sternal IO access was established using a Jamshidi needle to administer iodinated contrast for a thoraco abdominal CT on a 61-year old male who presented to the ED with respiratory distress. Picture quality was deemed excellent by the radiologists. The authors conclude that the sternal IO route can be used with excellent picture quality but it should be used only in exceptional cases due to the potential risks of a high-power injection through the bone. EZ-IO is mentioned as an alternative IO device available.
- Rogers J, Fox M. The safety of intraosseous vascular access. Emergency Medicine Patient Safety Foundation Forum. Fall 2012:18-21** 606
An article discussing the technique and safety profile of intraosseous access using the EZ-IO device. Needle selection, contraindications, insertion sites and techniques, catheter stabilization and removal are all discussed along with the safety profile of the EZ-IO against other IO devices and central venous catheters. The authors concluded that IO access should be considered whenever immediate vascular access is required. This article was co-written by an employee of Vidacare Corporation, acquired by Teleflex Incorporated.
- Rose EC. The evidence-based use of intraosseous lines in pediatric patients. Pediatr Emerg Med Pract 2012;9(6):1-12. www.edmedicine.net** 585
This article presents a general overview of intraosseous (IO) vascular access in the pediatric population through an IO literature review. Available IO devices were discussed.
- Seymour CW, Cooke CR, Hebert PL, Rea TD. Intravenous access during out-of-hospital emergency care of noninjured patients: a population-based outcome study. Ann Emerg Med 2012;59(4):296-303. doi:10.1016/j.annemergmed.2011.07.021** 465
The objective of this study was to retrospectively evaluate the relationship between out-of-hospital IV access and mortality among non-injured, non-cardiac arrest patients transported by 4 advanced life support agencies between January 1, 2002 and December 31, 2006. A total of 56,332 patients were included in the study. The author concludes that efforts to establish IV access in the out-of-hospital setting is was associated with reduction in hospital mortality among non-injured, non-cardiac arrest patients.
- Vassallo J, Horne ST, Smith JE. Intraosseous access on military operations: a 4 month review. Poster presentation at International Conference on Emergency Medicine, Dublin, Ireland. June 27-30, 2012** 593
This poster presented at the 2012 International Conference of Emergency Medicine described a 4 month review of intraosseous access in UK military operations in Afghanistan. During the timeframe the EZ-IO was used to establish IO access in the proximal humerus and tibia sites; the FAST1 was used to establish sternal IO access. Of the 87 EZ-IO applications there were 12 functional issues and the placement success rate for both sites combined was 86.3%. In 24 FAST1 applications there were 4 functional issues and the placement success rate was 83.4%.
- Voigt J, Waltzman M, Lottenberg L. Intraosseous vascular access for in-hospital emergency use: A systematic clinical review of the literature and analysis. Pediatr Emerg Care 2012;28(2):185-99** 562
In this article the authors review the evidence supporting the use of IO access; determine the utilization IO access as described in the literature; and assess the level of specialty society support. Various IO devices are mentioned including the EZ-IO
- Weiser G, Hoffmann Y, Galbraith R, Shavit I. Current advances in intraosseous infusion - a systematic review. Resuscitation 2012;83(1):20-6. doi:10.1016/j.resuscitation.2011.07.020** 454
A literary search of electronic databases was performed to identify publications comparing IO access devices. Publications qualifying for study evaluation must have compared two or more semi-automatic IO devices or at least one semi-automatic device and a manual device. Reviews, editorials, surveys, and case reports were excluded. Ten comparative studies met the qualifications for inclusion and are briefly discussed. The studies evaluated suggested superiority of the battery powered IO driver over manual needles and other semi-automatic IO infusion devices.

Intraosseous Vascular Access Bibliography

Infusion Devices

YEAR: 2011

- Aliman AC, Piccioni Mde A, Piccioni JL, Oliva JL, Auler Junior JO. Intraosseous anesthesia in hemodynamic studies in children with cardiopathy. Rev Bras Anesthesiol 2011;61(1):41-9** 654
A comparative study evaluating the effectiveness of IO access in relation to IV access for infusion of anesthetics (ketamine, midazolam, and fentanyl) and fluids during hemodynamic studies in 21 infants with congenital heart disease. IO access was established in the proximal tibia (n=11). Results showed, time to access was significantly shorter with IO access (3.6 vs 9.6 minutes); anesthetic onset was shorter with IV access (56.3 vs 71.3 seconds); and no significant difference between groups for hydration volume and anesthesia recovery time. The authors concluded that due to its easy manipulation and efficiency, hydration and anesthesia by IO access was satisfactory without necessity of other infusion access.
Brazil
- Auerhammer J. [Lebensbedrohliche arterielle blutung aus der a. carotis communis: Fallstricke bei der intraossaren punktion]. Notfall Rettungsmedizin 2011;14(2):147-150;doi 10.1007/s10049-010-1380-1. German** 490
This article in German presents a case of a 67-year-old female patient with an arterial bleed and venous access difficulties in whom IO access was attempted unsuccessfully two times using two different IO systems. The author concluded that IO success is dependent upon IO anatomy and physiology knowledge as well as knowledge of the device being used.
- Borron SW, Arias JC, Bauer CR, et al. Intraosseous line placement for antidote injection by first responders and receivers wearing personal protective equipment. Am J Emerg Med 2011;29(4):373-81.doi:10.1016/j.ajem.2009.10.009** 424
This article describes a preclinical trial with a caprine model that assessed the ability of protected, experienced first responders and limited-experience first receivers to place IO lines for antidote administration using the EZ-IO device. First responders placed IO lines successfully in 100% of cases, and first receivers placed IO lines successfully in 91% of the cases. Investigators concluded that IO lines may facilitate earlier administration of antidotes to hazardous material victims.
- Byars DV, Tsuchitani SN, Erwin E, Anglemeyer B, Eastman J. Evaluation of success rate and access time for an adult sternal intraosseous device deployed in the prehospital setting. Prehosp Disaster Med 2011;26(2):127-9** 655
A prospective study evaluating use of the FAST-1 sternal IO device in critically ill or injured patients in cardiac arrest in the pre-hospital setting. In one year, 41 insertion attempts were performed using the FAST-1. Thirty (73%) of attempts were successful and the mean time to placement was 67 seconds from time of opening the packaging to ability to aspirate/infuse without infiltration. Of the 11 insertion failures, 7 were due to failure of the device to deploy; 2 infiltrations after insertion; 1 inability to aspirate; and 1 failure of the catheter to deploy though the needles were inserted.
- Cullen PM. Intraosseous cannulation in children. Paediatric Critical Care 2011;13(1):28-30** 523
This article presented a general overview of IO use in pediatrics. The history, techniques, anatomy and physiology, complications and a short discussion of most devices on the market, including the EZ-IO, were discussed.
UK
- Day MW. Intraosseous devices for intravascular access in adult trauma patients. Crit Care Nurs 2011;31:76-90. doi: 10.4037/ccn2011615** 540
An overview of available intraosseous vascular access devices, including the EZ-IO.
- Emergency Nurses Association (ENA). Emergency nursing resource: Difficult intravenous access. Des Plaines, IL: Emergency Nurses Association;December 2011** 603
The Emergency Nurse's Association (ENA) published a series of Emergency Nursing Resources with emphasis on clinical or practice based issues. This issue focused on difficult IV access and provides a summary of the literature review, with graded recommendations and decision options for practice for IO access, ultrasound guidance, subcutaneous rehydration therapy and several other alternatives. IO access is graded as having a high level of evidence supporting use of IO access when difficult IV access is known or suspected for high success rates and rapid time to insertion.
- Hafeez W, Ronca LT, Maldonado TE. Pediatric advanced life support update for the emergency physician: Review of 2010 guideline changes. Clin Pediatr Emerg Med 2011;12(4):255-65** 525
General overview of PALS updates. Various IO devices were specifically mentioned in the vascular access section, including the EZ-IO.
- Harcke T, Crawley G, Ritter B, Mazuchowski E. Feedback to the field: an assessment of sternal intraosseous (IO) infusion. J Spec Oper Med 2011;11(1):23-6** 544
This article summarizes the case-based observations made by the Armed Forces Medical Examiner System on soldiers killed in action/died of wounds who had evidence of sternal intraosseous access. The Pyng Fast-1 is noted in the article as the sternal IO device most widely distributed by the department of defense (DOD); the EZ-IO is listed as another device that may be seen in emergency care facilities within the DOD. Of 98 cases, 78 (80%) showed proper placement; 20% were unsuccessful. It should be noted that the article incorrectly states that the EZ-IO using the powered driver is indicated for sternal placement.

Intraosseous Vascular Access Bibliography

Infusion Devices

- Kehrl T, Broderick E. Relationship of body mass index and increased difficulty with intraosseous needle placement: assessment of tissue depth using ultrasound. *Ann Emerg Med* 2011;54(4s):S263** 531
- In this abstract the authors attempted to establish a relationship in obese patients (BMI >30) between BMI, ability to palpate the tibial tubercle, and tissue depth at the IO insertion sites. Results showed that in obese patients, IO placement with a 25mm catheter is feasible at the proximal and distal tibial sites if the tibial tubercle is palpable and that insertion into the proximal humerus in this population is not recommended.
- Abstract only*
- Larabee TM, Campbell JA, Severyn FA, Little CM. Intraosseous infusion of ice cold saline is less efficacious than intravenous infusion for induction of mild therapeutic hypothermia in a swine model of cardiac arrest. *Resuscitation* 2011;82(5):603-6.doi:10.1016/j.resuscitation.2011.01.007** 476
- This study compared the effectiveness of infusing ice cold saline via IO and IV to induce mild therapeutic hypothermia (temperature drop to 34°C) within a 30 minute timeframe, in a swine model of cardiac arrest. Five swine were evaluated in each the IV and IO groups. Goal temperature was reached in 4/5 animals in the IV group and 0/5 animals in the IO group in the allotted time frame; IV was superior in terms of rate of infusion, rate of temperature change, and time to achieve target temperature.
- Myers L, Russi CS, Arteaga GM. Semiautomatic intraosseous devices in pediatric prehospital care. *Prehosp Emerg Care* 2011;15(4):473-6.doi:10.3109/10903127.2011.598611** 431
- This article describes the changes in practice experienced when a 12-site statewide ambulance service changed from the manual to the semi-automatic IO device (EZ-IO). There was no statistically significant change in first-attempt success or the number of successes per attempt. However, the use of IO access more than tripled when changing from the manual to the semi-automatic device and PIV access attempts before IO access went from occurring in 35.5% of patients to 1.7% of patients.
- Myers LA, Russi CS, Arteaga GM. The introduction of a semiautomated (EZ-IO) device in pediatric prehospital care replacing a manual intraosseous (IO) device improves the success rate for attempts at vascular access. *Prehosp Emerg Care* 2011;15(1):110** 508
- This abstract describes a 93 patient study presented at the 2011 National Association of EMS Physicians Annual Conference that examined the characteristics of pediatric patients receiving IO infusions and the primary EMS clinical impressions, success rates, and subsequent treatments delivered via manual IO vs. the powered EZ-IO device. Investigators concluded that for the pediatric cohort use of the powered device offered a marginally higher first-attempt success rate compared to the manual device; and that the rate of IO access utilization by EMS more than tripled after adoption of the powered device.
- Nagler J, Krauss B. Intraosseous catheter placement in children. *NEJM* 2011;364(8):e14-8** 491
- This article provides an overview of intraosseous vascular access for pediatrics and discusses general indications, contraindications, complications, and intraosseous devices.
- Navarro Suay R, Bartolome Cela E, Hernandez Abadía de Barbará A, Tamburri Barriain R, Rodriguez Moro C, Olivera Garcia J. [Intraosseous access for fluid therapy in combat situations: use by Spanish military medical staff in Afghanistan]. *Rev Esp Anestesiol Reanim* 2011;58(2):85-90** 645
- This article in Spanish describes the Spanish military medical staff's experience with the use of intraosseous lines for fluid therapy in a combat zone from March 2007 to June 2008. Twenty-five patients had an IO placed with the Bone Injection Gun (BIG). Placement success rates were 76% for the 19 pre-hospital placements and 100% for the 6 in-hospital placements. There were no complications during insertion. Conclusion was intraosseous access can provide an alternative to venous access for treating trauma patients in combat zones.
- Olaussen A. Best evidence topic reports: which intraosseous device is best in the prehospital setting? *Emerg Med J* 2011;28(8):717-8. doi: 10.1136/emj.2010.108381** 724
- This article describes a literature review study with the objective of establishing which intraosseous device is best for prehospital use. This short review searched Medline 1950-2010, CINAHL 1982-2010 and EMBASE 1980-2010 and identified two studies meeting their evidence search criteria, one study compared the BIG vs. manual; the second compared EZ-IO vs. FAST-1. The clinical bottom line asserted by the author was traditional manual IO devices have faster, better success rates in the pre-hospital setting; but that more randomized trials are needed to determine the best device.
- Australia*
- Rajani AK, Chitkara R, Oehlert J, Halamek LP. Comparison of umbilical venous and intraosseous access during simulated neonatal resuscitation. *Pediatrics* 2011;128(4):e954-8.doi:10.1542/peds.2011-0657** 478
- This study compared time to placement, errors in placement and perceived ease of use for healthcare providers placing umbilical venous catheters (UVC) and intraosseous needles in a simulated delivery room, responding to persistent bradycardia. Results showed mean IO placement time was 46 seconds faster than UVC placement; there was no significant difference in the number of errors and the perceived ease of use between UVC and IO.

Intraosseous Vascular Access Bibliography

Infusion Devices

- Reades R, Studnek JR, Vandeventer S, Garrett J. Intraosseous versus intravenous vascular access during out-of-hospital cardiac arrest: a randomized controlled trial. *Ann Emerg Med* 2011;58(6):509-16. doi:10.1016/j.annemergmed.2011.07.020** 470
- The objective of this study was to determine the frequency of first-attempt success of humeral IO, tibial IO, and peripheral IV (PIV) insertions during out-of-hospital cardiac arrest. Patients were randomized to receive one of the 3 methods. There were 182 patients enrolled, 64 were assigned to tibial IO, 51 to humeral IO and 67 to PIV. Of all patients 130 (71%) were successful on first attempt with 17 (9%) needles dislodged. First attempt success within the treatment groups was 91% for tibial IO, 51% for humeral IO, and 43% for PIV.
- Ruiz-Hornillos PJ, Marinez-Camara F, Elizondo M, et al. Systemic fibrinolysis through intraosseous vascular access in ST-segment elevation myocardial infarction. *Ann Emerg Med* 2011;57(6):572-4. doi:10.1016/j.annemergmed.2010.09.011** 496
- This article describes a case in which systemic fibrinolysis was administered through the intraosseous route in a patient with ST-segment elevation myocardial infarction. Fibrinolytics and antiarrhythmic drugs were administered through the IO line, resulting in resolution of coronary ischemia and electrical instability, without complications. Authors concluded that intraosseous cannulation represents a novel route for administration of systemic fibrinolysis in cases of difficult peripheral venous access in the out-of-hospital setting.
- Schexnayder SM, Storm EA, Stroud MD, et al. Chapter 15-Pediatric vascular access and centeses. *Pediatric Critical Care* 2011;4th ed:139-63. ISBN: 978-0-323-07307-3** 680
- This document addresses pediatric vascular access and includes an overview of intraosseous vascular access. Indications, contraindications, supplies and equipment, technique, complications and maintenance are discussed.
- Smart RJ, Marsh S, Rosenberg M. Intraosseous access in oral and maxillofacial surgical practice. *J Oral Maxillofac Surg* 2011;69(11):2708-13. doi:10.1016/j.joms.2011.02.101** 441
- This article describes IO access in terms of efficacy, indications/contraindications for use, and the IO procedure and comparison of devices to make a case for IO use in oral and maxillofacial surgical practice. In discussing IO devices citing published data, the author identified the EZ-IO device as the most accurate, efficacious, and precise system when trying to achieve IO access.
- Waltzman ML. Amputation and intraosseous access in infants-Intraosseous access: It's the operator and not the device. *BMJ* 2011; <http://www.bmj.com/rapid-response/2011/11/03/intraosseous-access-its-operator-and-not-device>** 563
- This article is a response to the Taylor and Clarke 2011 report of two amputations required following development of compartment syndrome after IO infusion. The author notes that complications are possible with all methods of establishing IO access including manual, spring loaded and power driven needles and that it is not accurate to directly relate the adverse events to the power driven device only.
- YEAR: 2010**
- Alexandrou E, Spencer T, Frost SA, Parr M, Davidson PM, Hillman KM. Establishing a nurse-led central venous catheter insertion service. *JAVA* 2010;15(1):21-7. doi:10.2309/java.15-1-5** 436
- This paper describes the process of establishing a nurse-led central venous catheter insertion service in a university affiliated hospital using a process evaluation method. Introduction discusses CVC adverse events rate and mortality.
- Bukoski A, Winter M, Bandt C, Wilson M, Shih A. Comparison of three intraosseous access techniques in cats. *J Vet Emerg Crit Care* 2010;20(4):393-7.doi:10.1111/j.1476-4431.2010.00558.x** 437
- This veterinary study evaluated 3 IO access devices, impact driven, automatic rotary, and manual, to compare the placement feasibility and amount of bone trauma induced when used in adult feline cadavers. Seventy-two IO insertion locations were used, the 3 devices were equally randomized to the insertion site. The rotary device was found to have shorter time to insertion and better ease of insertion. No statistically significant differences between number of bone fragments, defect diameter, or success rate were found between devices.
- Craiu M, Iordachescu M, Stan I, et al. Alternative intraosseous infusion technique via spinal needle, valuable tool for pediatric resuscitation. *Resuscitation* 2010;81S:S76. doi:10.1016/j.resuscitation.2010.09.312** 609
- This abstract describes a retrospective case-series analysis of pediatric IO recipients from 1998-2009. Seventy-two (72) patients were included in the study; IO access was established in the proximal tibia (n=61), medial tibia (n=8), distal tibia (n=1), sternum (n=1), and iliac crest (n=1). IO access devices used in the proximal tibia included the Cook Critical Care needle (n=4), the Jamshidi needle (n=2), the BIG (n=1), and an 18 gauge spinal needle (n=54). The authors concluded that a spinal needle can be used to provide IO vascular access in children.
- Dasgupta S, Playfor S. Intraosseous fluid resuscitation in meningococcal disease and lower limb injury. *Pediatr Rep* 2010;2(1):e5:18-9** 426
- Authors reviewed two complications (extravasation and compartment syndrome) associated with IO access in children with meningococcal disease. Authors concluded that IO systems need formal evaluation to assess safety and complication profiles.

Intraosseous Vascular Access Bibliography

Infusion Devices

- Detaille T, Pirotte T, Veyckemans F.. Vascular access in the neonate** *Best Pract Res CL Anesth* 2010;24(3):403-18. doi:10.1016/j.bpa.2010.02.017 913
- This article discusses the challenges of gaining vascular access in small infants and neonates and how new equipment such as ultrasound machines with pediatric probes can provide better guidance and improve safety and efficacy. The article also addresses the importance of education and training in ultrasound use. This article was based on literary research as well as authors' experience.
- Eich C, Weiss M, Neuhaus D, et al. Intraosseous infusion in paediatric emergency medical care and anaesthesia.** *Anasth Intensivmed* 2010;51:75-81. German 972
- This article, written in German, gives an overview of intraosseous access in pediatric patients especially with regard to particularly difficult vascular access in the areas of pediatric anesthesia and perioperative care. The article also gives an overview of various devices available to gain IO access, including the Cook needle and the EZ-IO device.
- Fenwick R. Intraosseous approach to vascular access in adult resuscitation.** *Emerg Nurse* 2010;18(4):22-5 456
- This article reviews intraosseous vascular access and its increased use in adult resuscitation. The IO route is described, including indications, contraindications, insertion sites and devices.
- Hartholt KA, van Lieshout EM, Theis WC, Patka P, Schipper IB. Intraosseous devices: a randomized controlled trial comparing three intraosseous devices.** *Prehosp Emerg Care* 2010;14(1):6-13. doi: 10.3109/10903120903349861 443
- This article describes a randomized, single-blind, controlled trial to determine which IO needle can be used best for gaining IO access in patients requiring acute administration of fluids or medication in a prehospital setting. The study was performed at a level 1 trauma center in the Netherlands with a Helicopter Emergency Medical Service (HEMS). Adult and pediatric patients meeting inclusion criteria were randomized between Jamshidi 15G, B.I.G. 15G/18G and F.A.S.T.1. Insertion time, success, aspiration of bone marrow, side effects, medication given, trauma mechanism, and user satisfaction were recorded. In the adult group Jamshidi was placed fastest, significantly faster than the F.A.S.T.1. (p=0.002). Time to insert the B.I.G. 15G did not differ statistically from other devices. In the pediatric group insertion time of the Jamshidi did not differ statistically from the B.I.G. 18G. On average, the devices (adult and pediatric) did not differ significantly with respect to success rate, complication rates, and user satisfaction. EZ-IO was not included in this study as it was not approved for use in the Netherlands at the time the trial began. Authors recommend comparison with EZ-IO in future research.
- Hulse EJ, Thomas GOR. Vascular access on the 21st century military battlefield.** *J R Army Med Corps* 2010;156(4 Suppl 1):s385-90 629
- An article evaluating various methods of obtaining vascular access in the management of 21st century battlefield trauma including, peripheral IV access, intraosseous access, venous cut-down, and central venous access. The authors conclude that IO access should be the first line vascular access in casualties with severe trauma to avoid delay initiating resuscitation in pre-hospital or hospital setting.
- Lairet JR, Bebarta V, Lairet K, et al. Intraosseous pressure infusion comparison using a rapid infusion device and a pressure bag in a swine model.** *Ann Emerg Med* 2010;56(3):S26 502
- In an abstract presented at the 2010 ACEP Research Forum, investigators describe a swine study designed to compare IO infusion rates using the Belmont FMS 2000 rapid infusion device and a pressure bag through the proximal tibia and proximal humerus. Investigators concluded that infusion rates were highest using the pressure bag via the proximal humerus.
- Lamhaut L, Dagron C, Apriotesei R, et al. Comparison of intravenous and intraosseous access by pre-hospital medical emergency personnel with and without CBRN protective equipment.** *Resuscitation* 2010;81(1):65-8. Epub 2009 Oct 24 437
- Training study with nurses and physicians comparing EZ-IO to IV lines under Hazmat conditions. IO procedure significantly shorter.
- Larson SD, Hebra A, Raju R, Lee S. Vascular access, surgical treatment.** <http://emedicine.medscape.com/article/1018395>. Updated January 25, 2010 446
- This article describes the vascular access options available to physicians caring for children, including details about each method, placement technique, indication, and complications.
- Leidel BA, Kirchoff C, Braunstein V, Bogner V, Biberthaler P, Kanz KG. Comparison of two intraosseous access devices in adult patients under resuscitation in the emergency department: A prospective, randomized study.** *Resuscitation* 2010;81(8):994-9. doi:10.1016/j.resuscitation.2010.03.038 430
- Authors describe a randomized, controlled trial comparing two different IO access devices in adults in the hospital setting. Twenty patients received the BIG and 20 received the EZ-IO. Success rate on first attempt was 80% for the BIG and 90% for the EZ-IO. Mean procedure time was 2.2 minutes for the BIG vs. 1.8 minutes for the EZ-IO. Differences in success rate and procedure time were not statistically significant, and there were no significant complications for any patients. Investigators concluded that IO access is a reliable and safe method for rapid vascular access for in-hospital adult patients under resuscitation.

Intraosseous Vascular Access Bibliography

Infusion Devices

LeMaster CH, Schuur JD, Pandya D, et al. Infection and natural history of emergency department-placed central venous catheters. *Ann Emerg Med* 2010;56(5):492-7. doi:10.1016/j.annemergmed.2010.05.033 457

A retrospective chart review in an urban emergency department (ED) was performed to identify central venous catheters placed in the ED and determine the bloodstream infection and duration of catheterization within a one year period. A total of 656 patients (3,622 catheter-days) with CVCs placed in the ED were identified, with 7 bloodstream infections. The mean duration of catheterization was 5.5 days. Within the infected CVC group, the mean duration of catheterization was 8.6 days

Luck RP, Haines C, Mull CC. Intraosseous access. *J Emerg Med* 2010;39(4):468-75. doi:10.1016/j.jemermed.2009.04.054 492

This article provides an overview of intraosseous vascular access and discusses general indications, contraindications, complications, and intraosseous devices.

Mahajan R, Nazir R, Mehta S. An overview of intraosseous access. *Anesth Analg* 2010;111(3):825-6. http://www.anesthesia-analgesia.org/content/111/3/825.2.full. doi:10.1213/ANE.0b03e3181e9e67e 467

In this letter to the editor, the author discusses the use of IO access concluding that a change in practice should be made in which immediate IO access should be established for initial emergency resuscitation and serve as a bridging technique when peripheral IV access has been unsuccessful 3 times over a maximum duration of 2 minutes.

Mitchell C, Tauferner D, Huebner K. Placement of the EZ-IO sternal and EZ-IO manual needle sets with and without chemical protective equipment: a cadaveric study. *Prehosp Emerg Care* 2010;14:14-5 448

In this abstract of a study presented at the 2010 National Association of EMS Physicians Meeting, researchers describe a study in which sternal and tibial IO devices were evaluated with and without chemical protective equipment. Researchers concluded that the use of the protective equipment did not affect the success rate or time to placement for the two IO devices.

Neuhaus D, Weiss M, Engelhardt T, et al. Semi-elective intraosseous infusion after failed intravenous access in pediatric anesthesia. *Pediatr Anesth* 2010;20(2):168-71. doi: 10.1111/j.1460-9592.2009.03244.x 425

Authors report an observational study of 14 children in whom semi-elective IO infusion was performed under anesthesia after peripheral IV had failed. IO infusion was successful for all 14 patients, using the EZ-IO system for 8 patients and the Cook system for 6 patients.

Rahman O, Willis L. Vascular procedures in the critically ill obese patient. *Crit Care Clin* 2010;26(4):647-60. doi:10.1016/j.ccc.2010.08.003 451

This article discusses vascular access procedures in critically ill obese patients. Anatomic considerations, general procedural considerations such as location of the procedure and patient positioning, catheter insertion technique, ultrasound guided insertion, intraosseous insertion, and other various considerations are evaluated.

Sunde GA, Heradstveit BE, Vikenes BH, Heltne JK. Emergency intraosseous access in a helicopter emergency medical service: a retrospective study. *Scand J Trauma Resusc Emerg Med* 2010;18:52. doi: 10.1186/1757-7241-18-52. 495

This article describes a longitudinal study of intraosseous vascular access in pre-hospital emergency medicine handled by helicopter emergency medical services. Of the 78 IO insertion attempts made on 70 patients, overall success rates were 50% using manual needles, 55% using the Bone Injection Gun, and 96% using the EZ-IO. Investigators concluded that newer IO techniques may enable faster and more reliable vascular access; and that all emergency services should be familiar with IO techniques.

Vegunta RK. Chapter 8-Vascular access. *Ashcraft's Pediatric Surgery* 2010;5th ed:110-6 681

This document discusses various vascular access methods available for pediatric and neonate patients, including intraosseous access.

YEAR: 2009

Brenner T, Gries A, Helm M, Bernhard M. Letter to the editor: Intraosseous infusion systems in the prehospital setting. *Resuscitation* 2009; 80(5):607. doi:10.1016/j.resuscitation.2009.02.009 423

This letter to the editor discussed the experience of one ground emergency rescue service in Germany and their trial implementation of the EZ-IO, as compared to the David et al evaluation of the BIG by emergency physicians in which the rate of failure was 55%. Over a one year evaluation of the EZ-IO in the field, it was used in 20 patients, of which 19 were successfully placed (95%). The success of the field evaluation and a human cadaver study resulted in the addition of the EZ-IO to the receiving University Hospital emergency department.

David JS, Dubien PY, Capel O, Peguet O, Gueugniaud PY. Intraosseous infusion using the bone injection gun in the prehospital setting. *Resuscitation* 2009;80(3):384-5 421

This letter to the editor discusses the experience of a mobile intensive care unit use of the Bone Injection Gun (B.I.G.) from January 1, 2005 - December 31, 2006. Following two failed attempts to establish peripheral IV access, IO access was attempted at the proximal tibia insertion site. IO access was attempted in 11 patients and was successful in 5. The authors attributed the failures to an inability to control the path of the catheter, resulting in too shallow of attempts or complete transfixion of the bone.

Intraosseous Vascular Access Bibliography

Infusion Devices

- Day MW. Boning up on intraosseous. Nurs Crit Care 2009;4(3):22-6** 608
This article provides a general overview of intraosseous access and its use in emergency situations. A description of available IO access devices is provided.
- Fenton P, Bali N, Sargeant I, Jeffrey SLA. A complication of the use of an intra-osseous needle. J R Army Med Corps 2010;155(2):110-1** 450
This case report describes a complication of use of a sternal IO device (FAST-1, Pyng Medical Corporation, Richmond, Canada) in a 21-year-old soldier who suffered multiple soft tissue fragmentation injuries, in which the needle tip broke in situ. The author concluded the complication resulted from the IO needle being placed when the patient was lying in a lateral position with the skin over the manubrium displaced from the midline.
- Frascone RJ, Jensen J, Wewerka SS, Salzman JG. Use of the pediatric EZ-IO needle by emergency medical services providers. Pediatr Emerg Care 2009;25:329-32** 424
Prospective study of 246 EMS providers at 14 EMS agencies. Reports successful IO placement in 95% of cases (18 of 19).
- Gerritse BM, Scheffer GJ, Draaisma JM. Prehospital intraosseous access with the bone injection gun by a helicopter-transported emergency medical team. J Trauma 2009;66(6):1739-41** 426
Dutch study of IO use with the Bone Injection Gun by helicopter EMS teams. Reports 71% success rate for pediatric patients and 73% success rate for adults.
Abstract only
- Leidel BA, Kirchoff C, Bogner V, Stegmaier J, Mutschler W, Kanz KG, Braunstein V. Is the intraosseous access route fast and efficacious compared to conventional central venous catheterization in adult patients under resuscitation in the emergency department? A prospective observational pilot study. Patient Saf Surg 2009;3:24** 436
This article describes a study conducted at an urban Level I trauma center in Munich, Germany. Ten consecutive patients for whom PIV was difficult or impossible were simultaneously given a central line and an EZ-IO. Procedure times were measured and defined as the time the device package was taken off the shelf until the first drug or solution was administered. First attempt success rate was 90% for EZ-IO and 60% for CVC. The mean procedure times were 2.3 minutes for EZ-IO and 9.9 minutes for CVC, a clinically and statistically significant difference. Investigators concluded, because CVC was slower and less efficacious, IO may improve the safety of patients requiring resuscitation in the ED.
- Leviton RM, Bortle CD, Snyder TA, Nitsch DA, Pisaturo JT, Butler KH. Use of a battery-operated needle driver for intraosseous access by novice users: skill acquisition with cadavers. Ann Emerg Med 2009;54(5):692-4** 438
This article describes a cadaver study to determine skill acquisition and performance by use of the EZ-IO system by novices. Overall success rate for the 99 operators was 97%, and mean insertion time was 6 seconds. All operators rated the device faster and easier than using a central line, and 99% expressed willingness to use the device for cardiac arrest patients.
- Mader TJ, Walterschild JK, Kellogg AR, Lodding CC. Feasibility of intraosseous infusion of iced saline to induce therapeutic hypothermia after cardiac resuscitation. Ann Emerg Med 2009;54(3):S140** 477
This abstract for a presentation at the 2009 ACEP Research Forum describes a swine study designed to determine the feasibility of inducing therapeutic hypothermia (TH) after resuscitation by giving an IO infusion of iced saline. Researchers concluded that rapid, large volume IO infusion of iced saline is as effective for lowering core body temperature after resuscitation as central access and peripheral IV. This research was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.
- Ngo AS-Y, Oh JJ, Chen Y, et al. Intraosseous vascular access in adults using the EZ-IO in an emergency department. Int J Emerg Med 2009. Available at <http://www.springerlink.com/content/d16841757807k635/fulltext.pdf>. Accessed 09/09/2009** 411
This article describes a prospective, observational study involving a convenience sample of 25 medical students, physicians and nursing staff recruited evaluate the EZIO powered drill device on a bone model. Twenty-three (92%) of the 25 study subjects required only one attempt at placing the EZ-IO. Investigators concluded that the device was easy to use with high success rates of insertion with inexperienced participants.
- Nutbeam T, Fergusson A. Intraosseous access in osteogenesis imperfecta (IO in OI). Resuscitation 2009;80(12):1442-3. doi:10.1016/j.resuscitation.2009.08.016** 408
This article describes a case in which IO access, using the EZ-IO, was attempted in a patient with osteogenesis imperfecta. In each of 3 attempts, the needle became loose immediately after IO insertion. The author acknowledged that during emergencies it is difficult to assess and consider every possible contraindication for every intervention; and that IO access using the EZ-IO is the author's choice for emergency vascular access when peripheral access is difficult or has failed.

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- Ong ME, Chan YH, Oh HH, Ngo AS. An observational prospective study comparing tibial and humeral intraosseous access using the EZ-IO. Am J Emerg Med 2009;27:8-15** 417
Comparison of tibial and humeral IO use in 24 adults. Both sites suitable for IO infusion. This study was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.
- Ong ME, Ngo AS, Wijaya R. An observational prospective study to determine the ease of vascular access in adults using a novel intraosseous access device. Ann Acad Med Singapore 2009;38:121-4** 420
This article describes a prospective, observational study involving a convenience sample of 25 medical students, physicians and nursing staff recruited evaluate the EZIO powered drill device on a bone model. Twenty-three (92%) of the 25 study subjects required only one attempt at placing the EZ-IO. Investigators concluded that the device was easy to use with high success rates of insertion with inexperienced participants. (Note: This study was also described in an earlier article published in American Journal of Emergency Medicine) This study was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.
- Schutt RC, Bowman B, Cevik C, et al. Intraosseous line placement does not improve outcome in adults with out-of-hospital cardiac arrest. Prehosp Emerg Care 2009;13(1):102** 417
This abstract describes a small study designed to determine if IO line placement improves outcome in adult patients with out-of-hospital cardiac arrest. This 165 patient study did not demonstrate improved survival.
- Shavit I, Hoffmann Y, Galbraith R, Waisman Y. Comparison of two mechanical intraosseous infusion devices: a pilot, randomized crossover trial. Resuscitation 2009;80(9):1029-33. doi: 10.1016/j.resuscitation.2009.05.026** 429
Authors of this article describe a pilot study designed to compare the success rate for insertion and ease-of-use of the Bone Injection Gun (BIG) spring-loaded device and the EZ-IO battery-powered device on a turkey bone model. Investigators concluded that the EZ-IO demonstrated higher success rates than the BIG (28/29 vs. 19/29, p=0.016), and the EZ-IO was the preferred device.
- Sunde GA, Thoresen A, Heltne J-K. [Intraossøs tilgang på kritisk syke pasienter - gammel teknikk får ny heder, eller kun for spesielt interessert]? NAForum 2009;22(1):33-7. German** 407
This article, in German, describes the technique of IO access, the introduction of two different IO devices (Cook and EZ-IO) and describes IO use in pediatric emergency care.
- Toursarkissian M, Schmidbauer W, Breckwoldt J, Spies C. [Präklinischer Einsatz von intraossären Zugängen beim Erwachsenen: Überblick und Anwendungsbeispiele] Preclinical use of intraosseous access (IO) in adults: ILterature review and case reports. Anasthesiol Intensivmed Notfallmed Schmerzther 2009;44(1):22-7. German** 416
This review article in German describes intraosseous vascular access, and includes descriptions of the Waismed Bone Injection Gun, Vidacare EZ-IO, Jamshidi and Cook Medical IO devices.
- Von Hoff DD, Kuhn JG, Burris HA, Miller LJ. La perfusion intraosseuse est-elle equivalente a la perfusion intraveineuse? Urgence Pratique 2009;36:36-40** 507
This French version of an article previously published in American Journal of Emergency Medicine describes a 25-patient clinical study that compared the pharmacokinetics of intraosseous using the Vidaport (a predecessor of the Vidacare EZ-IO) vs. intravenous administration of morphine sulfate in adults. Results showed no differences between IO and IV administration of morphine for nearly all pharmacokinetic parameters, including maximum plasma concentration, time to maximum plasma concentration, and area under plasma concentration-time curve. There was a significant difference in the volume of distribution in the central compartment, which investigators attributed to a minor deposition effect near the IO port or in the bone marrow. Investigators concluded that the results support the bioequivalence of IO and IV administration of morphine in adults.
- Weiss M, Henze G, Eich C, Neuhaus D. [Intraossäre infusion: Eine wichtige technik auch für die kinderanästhesie]. Der Anaesthetist 9 2009:863-75. Norwegian** 406
This article, in Norwegian, describes IO access and modern IO devices, including the Bone Injection Gun, FAST1, and EZ-IO.
- YEAR: 2008**
- Blumberg SM, Gorn M, Crain EF. Intraosseous infusion: A review of methods and novel devices. Pediatr Emerg Care 2008;24:50-6** 368
Review of IO infusion methods and devices. Devices described include Jamshidi, Cook, FAST 1, BIG, and EZ-IO.

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- Borron S, Arias J, Sanchez M Bauer C. Hemodynamics following intraosseous administration of hydroxocobalamin in the goat. *Ann Emerg Med* 2008;52(4):S96** 421
Animal (goat) study to determine if IO administration of hydroxocobalamin for antidotal treatment for exposure to cyanide and other poison agents would be faster and require less fine motor coordination and sensitivity; and would result in similar hemodynamic changes compared to IV administration. Using the EZ-IO device, researchers concluded that hemodynamic effects of hydroxocobalamin given by the IO route in non-poisoned goats are mild and similar in magnitude to those of saline control animals.
- Bosomworth NJ. The occasional intraosseous infusion. *Can J of Rural Med* 2008; 13: 80-3** 369
Overview of intraosseous vascular access in infants; includes indications, contraindications, complications, equipment (Sur-Fast and Jamshidi), and procedure. Also, small section on IO for adults; describes the FAST-1, Bone Injection Gun, and EZ-IO.
- Brenner T, Bernhard M, Helm M, et al. Comparison of two intraosseous infusion systems for adult emergency medical use. *Resuscitation* 2008;78(3):314-9** 380
Study comparing manual intraosseous insertion with EZ-IO using adult human cadavers as a model. No significant difference in insertion time between 39 manual insertions and 45 EZ-IO insertions. Found a difference in the success rate (manual, 79.5% vs. EZ-IO 97.8%, $p<0.01$). The EZ-IO had fewer complications (manual, 15.4% vs. EZ-IO 0.0%, $p<0.01$) and scored higher on user friendliness (school grading system: manual, 1.9 ± 0.7 vs. EZ-IO 1.2 ± 0.4 , $p<0.01$).
- de Caen AR, Reis A, Bhutta A. Vascular access and drug therapy in pediatric resuscitation. *Pediatr Clin N Am* 2008;55:909-27** 363
Describes common drugs used in pediatric resuscitation and evidence supporting their use. Also describes routes of administration including intravenous, intraosseous, and intratracheal. Describes IO systems including Bone Injection Gun, FAST-1, and EZ-IO.
- Fowler RL, Pierce A, Nazeer S, Philbeck TE, Miller LJ. 1,199 case series: Powered intraosseous insertion provides safe and effective vascular access for emergency patients. *Ann Emerg Med* 2008;52(4):S152** 418
Large retrospective study of patients for whom emergency vascular access was obtained using the Vidacare EZ-IO intraosseous system. Insertion success was 92% and within 10 seconds for 84% of the one-attempt successful cases. Complication rate was low (4.8%), none were serious, and extravasation was the most frequent (0.8%). The device was rated easy to use 72% of the time, and researchers concluded that the powered IO device is safe and effective for achieving vascular access in the resuscitation and stabilization of emergency patients. This study was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.
- Horton MA, Beamer C. Powered intraosseous insertion provides safe and effective vascular access for pediatric emergency patients. *Pediatr Emerg Care* 2008;24(6):347-50** 381
A retrospective clinical study was conducted to demonstrate the safety and effectiveness of the EZ-IO intraosseous access device for pediatric patients. For the 95 eligible patients in the study, successful insertion and infusion was achieved in 94% of the patients. Insertion time was 10 seconds or less in 77% of the one-attempt successful cases reporting time to insertion. There were 4 minor complications (4%), but none significant. The results of this study support the use of the EZ-IO for children in emergency situations. The complication rate suggests that the powered IO device is safe and effective for the resuscitation and stabilization of pediatric patients. This study was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.
- Moloff A. IO objectives. *JEMS* 2008; 33: 22** 407
This is a letter to the editor challenging a recent publication in JEMS describing clinical studies involving various IO devices.
- Paxton JH, Knuth TE, Klausner HA. Humeral head intraosseous insertion: The preferred emergency venous access. *Ann Emerg Med* 2008;52(4):S58** 419
Interim report for quasi-controlled prospective study of emergency department patients for whom emergency vascular access using the Vidacare EZ-IO intraosseous (IO) system ($n=6$) inserted in the proximal humerus was compared to access using central or peripheral intravenous (IV) lines ($n=60$). Researchers concluded that proximal humerus IO insertion is significantly faster than central or peripheral intravenous (IV) line insertion. Complications and pain profiles were similar for IO and IV techniques. This study was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.
- Pointer JE, Vultaggio D, Schnepf R, Kleveno A. Fast or easy? Comparing two adult IO infusion devices. *JEMS.com* 2008** 382
This article describes an observational study in which two intraosseous devices were compared: the Pyng Medical F.A.S.T.1 and the Vidacare EZ-IO. For the 117 patients on which the F.A.S.T.1 was used, there was an 84% success; compared to a 97% success rate for the EZ-IO ($n=71$).
Available at http://www.jems.com/news_and_articles/articles/Fast_or_Easy.html. Accessed 01/24/2008

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Schwartz D, Amir L, Dichter R, Figenberg Z. The use of a powered device for intraosseous drug and fluid administration in a national EMS: a 4-year experience. J Trauma 2008;64(3):650-4; discussion 654-5. doi: 10.1097/TA.0b013e31814db2a6 385

Prospective observational study of the use of the Bone Injection Gun in Israel from 2000 to 2004. Of the 189 patients enrolled in the study, successful insertion on first attempt was accomplished in 91% of cases.

YEAR: 2007

Beekley AC, Starnes BW, Sebesta JA. Lessons learned from modern military surgery. Surg Clin N Am 2007;87:157-84 650

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Buck ML, Wiggins BS, Sesler JM. Intraosseous drug administration in children and adults during cardiopulmonary resuscitation. Ann Pharmacother 2007;41:1679-86 374

This article reviews and assesses the literature on the use of IO drug administration during cardiopulmonary resuscitation. It addresses the risks and benefits of using IO in adults and children. The article describes the FDA-cleared devices available for use including the Pyng F.A.S.T.1, Waismed Bone Injection Gun and the Vidacare EZ-IO.

Cooper BR, Mahoney PF, Hodgetts TJ, Mellor A. Intra-osseous access (EZ-IO®) for resuscitation: UK military combat experience. J R Army Med Corps 2007;153(4):314-6 379

Describes the experience of the UK Defence Medical Service using the EZ-IO for emergency vascular access in Afghanistan. They used the device for 26 patients, including 10 children. Of the 26 EZ-IO placements, 23 were made in the emergency department. There was a 97% insertion success rate with no infection. Significant infusion pain was felt by three patients.

de Caen A. Venous access in the critically ill child. Pediatr Emerg Care 2007;23:422-4 372

This review article states the availability of intraosseous (IO) needles for pediatric patients, outlines the limitations of traditional venous access, and discusses the various IO devices currently available, including the Vidacare EZ-IO®.

DeBoer S, Andrews D. Infant venous access: 'Counting fingers' and 'playing baseball'. Australasian Emerg Nurs J 2007; 10: 46-51 356

This article summarized the challenges and methods of providing vascular access for infants. It describes IO techniques and devices, including the Jamshidi, Cook, EZ-IO® and Bone Injection Gun (BIG) devices.

Fowler R, Gallagher JV, Isaacs SM, Ossman E, Pepe P, Wayne W. The role of intraosseous vascular access in the out-of-hospital environment (resource document to NAEMSP position statement). Prehosp Emerg Care 2007;11:63-6 355

Article calls for EMS medical directors to consider and use the intraosseous route for adult patients requiring immediate vascular access. Provides evidence in support of position statement by the National Association of EMS Physicians on IO use.

http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=17169880

Fowler RL. Prehospital intraosseous access: elemental to the field? JEMS 2007; doi:http://jems.com/print/9198 543

Discussion of the role intraosseous vascular access can play in the prehospital setting where vascular access is often difficult or impossible to establish. The EZ-IO is named as a new IO device along with descriptions of Jamshidi, Pyng Fast 1, and BIG needles.

Frascone RJ, Jensen JP, Kaye K, Salzman JG. Consecutive field trials using two different intraosseous devices. Prehosp Emerg Care 2007;11(2):164-71 357

This article describes authors' evaluation of provider performance using two IO devices; the Pyng Medical F.A.S.T.1™ and the Vidacare EZ-IO®. Of 89 insertions with each device, success rate for 72% for the F.A.S.T.1 and 87% for the EZ-IO, a significant difference (p=0.009). The time to fluid insertion for the EZ-IO was also faster (p=0.02). Authors noted that the EZ-IO is unique and much more useful than the F.A.S.T.1.

Gagliardi P, Purrone G. [Il potere di salvare vite: l'infusione di liquidi e farmaci in emergenza con accesso venoso non reperibile]. N & A Mensile Italiano del Soccorso 2007; 177: 20-3. Italian 376

Article in Italian describing IO access and EZ-IO

Landes AH. Intra-osseous infusions: the current status. Care of the Critically Ill 2007; 23: 53-8 361

Overview of IO access. Includes historical aspects, current status, indications for use, advantages and disadvantages, IO kinetics, insertion sites, complications and contraindications and description of available IO devices, including EZ-IO®.

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- Scheres M. [Nieuw hulpmiddel voor intra-ossale toegang]. Vakblad V & VN Ambulancezorg 2007;1:16-7. Dutch** 373
Article in Dutch describing IO access and EZ-IO.
- Wayne MA. Intraosseous vascular access: devices, sites and rationale for IO use. JEMS 2007;32:s23-5** 375
This article reviews intraosseous vascular access in general, and summarizes the various devices available. These include the Waismed B.I.G., the Vidacare EZ-IO, and Pyng F.A.S.T.1.
- Weiss M, Gächter-Angehrn J, Neuhaus D. [Intraossäre infusionstechnik]. German Interdisciplinary Journal of Emergency Medicine 2007; 10: 99-116. German** 358
This article in German (with abstract in English) describes IO infusion in detail. It includes techniques, indications, complications, and recommendations. Also describes the various devices available, including Cook, Bone Injection Gun (BIG), First Access for Shock and Trauma (F.A.S.T.1), and the EZ-IO®.
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Evaluation of the Pyng Medical F.A.S.T.1 intraosseous device in simulated prehospital scenarios. Mean procedure time for initiation of fluid flow was 92 ± 32 seconds. Concludes that the F.A.S.T.1 is fast, accurate and easy to use.
- Frascone RJ, Jensen J, Salzman J, Kaye K. EZ-IO: A field trial. Prehosp Emerg Care 2006;10(1):123-4** 354
In this study, presented at the NAEMSP 2006 annual meeting, investigators reported the results of a study that evaluated the performance of the EZ-IO® compared to an earlier evaluation of the Pyng F.A.S.T.1 system. There was a statistically significant higher success rate using the EZ-IO® compared to Pyng system, and investigators concluded that the EZ-IO® appears to be a superior device with regard to insertion success.
- Guyette FX, Rittenberger JC, Platt T, Suffoletto B, Hostler D, Wang HE. Feasibility of basic emergency medical technicians to perform selected advanced life support interventions. Prehosp Emerg Care 2006;10(4):518-21** 353
Prospective observational study evaluating EMT-B ability to provide care in out-of-hospital cardiac arrests. Found that EMT-Bs were able to place the EZ-IO with a 94% success rate. Median time to placement was 72 seconds.
- Hoskins SL, Kramer GC, Stephens CT, Zachariah BS. Abstract 79: Efficacy of epinephrine delivery via the intraosseous humeral head route during CPR. Circulation 2006;114:II_1204** 422
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- Peutrell JM. Intraosseous cannulation. Anesthesia and Intensive Care Medicine 2006;7(1):28-30. Doi:10.1383/anes.2006.7.1.28** 637
An overview of intraosseous cannulation in the pediatric population. Anatomy, technique, contraindications, complications and laboratory investigations are all discussed.
- Wayne M. [Perfusion intra osseuse chez l'adulte: il est temps d'y penser]. Urgence Pratique 2006; 77: 47-9. French** 371
Article in French describes IO access and IO devices, including B.I.G., F.A.S.T.1 and EZ-IO®.
- Wayne MA. Adult intraosseous access: an idea whose time has come. Israeli J Emerg Med 2006;6(2):41-5** 638
The author provides an overview of intraosseous vascular access discussing evolution of the practice, equipment, treatment options and contraindications.

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YEAR: 2005

Curran A, Sen A. Bone injection gun placement of intraosseous needles. *Emerg Med J* 2005;22(5):366 335
A review of 129 cases comparing the BIG to standard IO needles. Concludes that the BIG is equivalent to manually driven IO needles in effectiveness and likely faster than manual needles in achieving IO access.

DeBoer S, Seaver M, Morissette C. Intraosseous infusion: not just for kids anymore. *Emerg Med Serv* 2005;34(54):56-63 331
Article describes intraosseous access for adults and pediatrics. Describes and discusses IO devices available including Jamshidi, Bone Injection Gun, F.A.S.T.1, and EZ-IO®.

Heightman AJ. The rebirth of adult IO: a first-hand account of recent advances in intraosseous infusion for adults, drawn from a scientific workshop and practical lab experience. *JEMS* 2005;30(10):s4-7 337
Editorial article highlighting recent advances in intraosseous (IO) infusion and IO devices based on the author's experience at a scientific seminar hosted by Vidacare. Makes recommendations on the efficiency and safety of the devices.

Hoskins S, Nascimento P, Espana J, Kramer G. Pharmacokinetics of intraosseous drug delivery during CPR. *Shock* 2005;23:35 423
This animal study compared IO drug delivery in the tibia versus the sternum during CPR. Researchers concluded that during CPR IO infusions delivered via both sites were effective—although sternal delivery was faster; and that IO sternum access is comparable to IV access for drug delivery during CPR.

Hoskins S, Stephens C, Kramer G. Efficacy of intraosseous drug delivery during cardiopulmonary resuscitation in swine. Paper presented at the annual meeting of the National Association of EMS Physicians, Registry Resort, Naples, FL. 2009-05-25 from http://www.allacademic.com/meta/p64887_index.html 506
This study abstract discusses use of the EZ-IO to determine the pharmacokinetics (PK) and efficacy of tibial IO drug delivery during treatment of cardiac arrest in the swine model, as compared to IV access. Results showed that PK analysis of IO drug delivery via the tibial route showed a delay of 20-50 seconds compared to IV; however, physiologically significant levels of epinephrine were reached as MAP. This research was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.

Johnson DL, Findlay J, Macnab AJ, Susak L. Cadaver testing to validate design criteria of an adult intraosseous infusion system. *Mil Med* 2005;170(3):251-7 342
Preclinical study of one IO device (FAST-1) in cadavers. Design criteria were validated in that 75 out of 77 attempts were successful.

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Miller DD, Guimond G, Hostler DP, Platt T, Wang HE. Feasibility of sternal intraosseous access by emergency medical technician students. *Prehosp Emerg Care* 2005;9(1):73-8 351
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Miller LJ, Kramer GC, Bolleter S. Rescue access made easy: Intraosseous infusion, once limited to use in children, is now becoming a reliable access site for adults. *JEMS* 2005;30(10):Suppl 8-18 345
Overview of IO therapy. Includes 10 Myths about Adult IO and description of available IO devices, including the EZ-IO®.

Tabas JA, Rosenson J, Price DD, Rohde D, Baird CH, Dhillon N. A comprehensive, unembalmed cadaver-based course in advanced emergency procedures for medical students. *Acad Emerg Med* 2005;12(8):782-5 349
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YEAR: 2004

Carley S, Boyd R. Best evidence topic reports. Screw tipped needles for intraosseous access. *Emerg Med J* 2004;21(3):336-7 315
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Web publication discussing the indications, contraindications, insertion sites and complications of IO access.
- Haas NA. Clinical review: vascular access for fluid infusion in children.** *Crit Care* 2004;8(6):478-84.doi:10.1186/cc2880 323
Review article describing how IO has replaced saphenous venous cutdowns in pediatric emergencies and decreased need for immediate central venous access.
- Miller LJ, Morissette C. VidaPort-an advanced easy IO device.** *Prehosp Emerg Care* 2004;8(1):110-1 326
Study compared the VidaPort (now EZ-IO®) and the Bone Injection Gun (B.I.G.). Of 32 cases for each device, insertion rates were 100% for the VidaPort and 88% for the B.I.G. Average insertion times were 16 seconds for the VidaPort and 21 seconds for the B.I.G.
- Saglam M, Ugurel S, Kilciler M, et al. [Intraosseous urography compared with intravenous urography: An experimental study in the rabbit model].** *Turk J Vet Anim Sci* 2004; 28: 933-42. Turkish 384
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- Walls RM. Adult intraosseous device aids terrorism response.** *Journal Watch Emergency Medicine* July 28, 2004 318
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This article in Spanish discusses general IO principles.
- Day MW. Act FAST with intraosseous infusion.** *Nursing* 2003;33:50-2 312
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Web article discusses IO cannulation procedure insertion sites, pathophysiology, risks, contraindications and complications.
- Lake W, Emmerson AJB. Use of a butterfly as an intraosseous needle in an oedematous preterm infant.** *Arch Dis Child Fetal Neonatal Ed* 2003;88(5):F409 307
An 18 gauge butterfly needle was inserted into the proximal tibia of a premature infant born at 25-weeks gestation, following inability to establish other modes of vascular access due to gross oedema. The intraosseous line was left in place for 6 days until it was lost; there were no adverse events reported however the author noted that no safety data on long term use of the device was collected.
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- YEAR: 2002**
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- YEAR: 2001**
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- Frascone R, Dries D, Gisch T, Kaye K, Jensen J. Obtaining vascular access: is there a place for the sternal IO? Air Med J 2001;20:20-2** 280
Article for Air Medical EMS audience describing the FAST-1 and use in attaining IO access. Reports 74% successful for first time users.
- Hubble MW, Trigg DC. Training prehospital personnel in saphenous vein cutdown and adult intraosseous access techniques. Prehosp Emerg Care 2001;5(2):181-9** 276
Study in EMS personnel comparing saphenous vein cutdown to IO access (B.I.G.) in the adult patient. Times to fluid flow were 7.6 minutes for saphenous cutdown and 3.9 minutes for IO. Investigators conclude that use of the B.I.G. was more rapid and successful with fewer complications than saphenous vein cutdown.
- Kalappanavar NK, Kesaree N, Banapurmath CR. Simplified intraosseous needle. Indian Pediatr 2001; 38: 378-80** 274
Brief report on the development of 18G and 22G IO needles in India.
- Orgiler Uranga PE, Navarro Arnedo JM, De Haro Marin S. [The intraosseal route. When the veins have disappeared]. Enferm Intensiva 2001;12(1):31-40. Spanish** 275
Literature review on intraosseous administration of drugs during pediatric emergencies. Concludes that IO is a valid alternative route for infusion of drugs and other substances into the blood stream with a low complication rate.
- YEAR: 2000**
- Calkins MD, Fitzgerald G, Bentley TB, Burris D. Intraosseous infusion devices: a comparison for potential use in special operations. J Trauma 2000;48(6):1068-74** 261
Study comparing 4 IO devices (FAST-1, B.I.G., Sur-fast, and Jamshidi) used by 31 Navy Seals Special Operations personnel. Results: 29 of 30 FAST-1 insertions successful, mean placement time 114 ± 36 seconds; 30 of 31 B.I.G. insertions successful, mean placement time 70 ± 33 seconds; 31 of 31 Sur-fast placements were successful, mean placement time 88 ± 33 seconds; 30 of 31 Jamshidi insertions successful. Participants rated no one device significantly better than the others.
- Day MW. Using intraosseous access in children. Nursing 2000;30(1):68** 253
Nursing article discussing the role of IO infusion when peripheral veins are collapsed. Describes advantages of IO, including ready availability, ability to establish vascular access without interrupting CPR.

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- Dubick MA, Holcomb JB. A review of intraosseous vascular access: current status and military application. Mil Med 2000; 165: 552-9** 254
Literature review of safety and efficacy of IO infusion of drugs and fluids, with emphasis on utility for the injured soldier. Discusses insertion times and flow rates. Includes literature citations from non-military studies in pediatrics, animals, and human cadavers.
- Foex BA. Discovery of the intraosseous route for fluid administration. J Accid Emerg Med 2000;17:136-7** 270
Brief review of the discovery and evolution of IO access in emergency care.
- Macnab A, Christenson J, Findlay J, et al. A new system for sternal intraosseous infusion in adults. Prehosp Emerg Care 2000;4:173-7** 272
This article reports the first 50 uses of the Pyng F.A.S.T.1 sternal IO infusion system in adults. Six emergency departments and 5 EMS systems participated. Results showed the overall success rate for the system was 84%. Success rates were 74% for first-time users and 95% for experienced users. Mean time to vascular access was 77 seconds.
- Mattera CJ. Take aim--hit your IO target. A comprehensive approach to pediatric intraosseous infusion, including site selection, needle insertion & ongoing assessment. Part 2. JEMS 2000;25(4):38-48** 264
Overview of pediatric IO infusion targeted for an EMS/paramedic audience. Discusses anatomy of long bones, indications, advantages, contraindications, steps for insertion, fluid administration and ongoing assessment and documentation.
- Nijssen-Jordan C. Emergency department utilization and success rates for intraosseous infusion in pediatric resuscitations. Canadian J Emerg Med 2000;2(1):10-4** 679
A retrospective chart review that evaluated use of IO access in pediatric patient resuscitation in a tertiary emergency department between 1989 and 1995. Results showed IO access was successfully established in 86% of patients. Median time to placement was 8 minutes; two complications of bone fracture were reported in one 10-day-old neonate patient.
Canada
- Spriggs NM, White LJ, Martin SW, Brawley D, Chambers RM. Comparison of two intraosseous infusion techniques in an EMT training program. Acad Emerg Med 2000;7:1168** 266
Study comparing B.I.G. and Jamshidi IO needle in an EMS training program. 38 EMT trainees performed the insertion. Time to placement was 12 seconds for the B.I.G. and 17 seconds for the Jamshidi needle. There were no statistical differences in ease-of-use ratings between the devices.
- Vreede E, Bulatovic A, Rosseel P, Lassalle X. Intraosseous infusion. Update in Anesthesia 2000;12 (Article 10):1. <http://rcpals.com/downloads/2007files/may/pals/IntraosseousInfusion.html>** 263
Brief overview of IO infusion for an anesthesiology audience. Discusses technique, indications, contraindications, equipment, anatomical target sites and potential complications.
- YEAR: 1999**
- Claudet I, Alberge C, Bloom MC, Fries F, Lelong-Tissier MC. [Intraosseous infusion in children]. Ann Fr Anesth Reanim 1999;18:313-8. French** 239
A retrospective non-comparative study of IO infusion in 41 children. Concludes that IO insertion is an easy technique. Recommends IO for emergency cases when other vascular access techniques have failed in the first 5 minutes of treatment.
Abstract
- Daga SR, Gosavi DV, Verma B. Intraosseous access using butterfly needle. Trop Doct 1999;29(3):142-4** 236
Evaluation of the utility of 18-gauge butterfly needles for IO administration of fluids and drugs in 23 children presenting in shock. 22 of 23 children were successfully stabilized after IO infusion.
Abstract
- Day MW. Using a sternal intraosseous device in adults. Nursing 1999;29:22-3** 237
Nursing article describing the FAST-1, directions for use and device removal.
- Ellemunter H, Simma B, Trawoger R, Maurer H. Intraosseous lines in preterm and full term neonates. Arch Dis Child Fetal Neonatal Ed 1999; 80: F74-5** 241
Observational study in 27 newborns, describing 30 intraosseous lines placed after failed IV access. Reports that all patients survived the resuscitation procedures with no long-term side effects.

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- Kramer GC, Jenkinson JP, Castaldo D. Implantable intraosseous device for rapid vascular access. University of Texas Medical Branch, United States Patent 5,868,711 (1999). <http://www.google.com/patents/US5960797>** 245
 Patent application for a device and method for rapid access to the bone marrow for the infusion of drugs and other fluids into the bone marrow. US Patent issued on October 5th, 1999.
- YEAR: 1998**
- Halm B, Yamamoto LG. Comparing ease of intraosseous needle placement: Jamshidi versus Cook. Am J Emerg Med 1998; 16: 420-1** 228
 Study comparing placement of Cook and Jamshidi IO needles in turkey bones.
- Stovroff M, Teague WG. Intravenous access in infants and children. Pediatr Clin North Am 1998;45:1373-93** 227
 Review article discussing techniques for venous access in the pediatric patient includes anatomical target sites, clinical indications, advantages and disadvantages.
 Review
- YEAR: 1997**
- Waisman M, Waisman D. Bone marrow infusion in adults. J Trauma 1997;42(2):288-93** 221
 Seminal study on the use of the B.I.G. in elective and emergency situations in 50 adult patients. Success rate for IO insertion was 100%. No complications were observed.
- YEAR: 1996**
- Brandt MR. [Intraosseous administration]. Ugeskr Laeger 1996;158(40):5638. Danish** 206
 Article in Danish
- Dumillard C, Suze N, Duquesne JM, Petri S, Lode N, Maupetit B, Belotte F. [Intraosseous device of perfusion. Apropos of 3 cases before hospitalization]. Cah Anesthesiol 1996;44(1):71-6. French. Abstract** 212
 Discusses indications, contraindications, method of supervision, and complications intraosseous infusion. Concludes that intraosseous infusion is an attractive alternative to the intravenous route in emergency situations.
- Moller JC, Tegtmeyer FK, Schaible TF, Sussmane JB. [Intraosseous puncture as vascular access in pediatric emergency and intensive care medicine]. Anaesthesiol Reanim 1996;21(4):103-7. German. Abstract** 209
 Article describing IO infusion 18 pediatric resuscitative situations. Authors conclude that 11 patients would not have survived without IO access. Complications included a minor fracture, 1 case of compartment syndrome that did not require surgical intervention and a minor fat embolism that was of no clinical significance.
- YEAR: 1995**
- LaSpada J, Kissoon N, Melker R, Murphy S, Miller G, Peterson R. Extravasation rates and complications of intraosseous needles during gravity and pressure infusion. Crit Care Med 1995; 23: 2023-8** 199
 Study comparing extravasation rates and insertion complications between threaded and non-threaded IO needles. Needle type did not affect extravasation rate under ideal conditions. Common complications during stressful emergency situations included insertion difficulty and accidental penetration of both cortices of the bone. Concludes that these complications may lead to extravasation.
- Maguer D, Delaporte B, Godde F, Amusini P. [Intraosseous infusion: another emergency vascular access]. Arch Pediatr 1995;2(7):704-5. French** 198
 Article in French.
 No abstract available
- Moller JC, Reiss I, Schaible T. Vascular access in neonates and infants--indications, routes, techniques and devices, complications. Intensive Care World 1995;12(2):48-53** 197
 Suggests that intraosseous infusion is reliable alternative to peripheral vein access for rapid infusion of fluids in neonates and infants when venous access is impossible.
 Abstract only

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Rodriguez-Munez A, Martinez-Soto I, Martinon JM. Elective use of intra-osseous infusions in paediatrics. Eur J Pediatr 1995; 154: 755 202

Case report of IO access in a non-emergency situation. A blood transfusion was performed with no complications in a severely anemic 1-month old infant with an 18 G IO needle (Cook).

YEAR: 1994

Anderson TE, Arthur K, Kleinman M, Drawbaugh R, Eitel DR, Ogden CS, Baker D. Intraosseous infusion: success of a standardized regional training program for prehospital advanced life support providers. Ann Emerg Med 1994;23(1):52-5 165

Study of IO training for advanced life support providers. Providers were able to establish IO access in 13 of 15 (87%) of pediatric patients (age range 1-24 months) following completion of an 1-hour training course and supervised hands-on simulation. All procedures were performed in less than 10 minutes.

Bachmann DC. [Heart arrest: septic and hypovolemic shock--intraosseous infusion technique]. Ther Umsch 1994;51(9):593-7. German 189

Describes causes and treatment of hypovolemic and septic shock. Discusses techniques for intraosseous puncture and infusion. Article in German - abstract only

Banerjee S, Singhi SC, Singh S, Singh M. The intraosseous route is a suitable alternative to intravenous route for fluid resuscitation in severely dehydrated children. Indian Pediatr 1994;31:1511-20 188

Study of IO vs. IV for administering fluids for resuscitation in 60 children (age range 3-24 months) with severe dehydration. The IO route was successful in all cases within the first 5 minutes of attempt. The IV line could not be secured in 33% of patients within 5 minutes. Time for successful IV access was 129 seconds, significantly longer than time t for IO cannulation. Fluid infusion through either route was equally effective in stabilizing vital signs and normalizing laboratory values. No significant complications of IO route were noted on short-term follow-up.

Evans RJ, McCabe M, Thomas R. Intraosseous infusion. Br J Hosp Med 1994;51(4):161-4 175

Review of IO infusion in children 6 years old and younger. Recommends IO for patients with life-threatening conditions requiring immediate vascular access. Reports less than 1% complication rate.

Feenstra WR, Henderson JM, Kramer GC. Design of an intraosseous infusion system. Am J Emerg Med 1994; 12: 477-84 174

Describes design process and results for a high-pressured infusion system intended for automating external infusions in emergency situations.

Gayle M, Kissoon N. A case of compartment syndrome following intraosseous infusions. Pediatr Emerg Care 1994;10:378 185

Case report of compartment systems following improper intraosseous infusion technique.

Kruse JA, Vyskocil JJ, Haupt MT. Intraosseous infusions: a flexible option for the adult or child with delayed, difficult, or impossible conventional vascular access. Crit Care Med 1994;22(5):728-9 184

Discussion of IO infusion, including ease of use, low complication rates, and variety of fluids and drugs that can be administered through the IO route in children and adults.

Melker RJ, Miller GJ, Gearen PH, Molliter L. A novel intraosseous needle. Ann Emerg Med 1994;23(4):923 548

This abstract describes clinical use of the SurFast Cook Critical Care IO needle. Thirty-two IO insertion attempts were made, 87.5% were successful on first attempt. Average time to insertion was less than one minute; flow rate for infants and children was 1-2 mL/kg/min; flow rate for adults was 150-200 mL/min. There were two reports of minimal extravasation

Neal CJ, McKinley DF. Intraosseous infusion in pediatric patients. J Am Osteopath Assoc 1994;94(1):63-6. Review 187

Describes frustration associated with difficult venous access. Recommends intraosseous infusion technique as a non-collapsible vein for parenteral infusions.

Oriot D, Cardona J, Berthier M, Nasimi A, Boussemart T. [Intraosseous vascular access, a technic previously underestimated in France]. Arch Pediatr 1994;1(7):684-8. French 190

Review article suggesting that IO infusion should be the primary technique of intravascular access in infants for pediatric resuscitation and the first alternative technique for vascular access after failed intravenous access in young children.

Abstract only

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- Orlowski JP. Emergency alternatives to intravenous access. Intraosseous, intratracheal, sublingual, and other-site drug administration. *Pediatr Clin North Am* 1994;41(6):1183-99** 164
 Seminal article describing alternatives to intravenous cannulation including intraosseous access, intratracheal drug administration, sublingual and intralingual injection, intra-penile administration, and intracardiac injection. Concludes that the intraosseous method is an effective alternative to intravenous access in emergency situations.
Review
- Sawyer RW, Bodai BI, Blaisdell FW, McCourt MM. The current status of intraosseous infusion. *J Am Coll Surg* 1994;179:353-60.** 182
Review
 Review of the history, insertion techniques, available devices, and applications of the intraosseous infusion as well as the indications and contraindications for intraosseous infusion in all critically ill patients.
- Weaver BL. Intraosseous infusions. *Neonatal Netw* 1994;13(8):68-9** 162
 A brief overview on establishing intraosseous vascular access in the neonatal patient population. Discusses insertion techniques, anatomy and physiology, absorption rates, indications and contraindications.
- YEAR: 1993**
- Schwartz RE, Pasquariello CA, Stayer SA. Elective use in pediatric anesthesia of intraosseous infusion: proceed only with extreme caution. *Anesth Analg* 1993; 76: 918-9** 159
 Letter to the editor recommending intraosseous infusion only for truly urgent situations.
- YEAR: 1992**
- Cilley RE. Intraosseous infusion in infants and children. *Semin Pediatr Surg* 1992;1(3):202-7** 139
 Article promoting increased awareness of intraosseous infusion, familiarity with IO insertion techniques, and careful use of anatomical landmarks.
Abstract only
- Ghirga G, Ghirga P, Palazzi C, Befani P, Presti A. [Intraosseous route in pediatric emergencies. Description of 2 clinical cases and review of the literature]. *Minerva Pediatr* 1992; 44: 377-84. Italian** 123
 Case reports of resuscitation of 2 pre-term infants with medications administered via the intraosseous route. Also includes a short review of the history, physiology, technique, complications and contraindications of IO procedure.
Abstract only
- Gut J, Karbula D. [Intraosseous infusions in children]. *Cesk Pediatr* 1992;47:726-7. Czech** 133
 A review of intraosseous infusion and the possible applications in pediatric emergency medicine.
Abstract only
- Hapnes SA, Robertson C. CPR--drug delivery routes and systems. A statement for the Advanced Life Support Working Party of the European Resuscitation Council. *Resuscitation* 1992;24(2):137-42** 127
 Descriptive comparison of the 4 available routes to provide drugs to adult patients during cardiopulmonary resuscitation.
- Hoekstra JH, van Kempen AA. [Intraosseous infusions in children]. *Tijdschr Kindergeneeskde* 1992;60(4):123-6. Dutch** 128
 Recommendation of the tibial site for intraosseous infusion in children and discussion of risk for complications.
Abstract only
- Medina FA. Rapid sequence induction/intubation using intraosseous infusion of vecuronium bromide in children. *Am J Emerg Med* 1992;10(4):359-60** 121
 Case reports in 2 children finding IO infusion of vecuronium allowed for successful rapid sequence induction/intubation.
- Stewart FC, Kain ZN. Intraosseous infusion: elective use in pediatric anesthesia. *Anesth Analg* 1992;75(4):626-9** 140
 Case report of IO infusion for induction and maintenance of anesthesia in an infant with other IV access.

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- Welch RD, Waldron MJ, Hulse DA, Johnston CE 2nd, Hargis BM. Intraosseous infusion using the osteoport implant in the caprine tibia. J Orthop Res 1992;10(6):789-99** 129
Preclinical study of an implantable intraosseous infusion device (the osteoport) in a goat model. The device allowed for ready access to the vascular system through intraosseous infusion fluids and medications. IO infusion may result in fewer complications than conventional methods of vascular access.
- YEAR: 1991**
- Clarke P. Making sense of intraosseous infusion. Nurs Times 1991;87(1):40-1** 115
Article for nurses on intraosseous infusion as an alternative to intravenous vascular access presented in a question and answer format.
- Driggers DA, Johnson R, Steiner JF, Jewell GS, Swedberg JA, Goller V. Emergency resuscitation in children. The role of intraosseous infusion. Postgrad Med 1991;89(4):129-32** 105
Review article discussing aspects of intraosseous infusion, including indications, technique, and pharmacokinetic factors. Concludes that multiple drugs and fluids can be safely administered through the intraosseous route.
- Islam A. New sternal puncture needle. Journal of Clinical Pathology 1991;44(8):690-1** 107
Describes the design of a larger and more user friendly sternal intraosseous needle for bone marrow aspiration.
- Jaimovich DG, Kecskes S. Intraosseous infusion: a re-discovered procedure as an alternative for pediatric vascular access. Indian J Pediatr 1991;58(3):329-34** 110
Review of indications and benefits of intraosseous infusion. Concludes IO access may be especially valuable for medical personnel who rarely care for critically ill children because the IO technique is easily mastered even with limited practice.
- Von Hoff DD. Intraosseous infusions: an important but forgotten method of vascular access. Cancer Invest 1991;9(5):521-8** 116
Review of intraosseous vascular access targeted for an oncology audience. Describes an implantable IO device with potential to make intraosseous access more convenient for the patient.
- YEAR: 1990**
- Fiser DH. Intraosseous infusion. N Engl J Med 1990;322(22):1579-81** 98
Review of the use of intraosseous infusion in children in the prehospital setting and in the emergency department. Outlines anatomy, indications and contraindications, technique, complications and role of intraosseous infusion in pediatrics.
- Halvorsen L, Bay BK, Perron PR, Gunther RA, Holcroft JW, Blaisdell FW, Kramer GC. Evaluation of an intraosseous infusion device for the resuscitation of hypovolemic shock. J Trauma 1990;30(6):652-9** 90
Preclinical study comparing a sternal IO infusion device to IV fluids for resuscitation. Blood pressure and cardiac output were normalized at 10 minute post infusion in both groups. Advocates use of IO infusion as a way for pre-hospital rescuers to consistently incorporate fluid therapy in their scoop and run policies.
- Hopkins RL. Pediatric intraosseous infusion. J LA State Med Soc 1990;142(3):31-2** 104
Concludes that infusion of fluids and drugs can be readily performed with the intraosseous technique.
- King ML, Moses EC. Intraosseous infusion: a lifesaving technique. Nursing 1990;20:32K,32N-32P** 93
Nursing article describing intraosseous infusion techniques and benefits.
- Walter GP, Clark MR. A practical method of teaching emergency intraosseous infusions. Am J Emerg Med 1990;8(3):272-3** 101
Discusses method for teaching the IO technique using chicken legs. Format combining lecture with lab practical allows for IO technique to be taught quickly and inexpensively. Suggests turkey legs or beef ribs with thin bone cortex as alternatives to chicken legs.

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YEAR: 1989

Iserson KV. Intraosseous infusions in adults. J Emerg Med 1989;7(6):587-91 75

Study of 22 cardiac arrest patients arriving at the Emergency Department with no or insufficient intravenous access. Intraosseous needle placed and flow established in less than 1 minute in all patients. Observed flow rates of 5 to 12 mL/min with pressure bag attached. IO needle placed in the medial supramalleolus.

Schoffstall JM, Spivey WH, Davidheiser S, Lathers CM. Intraosseous crystalloid and blood infusion in a swine model. J Trauma 1989;29(3):384-7 85

Preclinical study of IO infusion in a swine model. Concludes that IO infusion holds potential as a first line of action for fluid resuscitation in pediatric subjects.

Wheeler CA. Pediatric intraosseous infusion: an old technique in modern health care technology. J Intraven Nurs 1989;12(6):371-6 76

Review article for a nursing audience presenting a brief historical overview of IO technique and insertion methods, with discussion of clinical applications and nursing management aspects.

YEAR: 1988

Brillman JC. Intraosseous infusion for emergency intravascular access. Top Emerg Med 1988;10(1):75-80 73

Description of IO infusion technique, site selection, procedure, anatomy, physiology, historical perspectives, contemporary research, indications, contraindications, complications, and future direction.

Brunette DD, Fischer R. Intravascular access in pediatric cardiac arrest. Am J Emerg Med 1988;6(6):577-9 63

Retrospective chart review of 33 pediatric patients finding 83% success in establishing IO infusion. IO and percutaneous peripheral catheterization were the quickest methods for vascular access. Observed no major and minimal delayed complications.

Glaeser PW, Losek JD. Intraosseous needles: new and improved. Pediatr Emerg Care 1988;4(2):87-91 607

This article describes the Kormed/Jamshidi disposable Illinois sternal/iliac needle as well suited to establish intraosseous vascular access in the pre-hospital and hospital setting.

Katan BS, Olshaker JS, Dickerson SE. Intraosseous infusion of muscle relaxants. Am J Emerg Med 1988;6(4):353-4 62

Case report of anesthetic induction through IO administration of succinylcholine chloride, atracurium besylate, and thiopental sodium in a child with seizure activity.

Manley L, Haley K, Dick M. Intraosseous infusion: rapid vascular access for critically ill or injured infants and children. J Emerg Nurs 1988;14(2):63-9 66

Article for emergency nursing audience describing IO technique, anatomy, absorption rates, clinical indications and contraindications, technique, complications and training in critically ill or injured infants and children.

Neish SR, Macon MG, Moore JW, Graeber GM. Intraosseous infusion of hypertonic glucose and dopamine. Am J Dis Child 1988;142(8):878-80 69

Preclinical study finding IO infusion of hypertonic glucose and dopamine to be as effective as IV administration.

Peck KR, Altieri M. Intraosseous infusions: an old technique with modern applications. Pediatr Nurs 1988;14(4):296-8 70

Nursing article recommending IO early in the treatment of critically ill or injured children with difficult venous access. Highlights speed and ease of IO technique.

Sacchetti A, Linkenheimer R. On the effectiveness of intraosseous infusion. J Emerg Med 1988;6(5):433 61

Article discussing IO infusion and associated rapid intravascular absorption of solutions.

Wagner MB, McCabe JB. A comparison of four techniques to establish intraosseous infusion. Pediatr Emerg Care 1988;4(2):87-91 64

Comparison study of success rate in establishing IO infusion in anesthetized piglets with 4 types of IO needles: standard hypodermic, spinal, bone marrow, Turkel. Practitioners were 24 medical residents with no prior experience in IO technique. Overall success rate was 67.7%. There were no statistical differences in success rate among the 4 different types of needles.

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YEAR: 1987

Spivey WH. Intraosseous infusions. J Pediatr 1987;111(5):639-43

56

Review article on IO infusion, includes historical background, physiology, method, clinical applications and complications of the IO procedure.

YEAR: 1986

Hoelzer MF. Recent advances in intravenous therapy. Emerg Med Clin North Am 1986;4(3):487-500

55

Review of medical literature and research on the problem of difficult intravenous access.

Iserson KV, Criss E. Intraosseous infusions: a usable technique. Am J Emerg Med 1986;4(6):540-2

54

This article describes case reports and also a study comparing 3 types of needles for IO insertion: spinal needles, standard IV needles, and bone marrow aspiration/biopsy needles on a pediatric cadaver leg. The bone marrow aspiration needle was easiest to insert. The clinical cases described 5 adult and 10 pediatric IO patients with insertion at the "medial malleolus".* Authors conclude that IO infusion is a safe, rapid way to access the venous circulation, providing a stable, usable fluid line in dehydrated pediatric patients. *(Often referred to as distal tibia.)

Kanter RK, Zimmerman JJ, Strauss RH, Stoeckel KA. Pediatric emergency intravenous access. Evaluation of a protocol. Am J Dis Child 1986;140(2):132-4

53

Evaluation of a sequential protocol comparing femoral vein catheterization, saphenous vein cutdown, and IO (in order) when conventional IV access was impossible in a pediatric patient population. Found that IV access was attained in 4.5 minutes when the protocol was followed, compared to 10 minutes when protocol was not followed. Suggests that IV access should always be attained in 5 minutes or less.

Mayer TA. Emergency pediatric vascular access: Old solutions to an old problem. Am J Emerg Med 1986;4(1):98-101

51

Discusses rediscovery of intraosseous infusion as a straightforward technique for an extremely difficult clinical problem. Suggests that many fluids and medications can be administered via the IO route.

Parrish GA, Turkewitz D, Skiendzielewski JJ. Intraosseous infusions in the emergency department. Am J Emerg Med 1986;4(1):59-63

47

Discusses IO route as a safe, proven, and technically easy method for administration of replacement fluids, blood products, and resuscitative drugs. Presents value, historical context, technique, and complications of the IO infusion.

Walsh-Kelly CM, Berens RJ, Glaeser PW, Losek JD. Intraosseous infusion of phenytoin. Am J Emerg Med 1986;4(6):523-4

52

Case report of child with status epilepticus. IO phenytoin resulted in seizure resolution and therapeutic serum levels of drug.

YEAR: 1985

Hodge D. Intraosseous infusions: a review. Pediatr Emerg Care 1985;1(4):215-8

44

Review of IO insertion techniques of insertion, clinical indications, contraindications, and complications.

Turkel H. Emergency bone marrow infusions. Am J Dis Child 1985;139(5):438-9

45

Letter to the editor asserting that while the Turkel trephine technique may stabilize the IO needle better and minimize fluid leakage into the subcutaneous tissue, few physicians are familiar with the technique and it is more time-consuming than using a standard bone marrow needle or standard hypodermic needle.

YEAR: 1984

Berg RA. Emergency infusion of catecholamines into bone marrow. Am J Dis Child 1984;138(9):810-1

40

Case report of continuous IO infusion of dopamine hydrochloride and dobutamine hydrochloride in a 6 month old infant. Concludes that IO infusion is efficacious and complications rare.

Turkel H. Emergency infusion through the bone. Military Medicine 1984;149:349-50

38

Article for military medicine audience concluding that the intraosseous route is more safe and effective than the intravenous route for several clinical indications, including burns and shock, circulatory collapse, uncooperative patients, patients in transit, shortage of physicians, especially under emergency conditions. States that IO infusion is an established alternative to intravenous infusion.

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YEAR: 1954

Pillar S. Re-emphasis on bone marrow as a medium for administration of fluid. *N Eng J Med* 1954;251(21):846-51 26
 Recommends IO for administering fluids, with the iliac crest as the preferred anatomical site.

YEAR: 1952

Tarrow AB, Turkel H, Thompson MS. Infusions via the bone marrow and biopsy of the bone and bone marrow. *J Anesthesiol* 1952;13(5):501-9 24
 Article for an anesthesiology audience discussing the extensive blood supply within the bone marrow and the utility of IO anesthesia administration.

YEAR: 1947

Bailey H. Sternal trocar and cannula. *Br Med J* 1947; 214: 499 19
 Describes a sternal trocar and cannula designed prevent accidental penetration of the mediastinum.

Elston JT, Jaynes RV, Kaump DH, Irwin WA. Intraosseous infusions in infants. *Am J of Clinical Path* 1947;17(2):143-50 20
 Early article on IO puncture and infusion, emphasizing technique. Concludes their technique is safer and more effective than previously described techniques.

YEAR: 1946

Quilligan JJ, Turkel H. Bone marrow infusion and its complications. *Am J Dis Child* 1946; 71: 457-65 18
 Historical article discussing refinements in IO technique and analysis of IO complications. Includes case report of an infant who developed osteomyelitis subsequent to IO infusion.

YEAR: 1944

Bailey H. Bone marrow as a site for the reception of infusions, transfusion and anesthetic agents. *Br Med J* 1944;1:181-2 15
 Recommends IO cavity of the manubrium as useful as IV for anesthetic infusion.

Gimson JD. Bone-marrow transfusion in infants and children-Introducing a specially designed needle. *Br Med J* 1944;1(4352):748-9 11
 Describes a simple method of bone marrow transfusion using a specially designed needle that is more safe and effective than intravenous needles.

Meola F. Bone marrow infusions as a routine procedure in children. *J Pediatr* 1944;25(1):13-6 13
 Early observational study on IO infusion at the Children's Hospital of Akron, OH.

YEAR: 1943

Macht D. Studies on intraosseous injections of epinephrine. *Am J Physiol* 1943;138(2):269-72 9
 Study of the clinical effects of intraosseous, intramuscular and intravenous injections of aqueous versus oil solutions of epinephrine.

Meyer LM, Perlmutter M. The absorption rate from the bone marrow. *Am J Med Sci* 1943;205(2):187-90 10
 Early study finding comparable circulation times between IV and IO infusions in 21 subjects.

YEAR: 1942

Doud E, Tysell, J. Massive intramedullary infusions *JAMA* 1942;120(15):1212. doi:10.1001/jama.1942.82830500006010c 914
 This article discusses use of the medullary route for massive replacement therapy when the usual methods of administration and not available or practical. The article also reviews a case study of a man in receipt of a sternal puncture needle inserted into the medullary cavity where he received the infusions through this needle of whole blood and fluids.

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Papper EM. The bone marrow route for injecting fluids and drugs into the general circulation. *Anesthesiology* 1942;3(3):307-13 8
Discusses IO infusion, pioneered by Tocantins, as a viable route for parenteral fluids, drug therapy, and anesthesia. Includes case reports.

YEAR: 1941

Tocantins LM, O'Neill JF, Price AH. Infusions of blood and other fluids via the bone marrow in traumatic shock and other forms of peripheral circulatory failure. *Ann Surg* 1941;114:1085-92 4

Early study of 4 patients with acute failure of the peripheral circulation. IO infusion of blood, fluids, or drugs via the bone marrow resulted in a prompt recovery from the state of collapse. Recommends IO route when peripheral veins are not available and a fluids are urgently needed.

Tocantins LM, O'Neill JF. Infusions of blood and other fluids into the general circulation via the bone marrow. *Surg Gynecol Obstet* 1941;73:281-7 5

Clinical study of 52 IO infusions of fluids in 40 patients (33 adults and 7 infants). Found no local, constitutional, immediate, or delayed reactions accompanying or following any infusion.

YEAR: 1940

Tocantins LM, O'Neill JF. Infusion of blood and other fluids into the circulation via the bone marrow. *Proc Soc Exp Biol Med* 1940;45(3):782-3 3

Clinical study finding that IO infusion for parenteral therapy was successful in 16 of 17 trials in 14 patients. Found that citrated blood, plasma, glucose and salt solutions could be infused with no complications.

Tocantins LM. Rapid absorption of substances injected into the bone marrow. *Proc Soc Exp Biol Med* 1940; 45: 292-6 2

Seminal study demonstrating that substances injected into the IO cavity of the tibia of the rabbit and the sternum of man immediately appeared in the central circulation, similar to IV administration.

YEAR: 1922

Drinker C, Drinker K, Lund C. The circulation in the mammalian bone marrow. *Am J Physiol* 1922;62(1):1-92 1

Seminal article on blood circulation in the IO space. Demonstrates movement of red blood cells from the bone marrow into the circulating blood by perfusion of the tibia of the dog and by injections into the bone marrow in the rabbit and cat.

Intraosseous Vascular Access Bibliography

International

YEAR: 2018

Markic J, Polic B, Mestrovic J, Kovacevic T, Zanchi I. Successful intraosseous therapy using EZ-IO system in a preterm neonate below 2 kg. *Minerva Pediatr* 2018;70(1):104-5. doi:10.23736/S0026-4946.16.04707-1. (Croatia) 928

This paper is a letter to the editor describing successful insertion of EZ-IO in a neonate weighing less than 2 kg with respiratory failure, signs of sepsis, and shock. After successful insertion the patient was resuscitated and later stabilized. The authors advise that IO access is safe, effective, and attainable in all age groups despite FDA approval only in patients greater than 3 kg.

Simsek P, Bayram SB, Gursoy A. İlaç uygulamaları için farklı bir yol: Intraosseöz ulaşım ve infüzyon [A different route for drug administration: Intraosseous access and infusion]. *HEAD* 2018;15(1):40-44. doi: 10.5222/HEAD2018.040. Turkish 1061

This is an article published in a Turkish nursing journal and written in Turkish. From the abstract, the IO route is described as an alternative approach to vascular access when venous access via a peripheral catheter cannot be obtained quickly. Complications of IO access and how to prevent them using nursing interventions are discussed. EZ-IO is discussed in the article.

YEAR: 2017

Afzali M, Kvisselgaard AD, Lyngeraa TS, Viggers S. Intraosseous access can be taught to medical students using the four-step approach. *BMC Medical Education* 2017;17(50):doi:10.1186/s12909-017-0882-7. (Denmark) 831

This study evaluated the ability to teach the skill of IO access in a four hour timeframe to medical students using a modified Walker and Peyton's four-step approach teaching method and a cadaveric model. The learner's competencies were evaluated with an objective structured clinical examination checklist. This study found the teaching method was successful. Authors recommend repetitive training to be integrated to medical curriculum for maximal skill retention.

Bromberg R, Dave K, Mankodi D, Danckers M. Soft tissue laceration caused by lower extremity intraosseous access insertion in an obese patient. *BMJ Case Rep* 2017;doi:10.1136/bcr-2017-220069. (United Kingdom) 938

This case report describes a complication of a laceration that occurred in an 85 year old morbidly obese female that presented in septic shock and received a proximal tibial IO placement. A 45 mm needle set was used for the initial insertion, which was completed without any initial problems; no stabilizer was placed. The patient had fluid resuscitation via the IO site with rapidly improved hemodynamics. During transport she developed a 7 cm laceration across the IO insertion site. The catheter was removed and laceration sutured. Authors opined that the lack of use of the EZ-Stabilizer dressing, the amount of soft tissue and thin skin and traction forces on the IO site applied during transport contributed to this complication.

Budach NM, Niehues SM. CT angiography of the chest and abdomen in an emergency patient via humeral intraosseous access. *Emerg Radiol* 2017;24(1):105-8. doi:10.1007/s10140-016-1438-6. (Germany) 823

This case report describes a CT angiography of the chest and abdomen done via an EZ-IO catheter placed in a critically ill patient's proximal humerus. The contrast media was infused at a rate of 4 mL/s and the infusion pressure never exceeded 300 mmHg. No immediate or short term complications were observed. The authors describe the overall image quality and vessel contrast observed as excellent.

Jansen G, Leimkuhler K, Mertzluft F. Intramedullary placement of intraosseous cannulas inserted in the preclinical treatment of polytrauma patients: A retrospective, computed tomography-assisted evaluation. *Anaesthesist* 2017;66(3):168-76. doi:10.1007/s00101-016-0257-1 985

This article describes a retrospective, CT-assisted evaluation of IO cannula placement. Over a 5 year period all multislice-CT trauma scans performed in a trauma center were monitored for intraosseous devices in situ. 982 patients were evaluated and 13 IO cannulas were found in 11 patients. In all cases, the EZ-IO device was used. Evaluation of placement found that all applications were placed correctly, but none were according to current guidelines. The site of puncture deviated in all cases with the most common error of overshooting during needle introduction. (Article in German)

Liu SX, Liu YG, Wang PH, Qi MF, Luo M. Efficacy of shengxue mixture combined with intraosseous infusion for treatment of aplastic anemia. *J Exp Hematol* 2017;25(5):1493-7 990

This study evaluated the efficacy and safety of Shengxue mixture when combined with IO blood infusion for the treatment of aplastic anemia patients at Shaanxi Medical University in China. Patients were treated with oral Shengxue mixture, stanozolol tabs, mycophenolate and IO infusion of recombinant human EPO, G-CSF, IL-11, and dexamethasone. After 1 month of treatment the response rate was 90.57%. After 3-6 months the response rate was 96.23%. The authors concluded that Shengxue mixture combined with IO infusion was a fast, efficient, and safe method of treatment of aplastic anemia. Article in Chinese.

Mercer SJ, Jones CL, Round J, et al. Military anaesthesia in contingencies: What skill sets are required and how will we prepare our trainees? *J R Army Med Corps* 2017;163(4):226-32. doi: 10.1136/jramc-2016-000722. (United Kingdom) 993

This paper describes skill sets and training for the Defence Medical Services in the UK, specifically the revised Military Higher Module and how it will be implemented in the future either during deployment or times of peace. IO devices as a means to control catastrophic haemorrhage is listed as a competency.

Intraosseous Vascular Access Bibliography

International

- Shina A, Baruch EN, Shlaifer A, et al. Comparison of two intraosseous devices: The NIO versus the EZ-IO by novice users- a randomized cross over trial. *Prehosp Emerg Care* 2017;21(3):315-21. doi:10.1080/10903127.2016.1247201** 817
- Using a porcine hind leg model authors compared the success rate and ease-of-use ratings of an IO device, the NIO® in comparison to the Arrow® EZ-IO by novice users. NIO success rates were comparable to those of EZ-IO; 54% of the participants preferred using the EZ-IO over the NIO.
- YEAR: 2016**
- Chin YX, Kiat Tan KB, Koh ZX, et al. Comparing intraosseous and intravenous access for out-of-hospital cardiac arrest in Singapore. *Resuscitation* 2016;106(S1):e25** 813
- The objective of this study was to determine if there would be a difference in rates of vascular access and ROSC if paramedics were able to use IO access after two initial IV attempts failed. Investigators found higher vascular access success and prehospital epinephrine administration rates with the addition of IO access but no significant difference for ROSC.
- Singapore
- Davis J, Bates L. Rapid sequence induction via an intraosseous needle. *J Intensive Care Society* 2016;17(2):178-9** 788
- This article presents a case study of rapid sequence intubation via intraosseous (IO) access with a review of relevant literature. The authors describe a case of an adult male patient, peri-arrest with cardiogenic shock, cyanosed with un-recordable oxygen saturations and blood pressure. IO access was established in the proximal tibia and rapid sequence induction was performed using fentanyl, ketamine and suxamethonium. After 30 seconds direct laryngoscopy was attempted and intubation was secured on first attempt. The authors concluded that use of IO access for RSI can be useful in cases of difficult vascular access and rapid intubating conditions can be achieved which are comparable to using IV drug delivery.
- Drozdz A, Madziara M. Which vascular access technique should be chosen during hypovolemic shock? *Am J Emerg Med* 2016;34(9):1886-7. doi:10.1016/j.ajem.2016.06.070** 824
- In this letter to the editor authors discuss the difficulties of obtaining vascular access in patients in shock; and make a case for use of intraosseous access (IOA) in shock. Authors note IOA access as a safe, effective alternative to venous access with relatively rare complications.
- Poland
- Engels P, Erdogan M, Widder S, et al. Use of intraosseous devices in trauma: A survey of trauma practitioners in Canada, Australia and New Zealand. *Can J Surg* 2016;59(6):374-82 doi:10.1503/cjs.011215** 918
- This study was conducted to determine the level of experience as well as the beliefs and attitudes of trauma practitioners in Canada, Australia and New Zealand about using IO devices in adult trauma patients. The study used a web-based survey submitted to 1771 to all members of 4 national emergency and trauma organizations. Surveys were completed by 425 participants and most participants surveyed were comfortable using the IO device in resuscitation of adult trauma patients.
- Eriksson M, Strandberg G, Lipcsey M, Larsson A. Evaluation of intraosseous sampling for measurements of alanine aminotransferase, alkaline phosphatase, aspartate aminotransferase, creatinine kinase, gamma-glutamyl transferase and lactate dehydrogenase. *Scand J Clin Lab Invest* 2016;76(8):597-600. doi:10.1080/00365513.2016.1230774** 809
- This preclinical study compared arterial and intraosseous derived biomarkers to determine if the results would correlate well enough over a period of 6 hours to consider use of IO derived blood when traditional samples are difficult to obtain. Authors noted there were no clinically relevant average differences between alanine aminotransferase, alkaline phosphatase, aspartate aminotransferase, creatinine kinase and gamma-glutamyl transferase values which may be good enough for initial estimates of these markers analyzed in intraosseous and arterial samples. However the lactate dehydrogenase levels showed less correlation; and the precision of IO samples may be limited.
- Garside J, Prescott S, Shaw S. Intraosseous vascular access in critically ill adults- a review of the literature. *Nurs Crit Care* 2016;21(3):16-7. doi:10.1111/nicc.12163** 749
- Literature review on contemporary practices of intraosseous (IO) vascular access in adult patients.
- Great Britain
- Hess T, Böhmer R, Arndt F, et al. Bilateraler intraossärer zugang am humerus bei reanimation eines 3-Jährigen [Case Report- Bilateral humeral intraosseous access for CPR in a 3-years-old child]. *Anästhesiol Intensivmed Notfallmed Schmerzther* 2016;51(07-08):468-74. doi:10.1055/s-0042-110237.** 819
- This article in German describes a case study of a 3 year old child with a serious heart defect (after total cavopulmonary anastomosis) in which bilateral humeral IO access sites were obtained to manage her condition and the patient was discharged after 30 days without neurological deficits. Key messages include that IO access in children should be a primary access route in emergent and urgent situations, unless a suitable venous access is already available; the humeral head insertion site is an accepted method in emergency situations in adults and children; and IO access is intended for regular emergency administration of drugs. The purely preventive use of an IO is not indicated. Article in German.

Intraosseous Vascular Access Bibliography

International

- Malhotra R, Chua WL, O'Neill G. Calf compartment syndrome associated with the use of an intra-osseous line in an adult patient: A case report. *Malays Orthop J* 2016;10(3):49-51. doi:10.5704/MOJ.1611.014.** 868
- This reports a case of left lower extremity compartment syndrome in a multi-trauma patient that received bilateral proximal tibia IO catheters. The patient had 1L crystalloid and 2 units of packed red blood cells infused into his left IO tibial site. While in the operating room the team noticed the left leg was tense and swollen. He was diagnosed with compartment syndrome and fasciotomies were done. A left fibula fracture was also discovered but authors do not believe that or the soft tissue injuries present were enough to cause the compartment syndrome.
- Singapore
- Martinez AM, Pardo ML, Ricarcdio JH.. Perception of discomfort during injection and the need for supplemental anesthesia in the intraossious technique using 4% articaine. *Acta Odontol Latinoam* 2016;29(3):214-8.** 953
- This article describes an experimental study to determine patient perception of discomfort during IO injection for dental procedures involving the mandibular molars. Subjects (N=70) received either IO injection (N=35) or inferior alveolar nerve block (N=35) with articaine/epinephrine. Both groups reported similar rates of supplemental injection (P=0.80) while the IO group reported less perceived discomfort (P=0.00), differing statistically.
- (Colombia)
- Penketh J, McDonald M, Kelly FE. EZ-IO® intraosseous access teaching in the workplace using a mobile 'tea trolley' training method. *Resuscitation* 2016;99:e17-8. doi:10.1016/j.resuscitation.2015.11.016** 860
- This letter to the editor describes a novel training technique employed to provide training to clinicians on use of the EZ-IO system, in 15-minute sessions. Implementation of this program has resulted in 97% of participants reporting an increase in confidence using the EZ-IO system and 100% were able to correctly identify the locations of the devices for their clinical areas.
- United Kingdom
- Petitpas F, Guenezan J, Venduvre T, Scepi M, Oriot D, Mimoz O. Use of intra-osseous access in adults: A systematic review. *Crit Care* 2016;20:102. doi:10.1186/s13054-016-1277-6.** 810
- This article reports the results of a systematic review using PubMed for current evidence through 2015 for intraosseous (IO) vascular access use in adults requiring resuscitative procedures. General anatomy, indications and contraindications and available devices are discussed. Authors determined IO infusion is indicated in all critical situations with difficult vascular access; contraindications are few; and serious complications uncommon.
- France
- Singh S, Aggarwal P, Lodha R, et al. Feasibility study of a novel intraosseous device in adult human cadavers. *Indian J Med Res* 2016;143:275-80. doi:10.4103/0971-5916.182616** 861
- A cadaveric study evaluating the function and safety of a manual, screw IO device designed to gain access to the medullary space. Twelve insertions were performed by the same device operator, of which 10 were successful. The 2 failed insertions were due to overshooting of the needle. The authors concluded the new device could successfully penetrate the bone cortex in adult cadaver bones, and that further testing and comparison to commercially available devices is needed.
- India
- Smereka A, Stawicka I, Czyzewski L. Nurses' knowledge and attitudes toward intraosseous access: Preliminary data. *Am J Emerg Med* 2016;34(8):1724. doi:10.1016/j.ajem.2016.06.031** 850
- A survey study evaluating the perception and use of intraosseous vascular access among nurses in Poland. The study included 210 respondents. Fifteen (15) had previous experience with IO access and 10.9% had received intraosseous access training, suggesting a low level of knowledge. The authors concluded that providing intraosseous vascular access training to nurses will help improve their perception of IO access.
- Poland
- Strandberg G, Lipcsey M, Eriksson M, Lubenow N, Larsson A. Analysis of thromboelastography, PT, APTT and fibrinogen in intraosseous and venous samples-an experimental study. *Scand J Trauma Resusc Emerg Med* 2016;24:131. doi:10.1186/s13049-016-0318-0** 814
- In this porcine study IO and venous samples were analyzed for thromboelastography (TEG), prothrombin time (PT), activated partial thromboplastin time (APTT) and fibrinogen concentration. The IO samples were clinically hypercoagulable, rendering some samples unevaluable; clinically relevant differences were observed for APTT but not for PT and fibrinogen and the TEG demonstrated a shortened reaction time. The ability to use IO drawn blood for coagulation studies may be limited.

Intraosseous Vascular Access Bibliography

International

Szarpak L, Czyzewski L, Woloszczuk-Gebicka B, Krajewski P, Fudalej M, Truszewski Z. Comparison of NIO and EZ-IO intraosseous access devices in adult patients under resuscitation performed by paramedics: A randomized crossover manikin trial. *Am J Emerg Med* 2016;34(6):1166-7. doi:10.1016/j.ajem.2016.03.017. 774

This randomized crossover manikin trial compared the NIO and EZ-IO devices for time to placement and ease of use. For both parameters the NIO performed better.

Poland

Szarpak L, Kurowski A, Adamczyk P, Czyzewski L, Truszewski Z, Zasko ZP. Are junior doctors trained to use intraosseous access? *Am J Emerg Med* 2016;34(1):107. doi: 10.1016/j.ajem.2015.10.020 844

A questionnaire study among sixty junior doctors, in Poland, regarding their knowledge of intraosseous vascular access. The authors concluded the level of knowledge was insufficient.

Szarpak L, Ramirez JG, Buljan D, Drozd A, Madziala M, Czyzewski L. Comparison of Bone Injection Gun and Jamshidi intraosseous access devices by paramedics with and without CBRN person protective equipment. A randomized, crossover, manikin trial. *Am J Emerg Med* 2016;34(7):1307-8. doi:10.1016/j.ajem.2016.04.032 843

A manikin study in which 40 paramedics dressed with and without CBRN PPE attempted to establish tibial intraosseous (IO) access using the jamshidi and BIG devices, time to placement was measured. Results showed that in participants with and without CBRN PPE, BIG access was faster than Jamshidi.

Szarpak L, Truszewski Z, Smereka J, et al. A randomized cadaver study comparing first-attempt success between tibial and humeral intraosseous insertions using NIO device by paramedics. *Medicine* 2016;95(20):e3724. doi:10.1097/MD.00000000000003724 845

A prospective study comparing use of the NIO device by 84 paramedics to establish proximal humerus and proximal tibia intraosseous (IO) access for first attempt success rate, time to access, and user feedback on ease of use and preference. IO access was established in fresh (within 72 hours of expiration) cadavers. The first attempt success rate with tibial IO access was 89.3% vs 73.8% humeral; procedure time was significantly faster for the tibial IO site; and participants found IO access in the proximal tibia as easier to obtain than the proximal humerus IO site.

Szarpak L, Truszewski Z, Smereka J, Krajewski P, Fudalej M. Ability of paramedics to perform intraosseous access. A randomized cadaver study comparing EZ-IO and NIO devices. *Resuscitation* 2016;104:e5-e6. doi:10.1016/j.resuscitation.2016.04.011 795

This letter to the editor describes a prospective, randomized, cross-over cadaveric study that evaluated use of the EZ-IO and NIO devices by novice paramedic device users. Following a brief in-service on use of both devices and practice insertions using a leg-trainer manikin, each participant attempted to establish IO access using each device in a resuscitation simulation with in an adult cadaver with CPR in progress. Results showed first attempt success rates of 97.4% with the NIO and 100% with the EZ-IO; and mean time to insertion was 16.8 seconds with the NIO and 42 seconds with the EZ-IO.

Wang Y, Zu L, Gao W, Yu X, Liu S, Zhang M. Status quo study of the medical staffs in intraosseous infusion in Beijing area. *Chinese Journal of the Frontiers of Medical Science* 2016;8(9):77-81. doi:10.12037/YXQY.2016.09-09 837

This article describes a questionnaire study regarding knowledge and application of intraosseous vascular access among 420 clinical medical staff in 8 Beijing Hospitals. Based upon results of the questionnaire, the authors concluded that the awareness rate of intraosseous infusion in Chinese medical staffs and carry-out rate in the hospital is very low and strengthening of knowledge and training is necessary.

Zasko P, Szarpak L, Kurowski A, Truszewski Z, Czyzewski L. Success of intraosseous access procedure in simulated adult resuscitation. *Crit Care Resusc* 2016;18(2):134 834

A simulation study comparing use of peripheral IV access and tibial intraosseous access via the NIO device, by internal medicine specialists. Forty-three participants attempted to establish access using the two methods in a manikin; first attempt success, time to access and ease of procedure were measured. The NIO device was superior to IV access with regard to all endpoints.

YEAR: 2015

Eriksson M, Strandberg G, Lipcsey M, Larsson A. Intraosseös provtagning kan vara vardefull i akuta lagen [Intraosseous sampling can be valuable in emergency situations]. *Lakartidningen* 2015 Feb 24;112pii:DCR3. Swedish 789

This article in Swedish describes a study evaluating use of aspirate obtained from the IO space for laboratory analysis. The authors note that point-of-care equipment should be used for analysis. Creatinine, morphine and troponin was successfully analyzed; leucocytes and platelets were noted to possibly cause falsely elevated values.

Intraosseous Vascular Access Bibliography

International

- Eriksson M, Strandberg G, Lipcsey M, Larsson A. Troponin I can be determined in intraosseous aspirates in a porcine shock model. Clin Lab 2015;doi:10.7754/Clin.Lab.2015.141212** 758
- A preclinical study in which 8 anesthetized swine were put into an induced septic shock state to allow troponin I level measurements to be compared from serial venous plasma, arterial plasma and intraosseous aspirate specimens collected hourly. Two milliliters of IO aspirate were wasted before collecting each IO specimen for analysis. The levels of IO troponin I increased during the first 3 hours of shock but then plateaued at a high level while the venous and arterial levels continued to increase. Authors concluded that troponin I can be analyzed in bone marrow aspirates in a shock model and that this information may be useful in medical emergencies where cardiac damage is suspected to be involved.
- Hammer N, Möbius R, Gries A, Hossfeld B, Bechmann I, Bernhard M. Comparison of the fluid resuscitation rate with and without external pressure using two intraosseous infusion systems for adult emergencies, the CITRIN (comparison of intraosseous infusion systems in emergency medicine)- study. PLoS ONE 2015;10(12):e0143726. doi:10.1371/journal.pone.0143726** 791
- A cadaveric study performed by twenty-seven medical students, inexperienced with IO vascular access, that compared use of the EZ-IO for access in the proximal humerus and proximal tibia insertion sites and the FASTR for access in the sternum. First pass insertion success, insertion times, and one minute flow rates using external pressures from 0 to 300 mmHg were evaluated. The authors concluded that both the EZ-IO and FASTR devices may be effective IO devices and are likely suitable for fluid resuscitation using a pressure bag.
- Helm M, Haunstein B, Schlechtriemen T, Ruppert M, Lampl L, . Gäßler M. EZ-IO® intraosseous device implementation in German Helicopter Emergency Medical Service. Resuscitation 2015;88:43-7. doi: 10.1016/j.resuscitation.2014.12.015.** 737
- Retrospective analysis of IO needle insertions performed in all HEMS missions during the first three years (2009-2011) using the EZ-IO® system. Overall success rate of EZ-IO procedures (N=348) was 99.6%, with a first attempt success rate of 85.9%; and high user satisfaction rate of 93%. IO as access was mostly second line overall but first line in children <7, trauma and cardiac arrest. There was one failure and four needle insertion problems noted; no serious complications.
- Germany
- Hill SL, Thomas SHL, Flecknell PA, et al. Rapid and equivalent systemic bioavailability of the antidotes HI-6 and dicobalt edetate via the intraosseous and intravenous routes. Emerg Med J 2015;32(8):626-31. doi: 10.1136/emermed-2014-204171** 751
- A preclinical study evaluating the bioavailability of antidotes HI-6 oxime and dicobalt edetate when given via proximal tibia intraosseous (IO) access, established via the EZ-IO, compared to intravenous administration via central access in minipigs. Results showed rapid and similar systemic bioavailability of the antidotes when given by both routes and that IO access is an appropriate access route when IV access is impractical.
- Ohchi F, Komazawa N, Mihara R, Minami T. Comparison of mechanical and manual bone marrow puncture needle for intraosseous access; a randomized simulation trial. Springer Plus 2015;doi:10.1186/s40064-015-0982-y** 766
- A simulation study comparing use of manual (Cook Medical) and mechanical (Arrow EZ-IO) intraosseous (IO) devices to establish IO access in mannequin bones representing infant, pediatric and adult tibias. Twenty-two anesthesiologists with no prior experience with IO devices participated in the study. The outcome measures were success rate, insertion time and operator reported difficulty of use. Results were in favor of the mechanical device for insertion time in each category, and success rate in the adult tibia group; there was no statistical difference in the difficulty of use evaluation.
- Strandberg G, Larsson A, Lipcsey M, Michalek J, Eriksson M. Intraosseous and intravenous administration of antibiotics yields comparable plasma concentrations during experimental septic shock. Acta Anaesthesiol Scand 2015;doi: 10.1111/aas.12454** 738
- Preclinical study using a porcine model to determine whether there were differences in intraosseous (IO) and intravenous (IV) antibiotic (cefotaxime and gentamicin) concentrations during septic shock. Both methods of administration yielded comparable concentrations. Authors concluded in an emergency, IO administration of these antibiotics may be considered in severe infections when venous access is difficult
- Sweden
- Ventura AMC, Shieh HH, Bousso A, et al. Double-blind prospective randomized controlled trial of dopamine versus epinephrine as first-line vasoactive drugs in pediatric septic shock. Crit Care Med 2015;43(11):2292-302. doi:10.1097/CCM.0000000000001260** 840
- This article describes a prospective double-blind randomized controlled study evaluating the difference between use of dopamine and epinephrine as first-line vasoactive drug in pediatric septic shock patients. This study conducted in the pediatric intensive care unit (PICU) of Hospital Universitario da Universidade de Sao Paulo, Brazil. One hundred twenty-one patients aged 1 month to 15 years who met criteria were randomized to receive either epinephrine (n=57) or dopamine (n=63) via IV or intraosseous (IO) vascular access (via EZ-IO). The authors concluded dopamine was associated with an increased risk of death and healthcare-associated infection; whereas administration of epinephrine via IV or IO routes was associated with increased survival.
- Zu L, Zhou B, Wang Y, Gao W. The history, current situation and future of bone marrow intraosseous infusion. Chin Med Frontier Mag 2015;7(1):114-9.Chinese** 888
- This is a review article written in the Chinese language describing intraosseous vascular access.

Intraosseous Vascular Access Bibliography

International

YEAR: 2014

- Abbal B, Perbet S, Pereira B, et al. Utilisation de la voie intraosseuse chez l'adulte en France en 2012 [Use of the intraosseous access in adult patients in France in 2012]. Annales Francaises d'Anesthesie et de Reanimation 2014;33(4):221-6. <http://dx.doi.org/10.1016/j.annfar.2014.02.006>** 696
- This article in French is a survey of residents and doctors in France that practice in ED, ICU and anesthesiologists units seeking their opinions and practice habits in regard to IO access. Only 29% had ever used an IO kit; with a correlation between years of experience in practice and use of IO access. 555 had received some IO access training; 90% of untrained doctors believed training was necessary. The powered system was the most utilized (EZ-IO).
France
- Barnard EBG, Moy RJ, Kehoe AD, Bebarta VS, Smith JE. Rapid sequence induction of anesthesia via the intraosseous route: a prospective observational study. Emerg Med J 2014;32(6):449-52. doi:10.1136/emmermed-2014-203740** 702
- A prospective observational study that evaluated use of intraosseous vascular access for delivery of rapid sequence intubation (RSI) drugs. Data was collected between January and May 2012 at a combat hospital in Afghanistan. Thirty-four (34) patients underwent RSI with drug delivery via the IO route. Access was established in the proximal humerus and tibia using the EZ-IO and in the sternum using the FAST-1. All placements were successful on first attempt; first pass intubation success rate was 97%; a Cormack-Lehane (C-L) laryngoscopic grade view of 1 was reported 91%. Authors concluded that IO access is a safe and feasible route for delivery of anesthetic drugs for RSI.
- Chansa E, Kansen K, Gustafsson B. [An intraosseous blood transfusion in a critically ill child] Une transfusion sanguine par voie intraosseuse chez un enfant gravement malade. Afr J Emerg Med 2014;4(2):83-5. <https://doi.org/10.1016/j.afjem.2013.05.003>** 658
- This article describes a case study of a 31-month old infant that suffered hypovolemic shock due to severe epistaxis. After several failed peripheral and central line attempts an 18g needle was inserted intraosseously through the proximal tibia. The child received 300 mL of Ringer's Lactate in one hour then 200 mL of blood via the IO route by syringe boluses resulting in improvement. Cloxacillin was also administered IO as prophylaxis for infection. Authors conclude an IO blood transfusion should be the immediate intervention in similar life-threatening situations.
Zambia
- Cheung WJ, Rosenberg H, Vaillancourt C. Barriers and facilitators to intraosseous access in adult resuscitations when peripheral intravenous access is not achievable. Acad Emerg Med 2014;21:250-6. doi:10.1111/acem.12329** 705
- This survey study sought to identify the barriers and facilitators to use of intraosseous vascular access for adult resuscitations when peripheral IV (PIV) access is not available, among physicians from various clinical care settings in 3 teaching hospitals in Ottawa, Ontario. Completed survey responses were received from 205 physicians; results suggest that to increase IO use educational interventions need to address their attitudinal, normative, and control beliefs. Specific beliefs that act as barriers are described.
Canada
- Craiu M, Stan V, Cochino AV. Intraosseous access-A classical method for vascular access that regains an important role as resuscitation tool. Ro J Pediatr 2014;68(3):233-7. Romanian** 968
- This article reviews the initial development of IO access and provides an overview of IO use in pediatric populations including insertion technique, side effects, and contraindications.
English and Romanian article
- Cullen PM. Intraosseous cannulation in children. Anaesth Intensive Care Med 2014;15(12):567-9** 734
- This article presented a general overview of IO use in pediatrics. The history, techniques, anatomy and physiology, complications and a short discussion of most devices on the market, including the EZ-IO, were discussed.
UK
- Danz M, Schulz G, Hinkelbein J, Braunecker S. Breaking the needle: A rare complication on EZ-IO removal. Eur J Anaesthesiol 2014;31:172-80** 742
- This letter to the editor describes a single case of a needle breaking off after a proximal tibial insertion of the EZ-IO into a volunteer (one of the letter's authors) during a training session. "Divergent from manufacturer instructions the sterile steel stylet was put back into place to achieve better grip for a manual pull-out. Under steady pull in strict axial alignment and gentle clockwise turn, the needle broke away from the plastic connector". The needle was extracted using combination pliers and there is no evidence of damage to the leg. Authors acknowledge this can be avoided by adherence to manufacturer's directions for use.
Germany

Intraosseous Vascular Access Bibliography

International

Demir OF, Aydin K, Akay H, Erbil B, Karcioğlu O, Gulalp B. Comparison of two intraosseous devices in adult patients in the emergency setting: a pilot study. Eur J Emerg Med 2014;DOI:10.1097/MEJ.0000000000000187

735

This was a prospective, randomized controlled clinical pilot study comparing the BIG and EZ-IO intraosseous (IO) vascular access devices in 52 adult patients admitted to an emergency department with difficult peripheral venous access. Twenty-six patients were randomized to each device; results were first attempt insertion success BIG 92.3%, EZ-IO 84.6% (P=0.668); procedure time: BIG 2.8 ± 1.2 seconds, EZ-IO 5.2 ± 2.2 seconds (P<0.001), significant; difficulty of use (with visual analogue scale): BIG 8.6 ± 6.4 mm, EZ-IO 25.4 ± 12.6 mm (P<0.001), significant. Authors concluded both EZ-IO and BIG are shown to be reliable and safe methods for insertion of intravascular access in emergency conditions. There were no adverse events or complications reported.

Turkey

Derikx HJGM, Gerritse BM, Gans R, vander Meer NJM. A randomized trial comparing two intraosseous access devices in intrahospital healthcare providers with a focus on retention of knowledge, skill, and self-efficacy. Eur J Trauma and Emerg Surg 2014;doi:10.1007/s00068-014-0385-8

706

This article describes a randomized trial comparing the retention knowledge, skill and self-efficacy among anesthesiologists and registered nurses of anesthesia with use of the EZ-IO and Bone Injection Gun (B.I.G.). Participants were randomized to be trained on one device and were tested at 0, 3, and 12 months post training. The authors concluded that training anesthesiologists on use of the EZ-IO with the educational tools provided by the manufacturer will ensure optimal performance for a period of one year.

The Netherlands

Egyptian Pediatric Association Gazette. Hot topics in neonatology: Lecture given at the EPA's national conference-1.1.10. Vascular access. Egypt Pediatr Assoc Gazette 2013;61:92-5. <http://dx.doi.org/10.1016/j.epag.2013.11.007>

707

This article identifies new concepts and changes in neonatal resuscitation discussed at the Egyptian Pediatric Association national conference. Intraosseous vascular access is included stating, "temporary intraosseous access to provide fluids and medication to resuscitate critically ill neonates may be indicated following unsuccessful attempts to establish intravenous vascular access or when caregivers are more skilled at securing intraosseous access."

Egypt

Fischer H, Bachmann K, Strunk G, et al. Translation of ERC resuscitation guidelines into clinical practice by emergency physicians. Scand J Trauma Resusc Emerg Med 2014;22:9. doi:10.1186/1757-7241-22-9

708

The objective of this study was to use a competency exam to compare different emergency skills and knowledge between out of hospital emergency physicians (OOHEP) and those who are not OOHEP at the time of their mandatory biannual refresher courses. Results from 836 respondents suggested that OOHEP are significantly more likely to initiate intraosseous access, initiate mild-therapeutic hypothermia, and had higher knowledge about the used defibrillator.

Austria

Goldschalt C, Doll S, Ihle B, Kirsch J, Mutzbauer TS. Intraosseous vascular access through the anterior mandible- a cadaver model pilot study. PLoS ONE 2014;9(11):e112686. doi:10.1371/journal.pone.0112686

790

A cadaveric study performed by dentistry and medical students evaluating the feasibility of gaining vascular access via the anterior mandible bone.

Hess T, Bohmer R, Stuhr M, Kerner T.. Invasive Notfalltechniken- der intraossare zugang. Anasthesiol Intensivmed Notfallmed Schmerzther 2014;49:576-85

744

This article discusses use of IO access in adults in children with regard to implementation, indications, problems and risks.

German

Ibrahim M, Cairney K. A comparison of intravenous and intraosseous vascular access during simulated cardiac arrest on an Advanced Life Support course. Resuscitation 2014;85S:S20

711

This abstract describes a simulation study that evaluated the time to access and rate of first attempt success for establishing IV and proximal humerus IO access in an ALS training course. Thirty-three participants had a first attempt IV success rate of 70% compared to a 100% success rate with IO access. The authors concluded that successful humeral IO access can be achieved following a short education intervention.

UK

Intraosseous Vascular Access Bibliography

International

- Kurowski A, Timler D, Evrin T, Szarpak T. Comparison of three different intraosseous access devices for adults during resuscitation: randomized cross-over manikin study. Am J Emerg Med 2014;32:1490-3. DOI: <http://dx.doi.org/10.1016/j.ajem.2014.09.007>** 739
- Manikin study conducted in Poland with 107 paramedic operators designed to investigate the success rate, time of insertion and perceived difficulty of intraosseous access devices during simulated resuscitation using the EZ-IO, Bone Injection Gun and Jamshidi needles. Results were first attempt success: B.I.G.: 91.59%; EZ-IO: 82.66%; Jamshidi: 47.66%; mean procedure time: B.I.G.: 2.0 min \pm 0.7; EZ-IO: 3.1 min \pm 0.9; Jamshidi: 4.2 min \pm 1.0; and ease of use (1-very easy to 5-very hard): B.I.G.: 1.83; EZ-IO: 2.92; Jamshidi: 4.68.
- Poland
- Kwon OY, Park SY, Yoon TY. Educational effect of intraosseous access for medical students. Korean J Med Educ. 2014;26(2):117-24. <http://dx.doi.org/10.3946/kjme.2014.26.2.117>** 757
- The objective of this study was to evaluate inclusion of IO access in Korean medical education with a selected group of 50 medical students. Students received 1 hour of didactic lecture and a 1 hour hands on session using the EZ-IO and artificial tibias and were tested. Results showed an insertion success rate of 88%. The authors concluded IO access was adequate for medical education in Korea.
- Lewis P, Wright C. Saving the critically injured trauma patient: a retrospective analysis of 1000 uses of intraosseous access. Emerg Med J 2014;31(9):784. doi:10.1136/emered-2014-203588** 714
- This retrospective study reported IO use over a 7-year period during combat operations in Afghanistan by the UK Defence Medical Services. The EZ-IO and FAST1 IO devices were available for use; IO use data was collected from the front line, during helicopter evacuation and at the combat hospital. A total of 1014 IO devices were inserted into 830 adult patients; various medications infused via IO access are listed. Across all cases there were no serious IO complications and 14 minor complications. The author concluded that in the pre-hospital setting in particular and in severely injured trauma patients, IO access should be considered a primary method of obtaining vascular access.
- Lingner M, Niederer O, Majolk J, Kromholz K. Kasuistik: Die intraossäre Infusion als Alternative in der Sepsistherapie beim Erwachsenen [Case report: Intraosseous infusion as an alternative solution in the therapy of septicemia in an adult]. Anesthesiol Intensivmed Notfallmed Schmerzther. 2014;49(2):100-3. doi:10.1055/s-0034-1368674** 698
- Case study of 36 year-old in septic shock with co-morbidities of IV drug abuse, endocarditis, tricuspid valve insufficiency and pulmonary embolism. Initially impossible to obtain PIV or CVC access; then unable to give desired fluids through 22 gauge PIV when finally placed. Proximal humerus IO access was established with the EZ-IO 45 mm needle set and the patient was resuscitated with 30 mL/kg fluids and multiple medications given in first hour. Conclusions included that CVCs are not always possible and volume treatment with an IO placed sooner rather than later, especially in children but also in adults, can be lifesaving. IO systems should be extensively available throughout the clinical setting. Article in German.
- Germany
- Martin Reyes B, Abolafia del Balazo R, Estepa Sanchez A, Garcia Cazalilla M, Camara Anguita S, Rojas Jimenez AM. Emergencies medical services: intraosseous drill in CPR. Resuscitation 2014;85(S):S24** 715
- This abstract describes an observational study evaluating use of the intraosseous drill (EZ-IO) in 20 patients assisted by EMS and receiving CPR within a 3 year period. The study includes 4 pediatric and 16 adult patients. The authors concluded that IO access is a reliable alternative to peripheral venous access and can be implemented fast and with high success rate of CPR in which drugs and fluids are given.
- Spain
- Mochizuki T, Yamashita K, Matsushima H, Yoshino A. A practical seminar on intraosseous needle placement (IO) and point-of-care color Doppler ultrasound confirmation. The Journal of Japan Society for Clinical Anesthesia 2014;34(3):429** 752
- This abstract describes a practice seminar held at the 32nd annual meeting of the Japanese Society of Reanimatology for establishing intraosseous vascular access in simulation using the EZ-IO and using Doppler ultrasound to confirm placement. The authors concluded the EZ-IO system enables immediate vascular access to the central circulation and the Doppler method enables objective recognition of needle misplacement.
- Nadler R, Gendler S, Chen J, Lending G, Abramovitch A, Glassberg E. The Israeli Defense Force experience with intraosseous access. Military Medicine 2014;179(11):1254-7** 740
- Retrospective study of the Israeli Defense Force (IDF) registry from January 1999 through October 2012 to identify all cases in which IO access was attempted. The Bone Injection Gun (B.I.G.) was the device used for IO access. A total 37 attempts were made in 30 patients. First attempt success was 53% with an overall success rate 49% when factoring subsequent attempts. Most frequent cause for failure related to providers skill level, and due to the device design allowing little room for error. This study prompted the IDF to seek an alternative for the B.I.G.
- Israel

Intraosseous Vascular Access Bibliography

International

- Neuhaus D. Intraosseous Infusion in elective and emergency pediatric anesthesia: when should we use it? *Curr Opin Anaesthesiol* 2014;27(3):282-7. DOI: 10.1097/ACO.0000000000000069** 723
General review of IO access, with particular attention to perioperative setting and includes published guidelines of the German Scientific Working Group for Pediatric Anesthesia for use of intraosseous access. The author recommends that for children with known difficult venous access physicians discuss the possibility of IO access preoperatively with the family.
Switzerland
- Oesterlie GE, Petersen KK, Knudsen L, Henriksen TB. Crural amputation of a newborn as a consequence of intraosseous needle insertion and calcium infusion. *Ped Emerg Care* 2014;30(6):413-4** 699
Case study of newborn girl resuscitated with 15 mm EZ-IO catheter placed to her right proximal tibia. Medications given included antibiotics, "fluids" and calcium. Demarcation of the infants skin was noted immediately post-calcium administration; with progression to necrosis. Trans-tibial amputation was performed 1.5 months after initial IO access. Authors concluded calcium extravasation most likely caused the injury but were unable to identify extravasation cause; citing possible needle displacement. Cautionary steps to reduce risk emphasized by authors.
Denmark
- Polat O, Oguz AB, Comert A, Demirkan A, Gunalp M, Tuccar E. Intraosseous access learning curve; is it really practical? *Am J Emerg Med* 2014; 32(12):1543-4.doi: 10.1016/j.ajem.2014.09.018** 747
This letter to the editor describes a cadaver study performed by 50 interns who had never performed IO insertion, to determine if there is a learning curve associated with use of the EZ-IO for establishing IO vascular access in the proximal tibia. Following training each intern performed 10 IO insertions and were timed. The results showed a difference between the first and the eighth attempts resulting in a decrease in time to insertion by half. The authors concluded that practice insertions are necessary to become comfortable with the device.
Turkey
- Schlimp CJ, Solomon C, Keibl C, et al. Recovery of fibrinogen concentrate after intraosseous application is equivalent to the intravenous route in a porcine model of hemodilution. *J Trauma Acute Care Surg* 2014;76(5):1235-42** 717
A preclinical study comparing the recovery of fibrinogen in a porcine model when fibrinogen concentrate is administered via IV and IO access. The study results suggested intraosseous administration of fibrinogen concentrate results in a recovery of fibrinogen similar to that of intravenous administration.
- Sheils M, Ross M, Eatough N, Caputo ND. Intraosseous access in trauma by air medical retrieval teams. *Air Med J* 2014;33(4):161-4** 718
This article explores the use of IO access in the prehospital setting to determine if IO access is sufficient for massive fluid resuscitation in trauma patients or if central venous cannulation should be considered. Massive transfusion is defined as 10 units of blood within 24 hours at a rate of more than 150 mL/minute. Through a review of the literature the authors determine that IO access is rapid with a high success rate, IO access allows a bridge to initiate resuscitation while minimizing on scene delays, and has a low complication profile, all benefits over central venous cannulation.
Australia
- Vassallo J, Horne S, Smith JE. Intraosseous access in the military operational setting. *J R Nav Med Serv* 2014;100(1):36-9** 794
This article describes a prospective, observational study conducted March – July 2011 at the emergency department, Camp Bastion, Afghanistan evaluating use of IO access in 117 patients established using the EZ-IO and the FAST1 devices (76% EZ-IO).
- Vincent-Lambert C, Carpenter AP. Factors affecting the frequency of vascular access via intraosseous cannulation performed by paramedics in Johannesburg. *J Vasc Access* 2014;15(6):503-6. doi:10.5301/jva.5000263** 838
A questionnaire and interview study evaluating the reasons paramedics do not perform intraosseous (IO) vascular access more frequently. Twelve paramedics in Johannesburg, South Africa were interviewed for the study. Results suggested access to inappropriate equipment (pink hypodermic needles), inadequate training, lack of use in hospital Emergency Departments to which they serve, and the perceived invasiveness of the procedure and pain caused during infusion dissuaded paramedics from performing the procedure.
- Young SW, Zhang M, Freeman JT, Mutu-Grigg J, Pavlou P, Morre GA. The Mark Coventry Award: Higher tissue concentrations of vancomycin with low-dose intraosseous regional versus systemic prophylaxis in TKA. *Clin Orthop Relat Res* 2014;472(1):57-65. doi:10.1007/s11999-013-3038-z** 620
This randomized, controlled study compared tissue concentrations at the surgical site of regionally and systemically administered prophylactic vancomycin, in 30 patients undergoing total knee arthroscopy. The antibiotic was administered using three methods: 250mg through IO regional administration in the proximal tibia (IORA); 500mg through IORA; and 1g administered systemically through IV. Results showed the tissue concentration of vancomycin was greater in the 250mg IORA group than the systemic IV group, and the 500mg IORA group had higher concentrations than both groups.

Intraosseous Vascular Access Bibliography

International

Zielinski M, Skitek-Adamczak I, Sip M, Witt M. Ready-to-use devices for intraosseous injections (BIG) in the practice of emergency medical teams in the city and county of Poznan - Primary survey. Polish Annals of Medicine 2014;21:126-30. <http://dx.doi.org/10.1016/j.poamed.2014.07.011>

833

A survey study assessing the knowledge of members of emergency medical teams in Poznan about the BIG intraosseous device.

YEAR: 2013

Barratt JW. Re: reasons for not using intraosseous access in critical illness. Emerg Med J 2013;30(6):516-7. doi:10.1136/emermed-2012-202120

703

This article describes a questionnaire study that was given to UK Role One military clinicians deployed to Afghanistan to assess the level of experience and confidence rating with use of IO access, using the FAST-1 and EZ-IO, and IV access. Thirty-three responses were received; clinicians felt more confident with IV access over IO access; clinicians felt more confident with FAST-1 IO access than EZ-IO IO access.

UK

Fetisssof H, Nadaud J, Landy C, Millot I, Paris R, Plancade D. Amines on intraosseous vascular access: A case of skin necrosis. Ann Fr Anesth Reanim 2013;32(5):e89-90. <http://dx.doi.org/10.1016/j.annfar.2013.02.022>

644

A letter to the editor reporting a case study of skin necrosis after IO administration of norepinephrine following resuscitation of a 74 years old in septic shock. The EZ-IO was placed to the proximal tibia; approximately 45 minutes post- norepinephrine administration symptoms of necrosis were evident.

Authors cite 3 hypotheses for the cause of necrosis and consider that amines' high level concentration could induce local toxicity in the bone matrix and artery spasm; suggesting it is necessary to define an upper limit of amines' concentration that should be administered through IO vascular access.

Hallas P, Brabrand M, Folkestad L. Complication with intraosseous access: Scandinavian users' experience. West J Emerg Med 2013;14(5):440-3. doi:10.5811/westjem.2013.1.1200

669

A questionnaire study in which Scandinavian emergency physicians, anesthesiologist and pediatricians reported complications they have experienced with IO vascular access based on recollection alone. Complications were reported related to establishing IO access and using established IO access. Out of 1,802 IO cases reported by 386 responders, the most frequently reported complications included difficulty with periosteum penetration and bone marrow aspiration when establishing IO access; and slow infusion and needle displacement with established IO access. Osteomyelitis and compartment syndrome were reported with an occurrence of 0.4% and 0.6%. Researchers concluded that potential complications following IO insertion should be addressed during training. Devices discussed included the EZ-IO, BIG, Cook-Surfast, and other unidentified IO devices

Denmar

Hamed RK, Hartmans S, Gausche-Hill M. Anesthesia through an intraosseous line using an 18-gauge intravenous needle for emergency pediatric surgery. J Clin Anesth 2013;25(6):447-51;pii: S0952-8180(13)00202-X. doi: 10.1016/j.jclinane.2013.03.013. <http://dx.doi.org/10.1016/j.jclinane.2013.03.013>. Accessed September 3, 2013

670

This 30 pediatric patient case series describes use of IO access in the perioperative setting when peripheral and central venous access failed during anesthesia administration for emergency surgery. Due to unavailability of modern IO devices, a standard 18-gauge IV needle with a handmade IV extension set were used to establish IO access. The authors reported administering ketamine, succinylcholine, pancuronium, atracurium, halothane, neostigmine, atropine, blood products, fluids and hydrocortisone through the IO line without complication. The authors concluded that although it is not the first-line method for anesthesia, IO access should be considered by pediatric anesthesiologist when peripheral and central venous access has failed or is difficult.

Iraq

Helm M, Richter D, Schramm A, Lampl L, Hossfeld B.. Ist die intraossare punktion ein alternativer gefabzugang beim notfall in der zahnrztlichen praxis? Notfall Rettungsmed 2013;16:27-32. Doi:10.1007/s10049-012-1629-y. German

612

This article in German explores use of intraosseous access in a dental practice emergency. In a simulation study, dental students attempted to establish standard peripheral IV access and IO access using 3 different devices: EZ-IO, BIG, and manual IO. Results showed the manual was the fastest to insert, however, the EZ-IO had the highest first-attempt success rate as well as the lowest number of total attempts to IO access.

German

Junkin R, Litchfield K. Intraosseous vascular access skill acquisition in labour ward staff: results of a training programme. Int J Obstet Anesth 2013;22(1):S31

674

This abstract describes a study in which 66 obstetric anesthetists, obstetricians and midwives were training on the EZ-IO and evaluated for successful application of the skill in a mannequin study. The participants also completed a survey following their insertion attempt regarding their perceived ease of use and likeliness to consider IO use in the future. Results showed first attempt success was 95.5%; respondents indicated they found the EZ-IO to be easier than establishing PIV access and 100% indicated they would consider IO use in the future.

UK

Intraosseous Vascular Access Bibliography

International

- Junkin R, Selfridge J, Litchfield. Intraosseous vascular access in obstetric emergencies: an OAA approved national survey. *Int J Obstet Anesth* 2013;22(1):S31** 673
- This abstract describes the results of an online survey taken by members of the Obstetric Anaesthetists' Association, evaluating use of IO access in obstetric emergencies, and availability of IO equipment on UK labor wards. Results showed many members are trained on IO access, consider it a viable option during emergencies however have limited access to equipment.
- UK
- Larsson T, Strandberg G, Eriksson M, Bondesson U, Lipcsey M, Larsson A. Intraosseous samples can be used for opioid measurements- and experimental study in the anesthetized pig. *Scand J Clin Lab Invest* 2013;73(2):102-6. doi:10.3109/00365513.2012.744088** 605
- In this preclinical swine study, investigators sought to evaluate whether intraosseous blood samples can be used to measure opioids, and if so, to determine the level of accuracy of those measurements. Blood samples were drawn from bilateral tibial IO catheters and from a central venous catheter for six hours. Authors concluded that IO blood samples can be used for the analysis of opioids if an IV route is not available.
- Manrique Martinez I, Pons Morales S, Casal Angulo C, Garcia Aracil N, Castejon de la Encina ME. Accesos intraoseos: revision y manejo. *An Pediatr Contin* 2013;11(3):167-73** 627
- This article in Spanish provides an overview of intraosseous vascular access.
- Article in Spanish
- Mills A, Pappin D, Field V, Thorp-Jones D. Intraosseous access in the peripartum patient: is your needle long enough? *Int J Obstet Anesth* 2013;22(1):S30** 675
- This abstract describes a study in which the investigators sought to determine the approximate patient population in which the 25mm EZ-IO needle set was sufficient length to establish IO access in peripartum patients. Ultrasound was used to determine the tissue depth at four insertion sites. Twenty-six women were recruited with a median gestation of 34 weeks. In 88% of patients with a BMI<40 kg/m² the 25mm needle is sufficient to reach the bone marrow at both tibial sites. For the humeral site, IO placement may be more difficult for patients with a BMI>25 kg/m².
- UK
- Oksan D, Ayfer K. Powered intraosseous device (EZ-IO) for critically ill patients. *Indian Pediatr* 2013;50(7):689-91** 685
- A retrospective chart review evaluating use of the EZ-IO in 25 pediatric patients between July 2008 and August 2010 at a Turkish university affiliated hospital. All attempts were made in the proximal tibia and IO access was attempted following failed PIV access within 60 seconds. First attempt success was 80%; the most reported complication was simple extravasation (3 cases) and needle dislodgement (1 case).
- Turkey
- Plancade D, Millot I, Fetissov H, et al.. Sternal perforation with an intraosseous device and hemomediastinum infusion *Ann Fr Anesth Reanim* 2013;<http://dx.doi.org/10.1016/j.annfar.2013.01.009>** 616
- A 45-year-old woman in hemorrhagic shock with multiple injuries to the limbs, secondary to a war wound, received sternal IO access using the Jamshidi trocar (not specifically intended for sternal use). After initiating a blood transfusion through the IO line a contrast CT scan revealed sternal perforation and hemomediastinum, secondary to the transfusion, as well as drainage into the left pleural cavity. The catheter was removed, right thoracic drainage was performed, and the patient was released from ICU 48 hours later. The authors conclude this case report demonstrates the difficulty in selecting emergency insertion sites and the necessity of choosing an appropriate IO catheter.
- Plancade D, Ruttimann M, Wagnon G, et al.. La perfusion intraosseuse chez l'adulte. *Annales Francaises d'Anesthesie et de Reanimation* 2013;<http://dx.doi.org/10/1016/j.annfar.2013.02.024>. French** 617
- This article in French gives an overview of intraosseous vascular access including the physiology of IO infusion, insertion sites, indications, and complications. Available IO devices on the market are described including, time to insertion, success rate and cost.
- Reinhardt L, Brenner T, Bernhard M, et al. Four years of EZ-IO system in the pre- and in-hospital emergency setting. *Central European Journal of Medicine* 2013;8(2):166-71. Doi:10.2478/s11536-012-0125-6** 618
- An observational study evaluating use of the EZ-IO by two ground and one air based physician staffed EMS and at a German surgical university hospital between January 1, 2008 and December 31, 2011. The EZ-IO was used to establish IO access 88 times in 87 patients; 83 insertions were performed in the EMS and 5 were performed in the hospital. The proximal tibia was the primary site used (97.7%) and the first attempt success rate was 94%. IO access was the first approach for vascular access in children compared to adults (38.9% vs. 86.2%). There were 5 failures attributed to missed insertions or extravasation and 2 for wrong needle length. There were no serious complications.

Intraosseous Vascular Access Bibliography

International

- Rosenberg H, Cheung WJ. Five things to know about intraosseous access. Canadian Medical Association Journal 2013;185(5):E238. Doi:10.1503/cmaj.120971** 619
Five point summary of things to know about intraosseous vascular access including, use of the IO access for fluid/drug/blood product infusion and obtaining blood samples, possible IO insertion sites, pain management, use during resuscitation efforts, contraindications, and possible complications.
- Santos D, Carron PN, Yersin B, Pasquier M. EZ-IO intraosseous device implementation in a pre-hospital emergency service: a prospective study and review of the literature. Resuscitation 2013;84(4):440-5. <http://dx.doi.org/10.1016/j.resuscitation.2012.11.006>** 604
An observational study evaluating use of the EZ-IO in a Swiss pre-hospital EMS system between January 1, 2009 and December 31, 2011 and comparing those results to the literature. Sixty IO insertions were performed on 58 patients; the proximal tibia was used in all attempts except 1 attempt made in the proximal humerus. Overall success rate was 90%; the 6 failures were attributed to impossibility to infuse, difficult needle insertion, and incorrect insertion site (tibial plateau). Some of the indications for IO access included cardiorespiratory arrest, major trauma, and shock; general anesthesia was successfully induced in 7 patients. Drugs infused are listed. There were no serious complications.
- Strandenes G, Skogrand H, Spinella PC, Hervig T, Rein EB. Donor performance of combat readiness skills of special forces soldiers are maintained immediately after whole blood donation: A study to support the development of a prehospital fresh whole blood transfusion program. Transfusion 2013; 53(3):526-30. doi:10.1111/j.1537-2995.2012.03767.x** 570
This study conducted by the Norwegian Navy evaluated the ability of 25 soldiers to perform buddy transfusion by starting phlebotomy, establishing sternal IO access using the FAST1, and infusing 1 unit of whole blood. Physical performance was evaluated pre and post blood donation and lactate levels were recorded. The authors concluded that physical and combat performances are preserved within limits post whole blood donation and that soldiers are able to learn the phlebotomy and sternal reinfusion with only a short lecture on the procedure.
- Torres F, Galán MD, Alonso MD, Suarez R, Camacho C, Almagro V. Intraosseous access EZ-IO in a prehospital emergency service. J Emerg Nurs 2013;39(5):511-4. doi: 10.1016/j.jen.2012.03.005** 572
This observational pre-hospital study conducted in Madrid, Spain prospectively evaluated use of the EZ-IO Jan 2007- Dec 2009 as an alternative to peripheral IV access. During the study period, 107 patients underwent 114 EZ-IO insertions and all were successful on first attempt. IO access was established in the proximal tibia (49%), distal tibia (25.2%), radius (14.9%), and humerus (10.5%) and all lines were the first form of vascular access established in the patient. There were no adverse events or complications.
- Verma PK, Srivastava R, Ramesh KM. Anesthetic efficacy of X-tip intraosseous injection using 2% lidocaine with 1:80,000 epinephrine in patients with irreversible pulpitis after inferior alveolar nerve block: a clinical study. J Conserv Dent 2013;16(2):162-66. doi:10.4103/0972-0707.108202** 839
A study evaluating the use of X-tip intraosseous injection of 2% lidocaine with 1:80,000 epinephrine in dental patients with irreversible pulpitis in whom inferior alveolar nerve block has failed. Thirty patients were included and 93% of X-tip injections were successful. Ninety-six percent of patients had subjective/objective increase in heart rate. Results showed X-tip intraosseous injection of 2% lidocaine was effective in achieving pulpal anesthesia in patients with irreversible pulpitis.
- Weiser G, Poppa E, Katz Y, Bahouth H, Shavit I. Intraosseous blood transfusion in infants with traumatic hemorrhagic shock - a case report and review of the literature. Am J Emerg Med 2013;31(3):640.e3-4. doi: 10.1016/j.ajem.2012.10.036** 646
This article describes a case study of a 5-month old infant that suffered a head injury resulting in shock. She received 100 mL of red blood cells via the EZ-IO in the proximal tibia, resulting in rapid hemodynamic improvement. A literature search was completed for cases of IO blood transfusion in pediatric trauma. Authors note IO availability and knowledge play an important role in hemorrhagic shock; and RBC infusions via the IO route are feasible in this age group.
- Wiese CHR, Semmel T. Aktuelles zum intraossaren Zugang- Weib das team bescheid? Notfall + Rettungsmedizin. 2013; doi:10.1007/s10049-013-1698-6. German** 621
- Young SW, Zhang M, Freeman JT, Vince KG, Coleman B. Higher cefazolin concentrations with intraosseous regional prophylaxis in TKA. Clin Orthop Relat Res 2013;471(1):244-9. doi:10.1007/s11999-012-2469-2** 576
A clinical study comparing Cefazolin concentrations found at the operation site following total knee arthroscopy when prophylactic antibiotics are administered systemically, through IV administration, and regionally, through IO injection directly at the site using the EZ-IO. Subcutaneous fat and bone samples were collected for evaluation from 22 subjects. Authors concluded that regional IO administration of prophylactic antibiotics can achieve tissues levels higher than with systemic administration.

Intraosseous Vascular Access Bibliography

International

YEAR: 2012

- Abrams-Ogg AC, Defarges A, Foster RA, Bienzle D. Comparison of canine core bone marrow biopsies from multiple sites using different techniques and needles. *Vet Clin Pathol* 2012;41(2):235-42. doi: 10.1111/j.1939-165X.2012.00422.x** 664
- A pre-clinical study that compared the EZ-IO 15 gauge 25mm needle set and the 13 gauge Jamshidi aspiration/biopsy needle when used to obtain core biopsy specimens in canines.
- Canada
- Civantos Fuentes E, Rodriguez Nunez A, Iglesias Vazquez JA, Sanchez Santos L. [Evaluacion de la actuacion de los peditras de atencion primaria en un escenario simulado de trauma pediatrico]. *An Pediatr (Barc)* 2012; doi: 10.1016/j.anpedi.2012.01.027. Spanish** 566
- This article in Spanish describes a study in which the management of simulated pediatric multiple trauma cases was compared to the 8 tasks validated in a polytrauma training program from Cincinnati Children's Hospital. The authors concluded that primary care pediatricians have difficulty applying the sequence of trauma and cervical screening maneuvers in a simulated setting and that pediatric training programs should strengthen practical initial care for trauma.
- Esteo OV. Intraosseous access in prehospital emergency care. *Emergencias* 2012;24:44-6** 764
- A prospective, observational study which evaluated use of the EZ-IO within the prehospital setting over the course of a 3 year period, in Barcelona, Spain. Included patients were in cardiac arrest or with hemodynamic instability, without peripheral venous access after 90 seconds or 3 attempts to establish access. Results showed IO access was attempted in 49 pediatric and adult patients with an overall success rate of 93.9%; complications included extravasation and pain. IO access sites included the proximal tibia (71.4%), proximal humerus (22.4%) and distal tibia (6.1%). The author concluded that IO access is a viable access route for the management of critical patients or those in cardiac arrest in the pre-hospital setting due to the ability to obtain rapid access and the high first attempt success rate.
- Ibrahim M, Cairney K. Intraosseous (IO) infusion as a means of vascular access. *Br J Resuscitation* 2012;Autumn:23-6** 599
- This article provides an overview of intraosseous vascular access, including applicable patient population, IO access sites, pain management, IO education and compares IO access to central venous access.
- Isayama K, Nakatani T, Tsuda M, Hirakawa A. Current status of establishing a venous line in CPA patients by emergency life-saving technicians in the prehospital setting in Japan and a proposal for intraosseous infusion. *Int J Emerg Med* 2012;5(1):2. doi:10.1186/1865-1380-5-2** 527
- This article discusses a retrospective review of Japanese prehospital system for intravenous infusion success rates in cardiopulmonary arrest (CPA) patients and a prospective simulation study. A nationwide database was reviewed for CPA records from 1 January 2005 to 31 December 2008 yielding 431,968 cases. Results showed the IV infusion success rate in adults increased annually, however the rate in pediatrics did not; and while the administration of adrenaline increased the 1-month survival rate did not. In the simulation study, 100 EMS technicians used the Bone Injection Gun (BIG) in simulator adult, pediatric and infant legs. There was no difference in the time to establish IO access between the simulation models. The authors concluded that IO access should be considered when IV access is difficult or impossible.
- Mazaheri-Khameneh R, Sarrafzadeh-Rezaei F, Asri-Rezaei S, Dalir-Naghadeh B. Evaluation of clinical and paraclinical effects of intraosseous vs intravenous administration of propofol on general anesthesia in rabbits. *Vet Res Forum* 2012;3(2):103-9** 614
- A preclinical study evaluating the effects of propofol on selected blood parameters and physiological variables during general anesthesia in rabbits when administered via intraosseous and intravenous routes. Results showed the IO route was as effective as the IV route for propofol administration at doses inducing general anesthesia. The authors concluded that use of IO propofol could be recommended as a safe method of anesthesia in small animals with limited vascular access.
- Mazaheri-Khameneh R, Sarrafzadeh-Rezaei F, Asri-Rezaei S, Dalir-Naghadeh B. Comparison of time to loss of consciousness and maintenance of anesthesia following intraosseous and intravenous administration of propofol in rabbits. *J Am Vet Med Assoc* 2012;241(1):73-80** 589
- A pre-clinical study evaluating the time to loss of consciousness and effective maintenance of anesthesia following IO and IV administration of propofol in 24 rabbits. The authors concluded that in all evaluated aspects of anesthesia, IO administered propofol was as effective as IV administration in rabbits
- Murray DB, Eddleston M, Thomas S, et al. Rapid and complete bioavailability of antidotes for organophosphorus nerve agent and cyanide poisoning in minipigs after intraosseous administration. *Ann Emerg Med* 2012;60(4):425-30. <http://dx.doi.org/10.1016/j.annemergmed.2012.05.013>** 587
- A pre-clinical study evaluating the systemic bioavailability of antidotes when administered via the intraosseous (IO), intravenous (IV), and intramuscular (IM) routes is described. Results showed rapid and substantial antidote bioavailability after IO administration similar to that of the IV route. Authors concluded that the IO route of antidote administration should be considered when IV access is difficult.

Intraosseous Vascular Access Bibliography

International

- Olaussen A, Williams B. Intraosseous access in the prehospital setting: literature review. *Prehosp Disaster Med* 2012;27(5):468-72. doi:10.1017/S1049023X12001124. http://journals.cambridge.org/abstract_S1049023X12001124** 582
- A literature review of articles describing intraosseous vascular access devices used in the pre-hospital setting. Twenty articles met the inclusion criteria and described the manual devices, BIG, Fast-1 and the EZ-IO. The authors concluded that the literature suggests that semiautomatic IO devices may be more effective than manual devices.
- Oriot D, Darrieux E, Boureau-Voultoury A, Ragot S, Scepti M. Validation of a performance assessment scale for simulated intraosseous access. *Simul Healthc* 2012;7(3):171-5. doi:10.1097/SIH.0b013e31824a5c20** 581
- This article describes the validation testing of a newly developed performance assessment scale for evaluating the intraosseous manual insertion process in the proximal tibia during simulated procedures. The authors concluded that the scale was a reliable tool to assess the overall IO insertion procedure and that with modifications this scale may be used with other IO devices and in the clinical setting.
- Papakonstantinou MK, Pan WR, Le Roux CM, Richardson MD. New approach to the study of intraosseous vasculature. *ANZ J Surg* 2012;82(10):704-7. doi:10.1111/j.1445-2197.2012.06142.x** 584
- This article describes a post mortem study evaluating a newly developed technique to study the intraosseous vasculature of the humerus involving injection of ink directly into the anterior circumflex humeral artery. This technique allowed visualization of the main nutrient artery to the proximal humerus vasculature until they reached articular cartilage or crossed cortical bone again to enter the rotator cuff tendons.
- Plancade D, Nadaud J, Lapierre M, et al. Feasibility of a thoraco-abdominal CT with injection of iodinated contrast agent on sternal intraosseous catheter in an emergency department. *Annales Francaises d'Anesthesie et de Reanimation* 2012;<http://dx.doi.org/10.1016/j.annfar.2012.10.009>** 580
- This letter to the editor describes a case in which sternal IO access was established using a Jamshidi needle to administer iodinated contrast for a thoraco abdominal CT on a 61-year old male who presented to the ED with respiratory distress. Picture quality was deemed excellent by the radiologists. The authors conclude that the sternal IO route can be used with excellent picture quality but it should be used only in exceptional cases due to the potential risks of a high-power injection through the bone. EZ-IO is mentioned as an alternative IO device available.
- Ribiero de Sa RA, Melo CL, Dantas RB, Delfim LVV. Vascular access through the intraosseous route in pediatric emergencies. *Rev Bras Ter Intensiva* 2012;24(4):407-14** 716
- The authors evaluated use of IO access in pediatric emergencies through a literature review. The objective was to describe the techniques, professional responsibilities, and care related to obtaining IO access.
- Brazil*
- Smith J, Rollin AM. The placement of an intravenous cannula is always necessary during general anesthesia in children: a pro-con debate. *Pediatr Anaesth* 2012;22(5):455-61. doi:10.1111/j.1460-9592.2012.03834.x** 573
- This article argues the pros and cons to routinely establishing IV access in anesthetized children. IO access is discussed in the con debate as an alternative to routine peripheral IV access in this population.
- Vassallo J, Horne ST, Smith JE. Intraosseous access on military operations: a 4 month review. Poster presentation at International Conference on Emergency Medicine, Dublin, Ireland. June 27-30, 2012** 593
- This poster presented at the 2012 International Conference of Emergency Medicine described a 4 month review of intraosseous access in UK military operations in Afghanistan. During the timeframe the EZ-IO was used to establish IO access in the proximal humerus and tibia sites; the FAST1 was used to establish sternal IO access. Of the 87 EZ-IO applications there were 12 functional issues and the placement success rate for both sites combined was 86.3%. In 24 FAST1 applications there were 4 functional issues and the placement success rate was 83.4%.
- Weiss M, Englehardt T. Cannot cannulate: bonulate! *Eur J of Anaesthesiology* 2012;29(6):257-8** 569
- This article is making a case for pediatric anesthesiologists to have IO access equipment readily available wherever children are anesthetized; and for anesthesiologists to consider IO access not only as a last resort but as the route of choice in children requiring urgent vascular access.

Intraosseous Vascular Access Bibliography

International

YEAR: 2011

- Aliman AC, Piccioni Mde A, Piccioni JL, Oliva JL, Auler Junior JO. Intraosseous anesthesia in hemodynamic studies in children with cardiopathy. Rev Bras Anesthesiol 2011;61(1):41-9** 654
A comparative study evaluating the effectiveness of IO access in relation to IV access for infusion of anesthetics (ketamine, midazolam, and fentanyl) and fluids during hemodynamic studies in 21 infants with congenital heart disease. IO access was established in the proximal tibia (n=11). Results showed, time to access was significantly shorter with IO access (3.6 vs 9.6 minutes); anesthetic onset was shorter with IV access (56.3 vs 71.3 seconds); and no significant difference between groups for hydration volume and anesthesia recovery time. The authors concluded that due to its easy manipulation and efficiency, hydration and anesthesia by IO access was satisfactory without necessity of other infusion access.
Brazil
- Auerhammer J. [Lebensbedrohliche arterielle blutung aus der a. carotis communis: Fallstricke bei der intraossaren punktion]. Notfall Rettungsmedizin 2011;14(2):147-150;doi: 10.1007/s10049-010-1380-1. German** 490
This article in German presents a case of a 67-year-old female patient with an arterial bleed and venous access difficulties in whom IO access was attempted unsuccessfully two times using two different IO systems. The author concluded that IO success is dependent upon IO anatomy and physiology knowledge as well as knowledge of the device being used.
- Baombe J, Foex B. Is intraosseous access a safe option in adult cardiac arrest? A review of literature. Critical Care 2011;15(S1):S105. doi:10.1186/cc9714** 594
This abstract reports a literature review using both MEDLINE and Embase databases up to August 2010 to determine feasibility and safety of IO administration during adult cardiac arrest. Authors reported a lack of literature (only two studies met their level of evidence criteria) but concluded IO access in adults appears to be a fast, reliable method to deliver drugs and fluid during CPR allowing adequate drug concentrations and pharmacological response; and should be considered if other medication delivery methods have failed. (Presented at the March 2011 International Symposium on Intensive Care and Emergency Medicine)
- Carreras-Gonzalez E, Brio-Sanagustin S, Guimera I, Crespo C. [Complicacion de la via intraosea en un neonate]. Med Intensiva 2011;doi:10.1016/j.medin.2011.05.004. Spanish** 487
This article in Spanish describes an IO complication case in which a newborn infant developed tissue necrosis as a result of extravasation during IO infusion.
- Cotte J, Prunet B, d'Aranda E, Asencio Y, Kaiser E. [A compartment syndrome secondary to intraosseous infusion]. Ann Fr Anesth Reanim 2011;30(1):90-1. doi: 10.1016/j.annfar.2010.05.038. French** 691
A case study report in French describing compartment syndrome secondary to intraosseous infusion in a 57-year-old burn patient. IO access was established in the proximal tibia on second attempt; both attempts were made in the same limb though it was noted that the first attempt did not penetrate the cortex. Drug and fluid infusion was initiated; ten hours later the limb was found to appear ischemic. The IO catheter was removed and compartment release was performed. The author concluded that IO access remains an important mode of vascular access and that adherence to contraindications and careful clinical monitoring should decrease risk of complications.
France
- Cullen PM. Intraosseous cannulation in children. Paediatric Critical Care 2011;13(1):28-30** 523
This article presented a general overview of IO use in pediatrics. The history, techniques, anatomy and physiology, complications and a short discussion of most devices on the market, including the EZ-IO, were discussed.
UK
- Eich C, Weiss M, Neuhaus D, et al. Handlungsempfehlung zur intraossären infusion in der kideranästhesie [Recommended action for intraosseous infusion in children's anesthesia]. Anästhesiologie 2011;52:S46-52. German** 770
German Society of Anaesthesiology and Intensivmedizin eV" (DGAI), includes a general discussion of intraosseous (IO) as vascular access, overview of devices and recommendations for pediatric anesthesia with indications for intraosseous infusion in pediatric anesthesia and perioperative care in children. Early or primary IO indications are respiratory and circulatory arrest; critical hemodynamic instability before or during anesthesia introduction; severe laryngospasm; anesthesia induction in respiratory bleeding. Urgent indications (decision based on each case is necessary) include urgent induction of anesthesia in non-fasted children (Ileus, RSI); induction of anesthesia in children with unstable circulation or severe cardiac insufficiency. Semi-elective indications (decision based on each case is necessary) after mask induction of anaesthesia (if vascular access required); mandatory induction of "intravenous" anaesthesia (as in malignant hyperthermia). This article is in German.
- Helm M, Hossfeld B, Schlechtriemen T, Braun J, Lampl L, Bernhard M. [Einsatz der intraossaren infusion im deutschen luftrettungsdienst]. Der Anaesthesist 2011;doi:10.1007/s00101-011-1937-5. German** 481
This article in German evaluates use of IO vascular access in rescue missions performed by rescue helicopters of the ADAC (German Automobile Club) Air Rescue as well as the German Air Rescue Service between January 2005 and December 2008. The author concluded that the expanded indication of IO access is relevant in the pre-hospital setting.

Intraosseous Vascular Access Bibliography

International

- Heyder-Musolf J, Giest J, Straub J. Kasuistik-Intraossärer Zugang bei einem 1300 g schweren septischen Neugeborenen[Case history-Intraosseous access on a 1300 g septical premature infant]. *Anesthesiol Intensivmed Notfallmed Schmerzther* 2011;46(10):654-7. doi: 10.1055/s-0031-1291943. [German]** 864
- Case description of a critically ill 15 day old premature infant weighing 1300 g. Tibial IO access was placed perioperatively for an urgent surgery.
- Kellner P, Eggers M, Rachut B. [Der intraossäre zugang in der präklinischen notfallmedizin-indikationen, equipment und durchführung] The Intraosseous access in preclinical emergency medicine-indication, equipment and procedure. *Anästhesiol Intensivmed Notfallmed Schmerzther* 2011;46(5):324-8.doi:10.1055/s-0031-12777974. German** 452
- This abstract in German explores the role of IO infusion in emergency cases with venous access difficulties. The author noted that IO access may help minimize the therapy-free period in which vascular access has not been established, and the preclinical rescue time all together.
- Navarro Suay R, Bartolome Cela E, Hernandez Abadía de Barbará A, Tamburri Barriain R, Rodriguez Moro C, Olivera Garcia J. [Intraosseous access for fluid therapy in combat situations: use by Spanish military medical staff in Afghanistan]. *Rev Esp Anestesiol Reanim* 2011;58(2):85-90** 645
- This article in Spanish describes the Spanish military medical staff's experience with the use of intraosseous lines for fluid therapy in a combat zone from March 2007 to June 2008. Twenty-five patients had an IO placed with the Bone Injection Gun (BIG). Placement success rates were 76% for the 19 pre-hospital placements and 100% for the 6 in-hospital placements. There were no complications during insertion. Conclusion was intraosseous access can provide an alternative to venous access for treating trauma patients in combat zones.
- Neuhaus D. [Intraossärer zugang]. *Notfall Rettungsmed* 2011;14(7):543. doi:10.1007/s10049-011-1445-9. German** 480
- This article in German discusses use of IO access and its multiple applications, focusing on the EZ-IO Infusion System.
- Olaussen A. Best evidence topic reports: which intraosseous device is best in the prehospital setting? *Emerg Med J* 2011;28(8):717-8. doi: 10.1136/emj.2010.108381** 724
- This article describes a literature review study with the objective of establishing which intraosseous device is best for prehospital use. This short review searched Medline 1950-2010, CINAHL 1982-2010 and EMBASE 1980-2010 and identified two studies meeting their evidence search criteria, one study compared the BIG vs. manual; the second compared EZ-IO vs. FAST-1. The clinical bottom line asserted by the author was traditional manual IO devices have faster, better success rates in the pre-hospital setting; but that more randomized trials are needed to determine the best device.
- Australia
- Schalk R, Schweigkofler U, Lotz G, et al. Efficacy of the EZ-IO needle driver for out-of-hospital intraosseous access- a preliminary, observational, multicenter study. *Scand J Trauma Resusc Emerg Med* 2011;19(1):65. doi:10.1186/1757-7241-19-65** 516
- This study conducted in Germany and Switzerland evaluated use of the EZ-IO in the prehospital setting over a 24 month period. The decision to use IO access was left to the discretion of the onsite clinician, a paramedic or an emergency physician. Results showed IO access was attempted in 77 patients, and was successful on first attempt in 75 patients. Significant pain with infusion was reported in the majority of responsive patients.
- Sommer A, Weiss M, Deanovic D, Dave M, Neuhaus D. [Einsatz der intraossaren infusion im padiatrischen notarztdienst: Analyse von notarzteinsetzten 1990-2009]. *Anaesthesist* 2011;60:125-131. German** 488
- This article in German concludes that the introduction of IO in pre-hospital pediatric emergency system has markedly reduced the number of critically ill or severely injured pediatric patients without vascular access or with less reliable alternative administration routes in the last 20 years.
- Strandberg G, Larsson A, Lipcsey M, Eriksson M. Intraosseous blood aspirates analysed by a portable cartridge-based device. *Crit Care* 2011;15(S1):P138. doi:10.1186/cc9558** 571
- In this pre-clinical study, IO and arterial blood samples were collected over a 6-hour timeframe from the tibia of anesthetized swine, analyzed using an iStat and compared. Results showed compliant values between IO and arterial blood for electrolytes, hemoglobin, pH, and pCO2. Lactate, BE, PO2 and SO2 were less compliant. There were high correlations between SO2 and PO2 although the levels in arterial blood were higher.
- Thim T, Grove EL, Krarup NJV, Løfgren B. [Intraossøs adgang]. *Ugeskr Læger* 2011;173(21):1496-8. Danish** 474
- This article in Danish discusses use of the IO route for second line vascular access when peripheral IV access is difficult or impossible.

Intraosseous Vascular Access Bibliography

International

Wechselberger G, Radauer W, Schimpl G, et al. Lower limb salvage in a 7-month-old infant using free tissue transfer. *J Ped Surg* 2011;46:1852-4. Doi:10.1016/j.jpedsurg.2011.06.037 625

A 7-month-old male infant in septic shock from *Neisseria meningitidis* experienced a complication of bilateral extravasation of noradrenalin at the proximal tibia intraosseous infusion site resulting in severe soft tissue necrosis. Necrosectomy was performed bilaterally and surgical interventions were successfully performed to salvage both limbs. At 19 months the patient was able to crawl without extension deficit.

YEAR: 2010

Craiu M, Iordachescu M, Stan I, et al. Alternative intraosseous infusion technique via spinal needle, valuable tool for pediatric resuscitation. *Resuscitation* 2010;81S:S76. doi:10.1016/j.resuscitation.2010.09.312 609

This abstract describes a retrospective case-series analysis of pediatric IO recipients from 1998-2009. Seventy-two (72) patients were included in the study; IO access was established in the proximal tibia (n=61), medial tibia (n=8), distal tibia (n=1), sternum (n=1), and iliac crest (n=1). IO access devices used in the proximal tibia included the Cook Critical Care needle (n=4), the Jamshidi needle (n=2), the BIG (n=1), and an 18 gauge spinal needle (n=54). The authors concluded that a spinal needle can be used to provide IO vascular access in children.

Eich C, Weiss M, Neuhaus D, et al. Intraosseous infusion in paediatric emergency medical care and anaesthesia. *Anasth Intensivmed* 2010;51:75-81. German 972

This article, written in German, gives an overview of intraosseous access in pediatric patients especially with regard to particularly difficult vascular access in the areas of pediatric anesthesia and perioperative care. The article also gives an overview of various devices available to gain IO access, including the Cook needle and the EZ-IO device.

Hulse EJ, Thomas GOR. Vascular access on the 21st century military battlefield. *J R Army Med Corps* 2010;156(4 Suppl 1):s385-90 629

An article evaluating various methods of obtaining vascular access in the management of 21st century battlefield trauma including, peripheral IV access, intraosseous access, venous cut-down, and central venous access. The authors conclude that IO access should be the first line vascular access in casualties with severe trauma to avoid delay initiating resuscitation in pre-hospital or hospital setting.

Kellner P, Eggers M, Rachut B. [Der Einsatz des intraossären Zugangs im präklinischen Notarztdienst: Diskrepanz zwischen Leitlinien-Empfehlungen und Realität] *Notfall Rettungsmedizin* 2010; doi:10.1007/s10049-010-1381-0. German 489

This article in German describes the results of a survey of rescue assistants and physicians, in which they found that IO use was still a rarity in the Berlin emergency medical service and, therefore, presumably nationwide.

Nolan JP, Soar J, Zideman DA, et al. European resuscitation council guidelines for resuscitation 2010 Section 1. Executive summary. *Resuscitation* 2010;81(10):1219-76 689

2010 updated guidelines for resuscitation by the European Resuscitation Council. This update notes IO access as the preferred mode of vascular access for drug administration, over endotracheal administration, when IV access is unavailable. IO blood is also noted as useful for typing and evaluating laboratory values.

European Union

Ota S, Taguchi H, Otake Y, et al. Experience using bone marrow piercing drill EZ-IO system during adult cardiopulmonary resuscitation. *Japan Emerg Med J* 2010;21:143-5. Japan 1007

This paper describes experiences with the EZ-IO device in Japan in 24 adult patients during CPR. The device is not sold in Japan.

Article in Japanese

Turkan H. How does the training effect the use of intraosseous access with a battery driven device? *Resuscitation* 2010;81(2):S93. doi:http://dx.doi.org/10.1016/j.resuscitation.2010.09.380 768

This abstract describes a study in which 60 physicians, nurses, and paramedics naïve to IO vascular access were trained on the Arrow EZ-IO system. After lecture and hands-on training, the clinicians attempted to perform the procedure using a bone model and evaluated the device for ease of insertion, number of attempts, time to insertion, and their opinion on the device. The authors concluded use of the EZ-IO system can result in high success rates of insertion with inexperienced device users.

Werner M, Daniel HP, Hoitz J. [Intraossärer Zugang beim innerklinischen Notfall intensivmedizinischer Fallbericht]. *Der Anaesthesist* 2010;59(7):628-32. German 448

This article in German reports a case of IO access performed in the ICU due to difficult peripheral access. The authors suggested that based on this case different strategies of critical care and possible improvements should be made. .

Intraosseous Vascular Access Bibliography

International

Xie F, Hou KD, Song Q, Jiang CG. The change in bone marrow after intraosseous hypertonic saline-hydroxyethyl starch infusion for resuscitation of hemorrhagic shock in dog. Chin Crit Care Med 2010;22(5):309-12.doi.10.3760/cma.j.issn.1003-0603.2010.05.017 459

This article in Chinese, describes a study that evaluated the effects to the bone marrow following IO infusion of hypertonic saline-hydroxyethyl (HSH) in the dog model; using a normal saline group (NS) and a non-infusion group. The test subjects were put into shock and resuscitated. Results showed that at 48 hours post infusion and 1 week post infusion changes were seen in the bone marrow and peripheral blood in the HSH and NS groups as compared to the non-infusion group. At 4 weeks post infusion, the NS group and HSH group recovered to normal level. Bone marrow morphology changed slightly but no bone necrosis occurred. The author concluded that HSH in small amounts via IO is safe and effective as a fluid resuscitation measure for shock, and little change in bone marrow has been found after infusion.

YEAR: 2009

Fortin JL, Capellier G, Manzon C, Giocanti J, Gall O. Intraosseous administration of hydroxocobalamin in the acute treatment of cyanide poisoning. Burns 2009;35(S1):S15-6. doi: 10.1016/j.burns.2009.06.061. France 801

Case study of a 9- month old treated with IO hydroxocobalamin for suspected smoke inhalation cyanide poisoning. The patient was discharged from the ICU without neurological sequelae. Authors stated the IO route for hydroxocobalamin warrants further exploration to improve ease and speed of treatment.

Johr M. Das kind mit schwierigen venen [The child with difficult venous access]. Anaesthesist 2009;58:861-2. https://doi.org/10.1007/s00101-009-1609-x. German 433

This is a letter to the editor, written in German, that states that intraosseous access supplies should be available in every pediatric care setting. It also stresses the need for proper training and experience in order to use the IO devices safely and effectively.

Plancade D, Ruttimann M, Boulland P, et al. [Evaluation d'un nouveau catheter pour perfusion intra-osseuse en OPEX]. La Revue du CARUM-Réanoxyo 2009;25(2):49-50. French 410

This article describes an observational study performed by the French military air surgical team in Chad. There were 11 patients with no insertion failures. For 7 patients, the insertion site was the proximal tibia and for the remainder the site was the proximal humerus. The authors concluded that the EZ-IO is a device that is simple, reliable and which gives satisfaction for the administration of drugs.

Semjen F, Dobremez E, Bordes H. How to assess the correct position of intraosseous access? A case report. Arch Pediatr 2009; 16: 1298-300. [French] 432

Article in French. English translation not available.

Sunde GA, Thoresen A, Heltne J-K. [Intraossøs tilgang på kritisk syke pasienter - gammel teknikk får ny heder, eller kun for spesielt interessert]? NAForum 2009;22(1):33-7. German 407

This article, in German, describes the technique of IO access, the introduction of two different IO devices (Cook and EZ-IO) and describes IO use in pediatric emergency care.

Toursarkissian M, Schmidbauer W, Breckwoldt J, Spies C. [Präklinischer Einsatz von intraossären Zugängen beim Erwachsenen: Überblick und Anwendungsbeispiele] Preclinical use of intraosseous access (IO) in adults: ILterature review and case reports. Anasthesiol Intensivmed Notfallmed Schmerzther 2009;44(1):22-7. German 416

This review article in German describes intraosseous vascular access, and includes descriptions of the Waismed Bone Injection Gun, Vidacare EZ-IO, Jamshidi and Cook Medical IO devices.

Weiss M, Henze G, Eich C, Neuhaus D. [Intraossäre Infusion: Eine wichtige Technik auch für die Kinderanästhesie]. Der Anaesthesist 9 2009:863-75. Norwegian 406

This article, in Norwegian, describes IO access and modern IO devices, including the Bone Injection Gun, FAST1, and EZ-IO.

Weiss M, Henze G, Eich C, Neuhaus D. Intraossäre Infusion: Eine wichtige Technik auch für die Kinderanästhesie [Intraosseous infusion: an important technique also for paediatric anaesthesia]. Anaesthesist 2009;58(9):863-75.doi. 10.1007/s00101-009-1605-1 German 434

Discusses use of IO for pediatric anesthesia. Specifies importance of equipment, education, guidelines.

YEAR: 2008

Leidel BA, Kirchoff C. [Intraossäre Infusion beim Erwachsenen]. Der Chirurg 2008; 4:315-26. German 402

Article describing IO access.

Intraosseous Vascular Access Bibliography

International

- Salter R. Reply to letter: Blood sampling through intraosseous needles: time to stop? Resuscitation 2008;79:168-9. doi:10.1016/j.resuscitation.2008.04.017** 727
- Two letters to the editor regarding use of IO blood for sampling in the emergency setting. One letter by S. Nicoll and S. Rochester states it should no longer be done and only arterial or femoral venous samples should be used during resuscitation. The second by R. Salter notes the importance of IO blood sampling in emergency situations when time cannot be delayed for central line access, stating it is key that the sample be properly labeled as IO blood.
- UK
- YEAR: 2007**
- Favier JC, Landy C, Pernod G, Walkowiak P, Rottiman M. [Continuous intraosseous epinephrine infusions in adults: its interest when haemodynamics is poor]. Ann Fr Anesth Reanim 2007; 26: 884-5. French** 406
- Article describes the IO route to deliver epinephrine.
- Gagliardi P, Purrone G. [Il potere di salvare vite: l'infusione di liquidi e farmaci in emergenza con accesso venoso non reperibile]. N & A Mensile Italiano del Soccorso 2007; 177: 20-3. Italian** 376
- Article in Italian describing IO access and EZ-IO
- Pugh JA, Tyler J, Churchill TA, Fox RJ, Aronyk KE. Intraosseous infusion into the skull: potential application for the management of hydrocephalus. J Neurosurg 2007;106(2 Suppl):120-5** 859
- A pre-clinical study evaluating use of intraosseous infusion into the skull, in large adult swine, for the purpose of cerebrospinal fluid (CSF) reabsorption. The authors created intraosseous infusion devices designed specifically for use in this study. Results showed IO infusion demonstrated similarities to systemic absorption characteristics; and authors concluded IO skull infusion may eventually provide another alternative in the management of hydrocephalus.
- Canada
- Scheres M. [Nieuw hulpmiddel voor intra-ossale toegang]. Vakblad V & VN Ambulancezorg 2007;1:16-7. Dutch** 373
- Article in Dutch describing IO access and EZ-IO.
- Utkin EV. [Efficacy of intraosseous administration of antibiotics in the treatment of pelvic inflammatory disease in women]. Antibiot Khimioter 2007;52(7-8):37-40. Russian** 404
- Clinical study of intraosseous antibiotic administration in 87 women with acute pelvic inflammatory disease.
- Weiss M, Gächter-Angehrn J, Neuhaus D. [Intraossäre infusionstechnik]. German Interdisciplinary Journal of Emergency Medicine 2007; 10: 99-116. German** 358
- This article in German (with abstract in English) describes IO infusion in detail. It includes techniques, indications, complications, and recommendations. Also describes the various devices available, including Cook, Bone Injection Gun (BIG), First Access for Shock and Trauma (F.A.S.T.1), and the EZ-IO®.
- YEAR: 2006**
- Isbye DL, Nielsen SL. Intraosseous access in adults-an alternative if conventional vascular access is difficulty. Ugeskr Laeger 2006;168(34):2793-7. Abstract** 634
- This article in Danish covers an overview of intraosseous vascular access and its utility in the adult patient.
- Wayne M. [Perfusion intra osseuse chez l'adulte: il est temps d'y penser]. Urgence Pratique 2006; 77: 47-9. French** 371
- Article in French describes IO access and IO devices, including B.I.G., F.A.S.T.1 and EZ-IO®.
- Wayne MA. Adult intraosseous access: an idea whose time has come. Israeli J Emerg Med 2006;6(2):41-5** 638
- The author provides an overview of intraosseous vascular access discussing evolution of the practice, equipment, treatment options and contraindications.

Intraosseous Vascular Access Bibliography

International

YEAR: 2005

Helm M, Gries A, Fischer S, Hauke J, Lampl L. Invasive techniques in emergency medicine. III. Intraosseous puncture--an alternative vascular access in paediatric emergencies. *Anaesthesist* 2005;54(1):49-56 330

Review article on IO vascular access in the pediatric patient. Advises that it is not necessary to adjust doses from IV doses, except for hypertonic solutions. Recommends that IO needle be replaced by an IV within 2 hours to avoid complications.

Abstract only. Article in German

Rodriguez Nunez A, Garcia C, Lopez-Herce Cid J; Grupo de Estudio de la Parada Cardiorrespiratoria en Pediatria. [Is high-dose epinephrine justified in cardiorespiratory arrest in children?]. *An Pediatr (Barc)* 2005;62(2):113-6. Spanish 343

Multicenter, prospective study of cardiopulmonary resuscitation data over 18 months. The study was design to evaluate the impact of survival of IV or IO high-dose epinephrine compared to standard doses in children with cardiorespiratory arrest. Limited conclusions showed that there is no significant difference between the two treatments.

YEAR: 2004

Saglam M, Ugurel S, Kilciler M, et al. [Intraosseous urography compared with intravenous urography: An experimental study in the rabbit model]. *Turk J Vet Anim Sci* 2004; 28: 933-42. Turkish 384

Evaluation of the Bone Injection Gun (BIG) for the administration of contrast media for urography. Concludes that BIG-assisted intraosseous urography may be an effective and reliable alternative to intravenous urography in pediatric and adult human patients.

YEAR: 2003

Carillo A, Lopez-Herce J. [Canalización intraósea]. *An Pediatr Contin* 2003;1(1):38-41. Spanish 653

This article in Spanish discusses general IO principles.

Lake W, Emmerson AJB. Use of a butterfly as an intraosseous needle in an oedematous preterm infant. *Arch Dis Child Fetal Neonatal Ed* 2003;88(5):F409 307

An 18 gauge butterfly needle was inserted into the proximal tibia of a premature infant born at 25-weeks gestation, following inability to establish other modes of vascular access due to gross oedema. The intraosseous line was left in place for 6 days until it was lost; there were no adverse events reported however the author noted that no safety data on long term use of the device was collected.

Lopez BL, Davis-Moon L, Sterious W, Bulette M, Liang-Ma X, Christopher TA. The power infuser: A new device for rapid fluid infusion. *Am J Emerg Med* 2003;21:129-32 302

Study of the Power Infuser, a device that can infuse fluids up to 6 L/hr, on patients presenting to the Emergency Department with evidence of hypovolemia. Resolution of hypovolemia was significantly faster with the Power Infuser compared to gravity infusion.

YEAR: 2001

Orgiler Uranga PE, Navarro Arnedo JM, De Haro Marin S. [The intraosseal route. When the veins have disappeared]. *Enferm Intensiva* 2001;12(1):31-40. Spanish 275

Literature review on intraosseous administration of drugs during pediatric emergencies. Concludes that IO is a valid alternative route for infusion of drugs and other substances into the blood stream with a low complication rate.

YEAR: 2000

Dalenius E. [Reduced but better health care for armed forces]. *Lakartidningen* 2000; 97: 3624-8. Swedish. Abstract 265

Report on reorganization of the medical capacity of the Swedish Armed Forces focusing on new treatment modalities such as intraosseous infusion.

Nijssen-Jordan C. Emergency department utilization and success rates for intraosseous infusion in pediatric resuscitations. *Canadian J Emerg Med* 2000;2(1):10-4 679

A retrospective chart review that evaluated use of IO access in pediatric patient resuscitation in a tertiary emergency department between 1989 and 1995. Results showed IO access was successfully established in 86% of patients. Median time to placement was 8 minutes; two complications of bone fracture were reported in one 10-day-old neonate patient.

Canada

Intraosseous Vascular Access Bibliography

International

Pan'ko SV, Antipov IuG, Semenido IuN, Sosnovskaia Olu, Golovanova TA, Sanin AV. [Suppression of graft versus host reaction by depositing a magnet-controlled adriamycin dosage form in bone marrow allotransplantation in animal experiments]. Vestnik Rossiiskoi Akademii Meditsinskikh Nauk 2000;(3): 10-5. Russian. Abstract 251

Intraosseous transplantation of bone marrow in combination with long-acting Adriamycin may inhibit acute and chronic graft versus host reactions.

YEAR: 1999

Claudet I, Alberge C, Bloom MC, Fries F, Lelong-Tissier MC. [Intraosseous infusion in children]. Ann Fr Anesth Reanim 1999;18:313-8. French 239

A retrospective non-comparative study of IO infusion in 41 children. Concludes that IO insertion is an easy technique. Recommends IO for emergency cases when other vascular access techniques have failed in the first 5 minutes of treatment.

Abstract

Claudet I, Fries F, Bloom MC, Lelong-Tissier MC. [Retrospective study of 32 cases of intraosseous perfusion]. Arch Pediatr 1999; 6: 516-9. French 238

Retrospective study of 32 cases of IO infusion over a 3 year period. Concludes that IO is rapid, safe and effective and provides an essential alternative vascular route in pediatric resuscitation.

Abstract

Efimov IuV, Zaitsev VG, Sychugov AV. [The treatment of patients with complicated mandibular fractures using a method for the intraosseous administration of biologically active drug agents]. Stomatologiya (Mosk) 1999; 78; 26-7. Russian 248

Article in Russian; no English translation.

Feillet F, Borsa A, Monin P. [Intraosseous approach, yes but...]. Arch Pediatr. 1999; 6: 1349-50. French 232

No abstract available.

YEAR: 1998

Nasimi A, Gorin P, Berthier M, Boussebart T, Follet-Bouhamed C, Oriot D. [Use of the intraosseous route in a premature infant]. Arch Pediatr 1998; 5: 414-7. French 231

Case report of a 34-week-old pre-term neonate with septic shock requiring emergency treatment. Umbilical vein was unusable. Resuscitation with IO access was successful. Concludes that IO access be used before attempting access with superior longitudinal sinus.

Abstract

YEAR: 1996

Brandt MR. [Intraosseous administration]. Ugeskr Laeger 1996;158(40):5638. Danish 206

Article in Danish

Dumillard C, Suze N, Duquesne JM, Petri S, Lode N, Maupetit B, Belotte F. [Intraosseous device of perfusion. Apropos of 3 cases before hospitalization]. Cah Anesthesiol 1996;44(1):71-6. French. Abstract 212

Discusses indications, contraindications, method of supervision, and complications intraosseous infusion. Concludes that intraosseous infusion is an attractive alternative to the intravenous route in emergency situations.

YEAR: 1995

Carbajal R, Paupe A, Lenclen R, Blanc P, Olivier-Martin M, Simon N. [Intraosseous infusion in children]. Arch Pediatr 1995;2:339-42. French 191

Case report of successful IO administration colloid, human albumin, and 1.4% sodium bicarbonate via the left hip of a 5-month-old infant with profound hypovolemia. Patient was discharged 4 days after admission.

Abstract only

Maguer D, Delaporte B, Godde F, Amusini P. [Intraosseous infusion: another emergency vascular access]. Arch Pediatr 1995;2(7):704-5. French 198

Article in French.

No abstract available

Intraosseous Vascular Access Bibliography

International

YEAR: 1994

Kil'diushov AN. [Use of heparin in the early post-traumatic period in burns and hemorrhage]. *Anesteziol Reanimatol* 1994; Sept-Oct(5):26-8. Russian 163

Preclinical study in 86 injured dogs with hemostasis disorders. Plasma and platelet disorders normalized 3 hours after the onset of infusion therapy. The response was enhanced by IO infusion of isotonic saline.

Article in Russian-abstract only

Oriot D, Cardona J, Berthier M, Nasimi A, Boussemart T. [Intraosseous vascular access, a technic previously underestimated in France]. *Arch Pediatr* 1994;1(7):684-8. French 190

Review article suggesting that IO infusion should be the primary technique of intravascular access in infants for pediatric resuscitation and the first alternative technique for vascular access after failed intravenous access in young children.

Abstract only

YEAR: 1993

Salino D, Cottin X, Bordenet M. [Intraosseous infusions in pediatric life-threatening emergencies]. *Ann Fr Anesth Reanim* 1993; 12: 469-73. Review. French 154

Case reports of 2 9-month-old infants with severe dehydration treated with IO infusions after failed IV attempts. IO lines were replaced shortly after venous access was obtained.

Abstract only

YEAR: 1992

Ghirga G, Ghirga P, Palazzi C, Befani P, Presti A. [Intraosseous route in pediatric emergencies. Description of 2 clinical cases and review of the literature]. *Minerva Pediatr* 1992; 44: 377-84. Italian 123

Case reports of resuscitation of 2 pre-term infants with medications administered via the intraosseous route. Also includes a short review of the history, physiology, technique, complications and contraindications of IO procedure.

Abstract only

Gut J, Karbula D. [Intraosseous infusions in children]. *Cesk Pediatr* 1992;47:726-7. Czech 133

A review of intraosseous infusion and the possible applications in pediatric emergency medicine.

Abstract only

Zabala Arguelles JI, Maranon Pardillo R, Gonzalez Serrano P, Serina Ramirez C. [Main vascular access in situations of extreme urgency: intra-osseous infusion]. *An Esp Pediatr* 1992;37(6):489-92. Spanish 132

Review article on IO access for a pediatric medicine audience. Concludes that IO administration can be used for all forms of medications. Osteomyelitis appeared in 0.6% of the cases.

Abstract only

YEAR: 1991

Brattebo G, Wisborg T, Mellesmo S. [Intra-osseous infusion--a simple, rapid and lifesaving method]. *Nord Med* 1991;106(1):13-5. Norwegian 118

Discussion of case reports of IO infusion, as well as physiology of IO and technique for IO access. Concludes that IO infusion is simple and safe. The technique can be successfully performed under field conditions by paramedical personnel, even by untrained personnel.

Abstract only

YEAR: 1990

Dollberg S, Gale R. [Intraosseous emergency infusion]. *Harefuah* 1990;119(11):357-8. Abstract-Hebrew 96

Case report of a critically ill preterm neonate who received needed emergency fluids via IO infusion.

YEAR: 1934

Josefson A. A new method of treatment-Intraossal injections. *Acta Medica Scandinavica* 1934;81(5-6):550-64 687

This article describes one clinician's use of sternal IO access for infusion of campolon to treat anemia in 1930. The author performed over 50 injections without serious complications.

Sweden

Intraosseous Vascular Access Bibliography

Intraosseous Overview

YEAR: 2018

- Burgert J, Martinez A, O'Sullivan M, Blouin D, Long A, Johnson A. Sternal route more effective than tibial route for intraosseous amiodarone administration in a swine model of ventricular fibrillation. *Prehosp Emerg Care* 2018;22(2):266-75. doi:10.1080/10903127.2017.1358782** 903

This study examined the measured mean plasma concentration, maximum plasma concentration (Cmax), and time to maximum concentration (Tmax) of amiodarone administered by 3 different routes, sternal IO (SIO), tibial IO (TIO), and IV over a time period of 5 minutes in 21 swine who were randomly assigned to one of the 3 routes. The swine were under general anesthesia and ventricular fibrillation was induced and CPR initiated. After 4 minutes in ventricular fibrillation the swine were administered 300 mg of amiodarone and blood samples were taken at 30 second intervals over 300 seconds. Authors concluded that the SIO and IV routes of amiodarone were comparable. The TIO group took almost 3 times longer to reach Tmax than the SIO and IV groups. In the swine model used in this study, the authors concluded that SIO route was more effective than the TIO route for the amiodarone delivery in a swine with VF and ongoing CPR.

- Collins T. Intraosseous access use in chemical, biological, radiation, and nuclear personal protective equipment. *Prehosp Emerg Care* 2018;22(1):10. http://dx.doi.org/10.1080/10903127.2017.1377791** 910

The objective of this study was to evaluate success and ease-of-use ratings when experienced paramedics attempted EZ-IO intraosseous (IO) access in a cadaveric model when wearing their standard uniform and wearing Chemical, Biological, Radiation and Nuclear (CBRN) personal protective equipment. There was no significant difference for the tasks of land marking, humeral site insertion, saline flush, holding and manipulating driver and catheter removal. Insertion times were statistically longer (by 9.4 seconds) wearing CBRN. Investigator concluded IO access can be effectively and promptly achieved while wearing CBRN.

- Simsek P, Bayram SB, Gursoy A. İlaç uygulamaları için farklı bir yol: Intraosseöz ulaşım ve infüzyon [A different route for drug administration: Intraosseous access and infusion]. *HEAD* 2018;15(1):40-44. doi: 10.5222/HEAD2018.040. Turkish** 1061

This is an article published in a Turkish nursing journal and written in Turkish. From the abstract, the IO route is described as an alternative approach to vascular access when venous access via a peripheral catheter cannot be obtained quickly. Complications of IO access and how to prevent them using nursing interventions are discussed. EZ-IO is discussed in the article.

- Wagner M, Olischar M, O'Reilly M, et al. Review of routes to administer medication during prolonged neonatal resuscitation. *Pediatr Crit Care Med* 2018;19(4):332-8. doi: 10.1097/PCC0000000000001493** 1029

This article presents a review of current evidence regarding different routes for the administration of medications during neonatal resuscitation, of which the intraosseous route is included. A table comparing four different intraosseous devices, including EZ-IO, is presented in the document.

YEAR: 2017

- Afzali M, Kvisselgaard A, Viggers S. Early introduction of intraosseous access ought to be emphasized. *Am J Emerg Med* 2017;35(2):355-6. doi:10.1016/j.ajem.2016.10.062** 897

This journal article discusses the importance of early in medical school and/or residency training of intraosseous access by use of cadaver courses can help increase the skills for IO use needed for use in real life situations thus improving patient safety.

- Bewick VJ. Intraosseous cannulation in children. *Anaesth Intens Care Med* 2017;18(11):551-4. UK** 961

This article describes the anatomy and physiology of IO cannula insertion as well as indications and contraindications of IO use. Devices and techniques as applied to the pediatric population are discussed, including EZ-IO.

- Bielski K, Szarpak L, Smereka J, Ladny J, Leung S, Ruetzler K. Comparison of four different intraosseous access devices during simulated pediatric resuscitation. A randomized crossover manikin trial. *Eur J Pediatr* 2017;176(7):865-71. doi:10.1007/s00431-017-2922-z** 899

This study compared success rate, procedure time and user satisfaction of pediatric NIO vs. Pediatric BIG, EZ-IO and Jamshidi intraosseous access devices in pediatric manikins. Study was randomized, crossover trial with 87 paramedics participating. The study evaluated each device on the ease of use in performing their procedures. Results of this study found that paramedics favored the NIO in ease of use in the pediatric manikins.

- Elliott A, Dubé P, Cossette-Côté A, et al. Intraosseous administration of antidotes-a systematic review. *Clin Toxicol* 2017; 55(10):1025-54. doi:10.1080/15563650.2017.1337122** 917

This study reviews current IO administration of antidotes for patients that have presented to the emergency department with serious poisoning and IV access is not available. The study concluded that the evidence supporting the use of IO route for administering antidotes for poisoning patients is rare. Most evidence of IO access administration of antidotes has occurred in animal studies and case reports. Per author, despite lack of evidence, IO access is a potential option for antidotal treatments for resuscitation for patients where IV access is not available.

Intraosseous Vascular Access Bibliography

Intraosseous Overview

Feinstein B, Stubbs B, Rea T, Kudenchuk P. Intraosseous compared to intravenous drug resuscitation in out-of-hospital cardiac arrest. *Resuscitation* 2017;117:91-6. doi:10.1016/j.resuscitation.2017.06.014 922

This retrospective cohort study evaluated emergency medical services (EMS) that treated adult patients with atraumatic out of hospital cardiac arrest (OHCA) in order to compare drug administration via intraosseous (IO) versus intravenous (IV) and the effectiveness. Study endpoints were survival to hospital discharge, return of spontaneous circulation (ROSC), and survival to hospital admission. The study included 1,800 patients, 1,525 of whom received IV access and 275 who received IO access. The practice for OHCA management in the EMS system from which the data was obtained was to attempt tibial IO access after failed IV attempts. The authors concluded that use of IO access was associated with a lower likelihood of ROSC and hospitalization; and acknowledged that further study of how vascular access routes affect OHCA patient outcomes is warranted.

Rull G. Intraosseous infusion. [Http://patient.info/doctor/intraosseous-infusion](http://patient.info/doctor/intraosseous-infusion). Published February 28, 2017. Accessed August 2, 2018 1015

This article provides an overview of intraosseous infusion including indications, contraindications, types of devices, administration technique, and complications.

YEAR: 2016

Adams TS, Blouin D, Johnson D. Effects of tibial and humerus intraosseous and intravenous vasopressin in porcine cardiac arrest model. *Am J Disaster Med* 2016;11(3):211-8. doi:10.5055/ajdm.2016.0241 896

This study compared maximum concentration time (Cmax) to maximum concentration mean (Tmax) of mean serum concentration of vasopressin, return of spontaneous circulation (ROSC), time to ROSC, with odds of survival to vasopressin administration by tibial intraosseous, proximal humerus intraosseous (PHIO), and intravenous (IV) routes in a cardiac arrest model. Authors concluded TIO and PHIO provide rapid and reliable access in administration of life-saving medications during cardiac arrest and may be faster due to IV difficulty.

Baadh AS, Singh A, Choi A, et al. Intraosseous vascular access in radiology: review of clinical status. *AJR Am J Roentgenol* 2016;207:W1-7. doi:10.2214/AJR.15.15784 756

This article provides a brief overview of intraosseous access for radiologists followed by a discussion of the use of IO access devices in the radiology suite, particularly for CT imaging. The protocol established at the authors' institution for use of the EZ-IO system is described which emphasizes obtaining confirmation of proper IO catheter placement by use of imagery prior to full infusion of contrast medium.

Beaumont D, Baragchizadeh A, Johnson C, Johnson D. Effects of tibial and humerus intraosseous administration of epinephrine in a cardiac arrest swine model. *Am J Disaster Med* 2016;11(4):243-50. doi:10.5055/ajdm.2016.0246 898

This study examined the differences of pharmacokinetics and pharmacodynamics of epinephrine via of tibial intraosseous access and IV access. Interruptions in CPR in order to obtain vascular access reduces the flow of blood to vital organs. Study results showed that TIO access may be a faster alternative to IV access for delivery of vasoactive medications.

Blouin D, Gegel BT, Johnson D, Garcia-Blanco JC. Effects of intravenous, sternal, and humerus intraosseous administration of hextend on time of administration and hemodynamics in a hypovolemic swine model. *Am J Disaster Med* 2016;11(3):183-92. doi:10.5055/ajdm.2016.0238 900

This study was to determine if there were any significant differences between humerus intraosseous (PHIO), sternal intraosseous (SIO) and intravenous (IV) administration of Hextend on the hemodynamics or administration time in a hypovolemic swine model. Time of administration of the Hextend on effects on systolic and diastolic blood pressure, mean arterial pressure, heart rate, cardiac output and stroke volume. After administration of Hextend, data was collected every 2 minutes for 8 minutes total. Results found no significant difference in these measures among the PHIO, SIO or IV groups.

Burgert J. A primer on intraosseous access: History, clinical considerations, and current devices. *Am J Disaster Med* 2016;11(3):167-73. doi:10.5055/ajdm.2016.0236 901

This journal article literature review was written to provide information about the history, clinical considerations, and devices associated with intraosseous access to administer resuscitative drugs when IV access can't quickly or easily obtained.

Burgert J. Intraosseous vascular access in disasters and mass casualty events: A review of the literature. *Am J Disaster Med* 2016;11(3):149-66. doi:10.5055/ajdm.2016.0235 902

This literature review examined the increase in use of intraosseous access for administration of resuscitative fluids and drugs to patients where intravenous access could not quickly or easily obtained during disasters and mass casualty events. The review also included a comparison of IO route to other routes for establishing vascular access in patients that have been involved in mass casualty or disasters.

Intraosseous Vascular Access Bibliography

Intraosseous Overview

- Bustamante S, Cheruku S. Ultrasound to improve target site identification for proximal humerus intraosseous vascular access. *Anesth & Analg* 2016;123(5):1335-7. doi:10.1213/ane.0000000000001543** 904
- In this letter to the editor authors discuss intraosseous access (IO) via proximal anterior tibia and proximal humerus. Per authors, the tibial site was used more frequently due to ease of identifying the landmarks for insertion and accessibility to this area while proximal humerus intraosseous access (PHIO) site can be more difficult to identify landmarks for insertion. The authors discuss the use of ultrasound to identify structures for PHIO access has the potential to increase the success rate of proper site insertion.
- Celik T, Ozturk C, Balta S, Demirkol S, Iyisoy A. A new route to life in patients with circulatory shock: Intraosseous route. *Am J Emerg Med* 2016;34(5):922-23. doi:10.1016/j.ajem.2016.02.035** 906
- In this letter to the editor authors discuss the importance of establishing access to circulatory system during CPR. The authors referenced the study "The effects of proximal and distal routes of intraosseous epinephrine administration on short-term resuscitative outcome measures in an adult swine model of ventricular fibrillation: a randomized controlled study" and the study "Intraosseous versus intravenous vascular access during out-of-hospital cardiac arrest: a randomized controlled trial". Authors concluded that intraosseous access seems reasonable for patients in cardiopulmonary arrest or severe shock that do not have available and quick IV access for administration of medications and fluids.
- Cornell M, Kelbaugh J, Todd B, et al. Pharmacokinetics of sternal intraosseous atropine administration in normovolemic and hypovolemic swine. *Am J Disaster Med* 2016;11(4):233-6. doi:10.5055/ajdm.2016.0244** 911
- This prospective, experimental study was to characterize and compare the pharmacokinetics of atropine that is administered via sternal intraosseous (IO) route in hypovolemic and non-hypovolemic swine. Main outcomes PK parameters, maximum concentration (Cmax) and time to reach maximum concentration (Tmax). Authors concluded sternal IO route is effective for administration of atropine and data gained from this study was found to be similar to previous information reported on tibial IO and IV administration even in situations of significant hemorrhage.
- Drozd A, Madziala M. Nurses' attitudes and beliefs concerning intraosseous access in pediatric patients. *Am J Disaster Med* 2016;34(9):1890. doi:10.1016/j.ajem.2016.06.064** 916
- This study examined the attitudes of nurses working with pediatric patients and intraosseous access in pediatric patients. The study was conducted with the use of a diagnostic survey distributed to 200 nurses, with 135 nurses returning the surveys. The study found that there is a need for more training with nurses to increase their level of knowledge of intraosseous access and improve nurses attitudes for use of intraosseous access in pediatric population in emergency situations.
- Drozd A, Madziala M. Which vascular access technique should be chosen during hypovolemic shock? *Am J Emerg Med* 2016;34(9):1886-7. doi:10.1016/j.ajem.2016.06.070** 824
- In this letter to the editor authors discuss the difficulties of obtaining vascular access in patients in shock; and make a case for use of intraosseous access (IOA) in shock. Authors note IOA access as a safe, effective alternative to venous access with relatively rare complications.
- Poland
- Eriksson M, Larsson A, Lipcsey M, Strandberg G. Emergency intraosseous access: Novel diagnostic and therapeutic possibilities and limitations. *ICU Manag Pract* 2016;16(4):230-2** 1051
- This paper provides a brief overview of IO access and discusses advantages and disadvantages of IO use. Validation of IO blood gases by point-of-care technology, IO administration of antibiotics, IO monitoring of renal function, and IO access in acute cardiac care are also discussed.
- Garside J, Prescott S, Shaw S. Intraosseous vascular access in critically ill adults- a review of the literature. *Nurs Crit Care* 2016;21(3):16-7. doi:10.1111/nicc.12163** 749
- Literature review on contemporary practices of intraosseous (IO) vascular access in adult patients.
- Great Britain
- Petitpas F, Guenezan J, Vendevre T, Scepti M, Oriot D, Mimoz O. Use of intra-osseous access in adults: A systematic review. *Crit Care* 2016;20:102. doi:10.1186/s13054-016-1277-6.** 810
- This article reports the results of a systematic review using PubMed for current evidence through 2015 for intraosseous (IO) vascular access use in adults requiring resuscitative procedures. General anatomy, indications and contraindications and available devices are discussed. Authors determined IO infusion is indicated in all critical situations with difficult vascular access; contraindications are few; and serious complications uncommon.
- France

Intraosseous Vascular Access Bibliography

Intraosseous Overview

Riess ML. New developments in cardiac arrest management. *Adv Anesth* 2016;34(1):29-46.
<http://dx.doi.org/10.1016/j.aan.2016.07.003>

849

This article reviews the best practices for optimal cardiac arrest management, echoing the 2015 ACLS guidelines. Intraosseous vascular access is identified as an access route for delivery of pharmacological agents to aid in patient management.

Schwindt J. Intraosseous access- Of no value in neonatal resuscitation? *Resuscitation* 2016;103:e1.
<http://dx.doi.org/10.1016/j.resuscitation.2016.01.037>

853

In this letter to the editor, the author calls into question the continued recommended use of the umbilical venous catheter in neonatal resuscitation by the European Resuscitation Council and the lack of intraosseous vascular access recommendation. The author makes the argument that accessing the umbilical vein is difficult for even the most experienced NICU clinicians and that time cannot be spared in these resuscitations; and intraosseous access can provide a viable option for drug delivery.

YEAR: 2015

Anson JA, Sinz EH, Swick JT. The versatility of intraosseous vascular access in perioperative medicine: a case series. *J Clin Anesth* 2015;27(1):63-7.
<http://dx.doi.org/10.1016/j.jclinane.2014.10.002>

729

This article presents a 5-case series describing use of IO vascular access by anesthesiologists in the perioperative and critical care settings. All insertions were made in the proximal tibia and there were no adverse events reported. The devices cited as being used were the EZ-IO and the Cook Surfast manual needle. A proposed perioperative vascular access algorithm incorporating IO access is presented. The authors address key topics around IO access including use of same drug dosing as IV administered drugs, frequent palpation and monitoring of the insertion site for extravasation, low complication rate and actual risks associated with fat emboli and bone injury, pain and anxiety management in the awake patient and clinician-perceived pain. Administration of blood products, ACLS drugs, Lactated Ringer's solution and anesthetics are noted without complication. Use of IO aspirate for laboratory testing is noted, however use of the initial aspirate is indicated. Several patients in the case series were reported to find the discomfort of IO insertion preferable to multiple intravenous attempts. The authors concluded: IO lines can be placed quickly and safely in emergency situations or in elective surgical patients with difficult intravenous access; IO access can be useful in a wide variety of clinical settings; and is an important skill for anesthesiologist to learn.

Bradburn S, Gill S. Understanding and establishing intraosseous access (317). *World Federation of Societies of Anaesthesiologists*. June 26, 2015

955

This document is a tutorial provided by the World Federation of Anaesthesiologists geared at understanding and establishing intraosseous access. It provides an overview of venous blood drainage from bones as well as indications, contraindications, common access sites, advice for establishing access, an overview of device types, insertion techniques, and complications.

Cohen J, Duncan L, Triner W, Rea J, Siskin G, King C. Comparison of computed tomography image quality using intravenous vs. intraosseous contrast administration in swine. *J Emer Med* 2015;49(5):771-7. doi:10.1016/j.jemermed.2014.06.036

909

This crossover study using mature mini-swine was performed to assess the efficacy of intraosseous administration of contrast agents for CT (computed tomography) imaging of the chest and abdomen. Authors concluded that in the model used, an injection intraosseous (IO) of contrast through the proximal humerus resulted in improved quality of trauma-protocol CT images.

Douma M, Bara G, O'Dochartaigh D, Brindley P. Double-barrelled resuscitation: a feasibility and simulation study of dual-intraosseous needles into a single humerus. *Injury* 2015;46(11):2239-42. doi:10.1016/j.injury.2015.08.029

915

This study examined whether the use of dual-intraosseous needles to deliver fluid and medication when vascular access is insufficient. The study used a single porcine humerus. The authors concluded that dual intraosseous needles are feasible and may help the rapid resuscitation of patients.

Stimac J. Resuscitation and the humeral intraosseous line. *EM Resident* 2015; <http://www.emresident.org/resuscitation-and-the-humeral-intraosseous-line/>. Accessed June 13, 2015.

763

An overview of IO vascular access with a focus on the proximal humerus IO insertion site.

Zu L, Zhou B, Wang Y, Gao W. The history, current situation and future of bone marrow intraosseous infusion. *Chin Med Frontier Mag* 2015;7(1):114-9.Chinese

888

This is a review article written in the Chinese language describing intraosseous vascular access.

YEAR: 2014

Anson JA. Vascular access in resuscitation: Is there a role for the intraosseous route? *Anesthesiology* 2014;120(4):1015-31

695

Literature review through August 1, 2013 with primary aim to determine whether there is a role for intraosseous vascular access in the resuscitation of critically ill patients. Secondary aims were to investigate the evidence regarding clinical use, drug administration, and complications of IO access. The authors concluded that IO access can be achieved quickly and accurately in emergency situations and there is clearly a role for it in resuscitation of ill patients; anesthesiologists should become familiar with IO access.

Intraosseous Vascular Access Bibliography

Intraosseous Overview

- Cooper IF, Siadaty MS. Diseases or syndromes associated with injection intraosseous: top publications. BioMedLib Review 2014;**<http://bmlreview.com/bld/Wal5L4yR5Ln/BML-Review-DiseaseOrSyndrome-InjectionIntraosseous-706-11955.html> 730
- This literature review article sought to identify the diseases or syndromes most often associated with intraosseous injection within the published literature. The top 35 articles identified in the search are cited within the article; most are related to dental applications.
- Cooper IF, Siadaty MS. Functional concepts associated with injection intraosseous: top publications. BioMedLib Review 2014;**<http://bmlreview.com/bld/Wamk5tyXVD/BML-Review-functionalconcept-injectionintraosseous-706229811.html> 731
- This literature review article sought to identify the functional concepts associated with intraosseous injection within the published literature. The top 40 articles identified in the search are cited within the article.
- Cooper IF, Siadaty MS. Organic chemicals associated with injection intraosseous: top publications. BioMedLib Review 2014;**<http://bmlreview.com/bld/WakgYU2Picf/BML-review-organcichemical-injectionintraosseous-706014831.html> 732
- This literature review article sought to identify organic chemicals associated with intraosseous injection within the published literature. The top 31 articles identified in the search are cited within the article.
- Craiu M, Stan V, Cochino AV. Intraosseous access-A classical method for vascular access that regains an important role as resuscitation tool. Ro J Pediatr 2014;68(3):233-7. Romanian** 968
- This article reviews the initial development of IO access and provides an overview of IO use in pediatric populations including insertion technique, side effects, and contraindications.
- English and Romanian article
- Cullen PM. Intraosseous cannulation in children. Anaesth Intensive Care Med 2014;15(12):567-9** 734
- This article presented a general overview of IO use in pediatrics. The history, techniques, anatomy and physiology, complications and a short discussion of most devices on the market, including the EZ-IO, were discussed.
- UK
- Dev SP, Stefan RA, Saun T, Lee S. Insertion of an intraosseous needle in adults. N Engl J Med 2014;370(24):e35(1)-e35(5). Doi:10.1056/NEJMvcm1211371** 700
- Text article that accompanies video featured in The New England Journal of Medicine on intraosseous access which provides a general overview of IO access and demonstration of IO insertion using the EZ-IO and one manual IO needle set.
- Faminu F. Intraosseous vascular access: boning up on the basics. Nursing 2014;44(8):60-4. doi:10.1097/01.nurse.0000451529.25093.4b** 712
- This article provides an overview of intraosseous vascular access including history, cost and time savings, anatomical sites, infusion pain management, and complications, with a focus on the perspective of the nurse.
- Fowler RL, Lippmann MJ. Benefits vs risks of intraosseous vascular access. Patient Safety Network** 977
- <https://psnet.ahrq.gov/webmm/case/331> Published July-August 2014. Accessed August 6, 2018
- This is a discussion of a case study involving a hospitalized woman who had an IO line placed during a code after becoming unresponsive. Several unsuccessful attempts at peripheral venous access were made prior to IO access. The patient was diagnosed 3 hours later with compartment syndrome due to extravasation that required complex ongoing care in the ICU for 2 months.
- Gurman P, Chi A, Hood T, et al. Prefilled devices for parenteral applications. Expert Rev Med Devices 2014;11(2):205-223** 981
- This review provides a comprehensive summary of pharmacologic therapies that utilize prefilled devices as a delivery mechanism for parenteral application. Six categories are described: endocrine, neurological, pain management, immune disorders, anaphylaxis, and emergency medicine. Within emergency medicine IO access is recommended as an alternative to IV access when IV access cannot be obtained. Various devices for IO access, including the EZ-IO device, are listed.
- Hess T, Bohmer R, Stuhr M, Kerner T.. Invasive Notfalltechniken- der intraossare zugang. Anasthesiol Intensivmed Notfallmed Schmerzther 2014;49:576-85** 744
- This article discusses use of IO access in adults in children with regard to implementation, indications, problems and risks.
- German

Intraosseous Vascular Access Bibliography

Intraosseous Overview

Neuhaus D. Intraosseous Infusion in elective and emergency pediatric anesthesia: when should we use it? *Curr Opin Anaesthesiol* 2014;27(3):282-7. DOI: 10.1097/ACO.0000000000000069

723

General review of IO access, with particular attention to perioperative setting and includes published guidelines of the German Scientific Working Group for Pediatric Anesthesia for use of intraosseous access. The author recommends that for children with known difficult venous access physicians discuss the possibility of IO access preoperatively with the family.

Switzerland

YEAR: 2013

Bloch SA, Bloch AJ, Silva P. Adult intraosseous use in academic Eds and simulated comparison of emergent vascular access techniques. *Am J R Emerg Med* 2013. <http://dx.doi.org/10.1016/ajem.2012.11.021>

652

In a letter to the editor this study reports data collected (during a survey of one third of academic emergency medicine programs in the U.S.) regarding IO use in adults and comparing IO access with other vascular access techniques through simulation. Data suggest that IOs were used less than 5% of the time patients needed emergent access and a peripheral line was unobtainable. The EZ-IO was most often used IO device. Authors conclude IO use should be considered more frequently in critical, unstable patients. (This research was presented at the ACEP Research Forum in 2010).

Harris M, Balog R, Devries G. What is the evidence of utility for intraosseous blood transfusion in damage-control resuscitation? *J Trauma Acute Care Surg* 2013;75(5):904-6. doi:10.1097/TA.0b013e3182a85f71

671

This article explores the use of IO access for blood product administration and whether or not it is clinically effective. Based upon lack of clinical evidence and physics principles, the author argues that maximum flow rates attainable for IO blood infusion are not adequate for resuscitation.

Hunsaker S, Hillis D. Intraosseous vascular access for alert patients. *Am J Nurs* 2013;113(11):34-9

672

This article presents an overview of IO access focused on nurses' use of the technique. A list of available devices, history and support for use and possible complications are included.

Lairet J, Bebar V, Lairet K, et al. A comparison of proximal tibia, distal femur, and proximal humerus infusion rates using the EZ-IO intraosseous device on the adult swine (*Sus scrofa*) Model. *Prehosp Emerg Care* 2013;17:280-4. Doi:10.3109/10903127.2012.755582

642

Pre-clinical study comparing flow rates achieved after insertion with the EZ-IO in the proximal tibia, distal femur, and proximal humerus in a swine model. IO catheters were placed in each site and normal saline was infused for 10 minutes using a pressure bag at the highest achievable pressures greater than 300mmHg. The flow rates through the proximal humerus were statistically greater than that of the femur or proximal tibia. The femur flow rates were higher than the proximal tibia but similar. Post-mortem histopathologic evaluations done to assess for damage due to the high infusion pressures were consistent with IO catheter placement.

Lewis GC, Crapo SA, William JG. Critical skills and procedures in emergency medicine- vascular access skills and procedures. *Emerg Med Clin N Am* 2013;31(1):59-86. doi: 10.1016/j.emc.2012.09.006

631

This article provides an overview of various vascular access modalities in emergency medicine including peripheral IV, venous cut-down, central venous catheter, intraosseous access, umbilical vessel access, and arterial access. The anatomy and physiology, indications and contraindications, procedure steps and special considerations are outlined for each access methods discussed.

Manrique Martinez I, Pons Morales S, Casal Angulo C, Garcia Aracil N, Castejon de la Encina ME. Accesos intraoseos: revision y manejo. *An Pediatr Contin* 2013;11(3):167-73

627

This article in Spanish provides an overview of intraosseous vascular access.

Article in Spanish

Plancade D, Ruttimann M, Wagnon G, et al.. La perfusion intraosseuse chez l'adulte. *Annales Francaises d'Anesthesie et de Reanimation* 2013;<http://dx.doi.org/10.1016/j.annfar.2013.02.024>. French

617

This article in French gives an overview of intraosseous vascular access including the physiology of IO infusion, insertion sites, indications, and complications. Available IO devices on the market are described including, time to insertion, success rate and cost.

Rosenberg H, Cheung WJ. Five things to know about intraosseous access. *Canadian Medical Association Journal* 2013;185(5):E238. Doi:10.1503/cmaj.120971

619

Five point summary of things to know about intraosseous vascular access including, use of the IO access for fluid/drug/blood product infusion and obtaining blood samples, possible IO insertion sites, pain management, use during resuscitation efforts, contraindications, and possible complications.

Intraosseous Vascular Access Bibliography

Intraosseous Overview

Wiese CHR, Semmel T. *Aktuelles zum intraossaren Zugang- Weib das team bescheid? Notfall + Rettungsmedizin. 2013; doi:10.1007/s10049-013-1698-6. German*

621

YEAR: 2012

Barker LT. *In the child with gastroenteritis who is unable to tolerate oral fluids, are there effective alternatives to intravenous hydration? Ann Emerg Med 2012;60(5):607-8. doi: 10.1016/j.annemergmed.2012.04.003*

534

This article, part of a Review Snapshot series in Annals summarizes a literature review (Rouhani et al in Pediatrics 2011) for evidence of alternatives to traditional IV hydration in a dehydrated child. Thirty-eight articles were included for the analysis with five of them randomized controlled trials; and one of those comparing IO to IV rehydration. (Banerjee et al, which found IO placement faster with no therapeutic outcome differences). The focus of this review was on nasogastric tube rehydration as effective when IV fails and as less invasive than IO or CVC placement.

Carr BG, Proehl JA, Fox M, Miller LJ, Philbeck TE. *Intraosseous vascular access: physicians and nurses identify knowledge gaps and barriers to implementation. J Vasc Access 2012;13:13A. doi:10.5301/JVA.2012.9362*

596

This abstract presented at the 2nd World Congress on Vascular Access 2012 reports data collected on the knowledge gaps and barriers to IO vascular access use. Two focus group discussions were held at professional conferences (American College of Emergency Physicians and the Emergency Nurses Association) and facilitated by clinical researchers. Data was qualitatively evaluated and researchers identified several main areas of concern for clinicians in both implementation and knowledge gap areas. This study was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.

Davis DP. *The use of intraosseous devices during cardiopulmonary resuscitation: Is this the answer for which we have been searching? Resuscitation 2012;83(1):7-8. doi:10.1016/j.resuscitation.2011.11.017*

522

This editorial discussed the numerous changes in practice with regard to cardiopulmonary resuscitation, and explored the scientific basis upon which the changes were made. Changes in drug administration and vascular access methods, including IO, are discussed. The author's overall view was that perhaps clinical practice in cardiopulmonary resuscitation is too quickly changed with the presentation of minimal scientific data.

Hallas P, Brabrand M, Folkestad L. *Reasons for not using intraosseous access in critical illness. Emerg Med J 2012;29(6):506-7. doi:10.1136/emj.2010.094011*

438

This article describes a questionnaire study in which members of selected Scandinavian medical societies were surveyed to identify reasons for not using IO access during resuscitation when IV access is difficult. There were 759 evaluable responses from doctors, nurses, and ambulance staff. Of the respondents, 178 (23.5%) had experienced at least one situation where there was an indication for IO but it was not attempted. The most common reason for not using IO was unavailability of equipment (n=86) and lack of training. The author concluded that increased training in IO use and greater availability of IO equipment for front-line staff should be implemented.

Ibrahim M, Cairney K. *Intraosseous (IO) infusion as a means of vascular access. Br J Resuscitation 2012;Autumn:23-6*

599

This article provides an overview of intraosseous vascular access, including applicable patient population, IO access sites, pain management, IO education and compares IO access to central venous access.

Miller LJ, Montez DF, Puga TA, Philbeck TE. *Intraosseous vascular access in the 21st century: improvements further reduce complication rates. Ann Emerg Med 2012;60(4S):S112*

597

This abstract presented at the 2012 ACEP Research Forum discusses a literature review of intraosseous access publications since 1985 providing an updated safety profile for IO access. The search resulted in 192 articles describing IO access with 6 cases of osteomyelitis and 6 cases of compartment syndrome secondary to extravasation reported. Of the 192 articles identified, 140 described the EZ-IO. This study was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.

Olaussen A, Williams B. *Intraosseous access in the prehospital setting: literature review. Prehosp Disaster Med 2012;27(5):468-72. doi:10.1017/S1049023X12001124. http://journals.cambridge.org/abstract_S1049023X12001124*

582

A literature review of articles describing intraosseous vascular access devices used in the pre-hospital setting. Twenty articles met the inclusion criteria and described the manual devices, BIG, Fast-1 and the EZ-IO. The authors concluded that the literature suggests that semiautomatic IO devices may be more effective than manual devices.

Oriot D, Darrieux E, Boureau-Voultoury A, Ragot S, Scepti M. *Validation of a performance assessment scale for simulated intraosseous access. Simul Healthc 2012;7(3):171-5. doi:10.1097/SIH.0b013e31824a5c20*

581

This article describes the validation testing of a newly developed performance assessment scale for evaluating the intraosseous manual insertion process in the proximal tibia during simulated procedures. The authors concluded that the scale was a reliable tool to assess the overall IO insertion procedure and that with modifications this scale may be used with other IO devices and in the clinical setting.

Intraosseous Vascular Access Bibliography

Intraosseous Overview

Page D. Intraosseous intrigue: Studies examine success rates on pediatric, adult & obese patients. JEMS January 2012;32-3 515
In this article, the author discussed five recent studies on intraosseous access providing his opinion about the quality of each study.

Paxton JH. Intraosseous vascular access: A review. Trauma 2012;14(3):195-232. DOI:10.1177/1460408611430175 690
An overview of IO vascular access including a review of currently available literature. The author discusses various IO devices available and their performance metrics, IO access sites, flow rates, advantages and disadvantages of IO access compared to conventional access methods, complications and recommendations on use of the approach. The author concludes that while IO access may not be appropriate for all patients, it deserves a place in the modern provider's armamentarium.

Ribiero de Sa RA, Melo CL, Dantas RB, Delfim LVV. Vascular access through the intraosseous route in pediatric emergencies. Rev Bras Ter Intensiva 2012;24(4):407-14 716
The authors evaluated use of IO access in pediatric emergencies through a literature review. The objective was to describe the techniques, professional responsibilities, and care related to obtaining IO access.
Brazil

Rogers J, Fox M. The safety of intraosseous vascular access. Emergency Medicine Patient Safety Foundation Forum. Fall 2012:18-21 606
An article discussing the technique and safety profile of intraosseous access using the EZ-IO device. Needle selection, contraindications, insertion sites and techniques, catheter stabilization and removal are all discussed along with the safety profile of the EZ-IO against other IO devices and central venous catheters. The authors concluded that IO access should be considered whenever immediate vascular access is required. This article was co-written by an employee of Vidacare Corporation, acquired by Teleflex Incorporated.

Rogers JJ, Fox M, Miller LJ, Philbeck TE. Safety of intraosseous vascular access in the 21st century. J Vasc Access 2012;13:19A 579
This abstract presented at the 2nd World Congress on Vascular Access 2012 describes the results of an analysis of published IO complications since 1985. The safety profile of the EZ-IO is also discussed in this abstract. The authors conclude that new devices and techniques have resulted in an approved IO safety profile. This study was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.

Rose EC. The evidence-based use of intraosseous lines in pediatric patients. Pediatr Emerg Med Pract 2012;9(6):1-12. www.edmedicine.net 585
This article presents a general overview of intraosseous (IO) vascular access in the pediatric population through an IO literature review. Available IO devices were discussed.

Truemper EJ, Beamer CL, Miller LJ, et al. Distal femur site is a viable option for IO vascular access in pediatric patients. Ann Emerg Med 2012;60(4S):S90 761
This abstract presented at the 2012 ACEP Research Forum explored the viability of the distal femur as an IO insertion site with a literature review of IO vascular access and brief overview of a post-mortem study of pediatric distal femur insertion success. Authors concluded that clinical literature, clinical studies, and a post-mortem study confirm that the distal femur is a viable option for IO infusion in pediatric patients. This study was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.

Voigt J, Waltzman M, Lottenberg L. Intraosseous vascular access for in-hospital emergency use: A systematic clinical review of the literature and analysis. Pediatr Emerg Care 2012;28(2):185-99 562
In this article the authors review the evidence supporting the use of IO access; determine the utilization IO access as described in the literature; and assess the level of specialty society support. Various IO devices are mentioned including the EZ-IO

Weiss M, Englehardt T. Cannot cannulate: bonulate! Eur J of Anaesthesiology 2012;29(6):257-8 569
This article is making a case for pediatric anesthesiologists to have IO access equipment readily available wherever children are anesthetized; and for anesthesiologists to consider IO access not only as a last resort but as the route of choice in children requiring urgent vascular access.

YEAR: 2011

Baombe J, Foex B. Is intraosseous access a safe option in adult cardiac arrest? A review of literature. Critical Care 2011;15(S1):S105. doi:10.1186/cc9714 594
This abstract reports a literature review using both MEDLINE and Embase databases up to August 2010 to determine feasibility and safety of IO administration during adult cardiac arrest. Authors reported a lack of literature (only two studies met their level of evidence criteria) but concluded IO access in adults appears to be a fast, reliable method to deliver drugs and fluid during CPR allowing adequate drug concentrations and pharmacological response; and should be considered if other medication delivery methods have failed. (Presented at the March 2011 International Symposium on Intensive Care and Emergency Medicine)

Intraosseous Vascular Access Bibliography

Intraosseous Overview

- Cullen PM. Intraosseous cannulation in children. *Paediatric Critical Care* 2011;13(1):28-30** 523
This article presented a general overview of IO use in pediatrics. The history, techniques, anatomy and physiology, complications and a short discussion of most devices on the market, including the EZ-IO, were discussed.
UK
- Guthrie K. Intraosseous access and the emergency nurse. *Australas Emerg Nurs J* 2011;14(1):S9. doi:10.1016/j.aenj.2011.09.025** 511
This abstract explored the clinical utility of intraosseous vascular access and its development from exclusive use in children to widespread utility in the adult patient.
- Harcke HT, Crawley G, Mabry R, Mazuchowski E. Placement of tibial intraosseous infusion devices. *Mil Med* 2011;176(7):824-7** 469
This article describes a military study in which post-mortem preautopsy multidetector CT was used to assess placement of tibial IO needles in battlefield trauma deaths where IO was used as part of the medical intervention. Results showed 58 of 61 (95%) tibial IO needles were correctly placed. In this study, the device used for IO placement was not recorded, but may have been the manual device or EZ-IO as the Army has access to both.
- Lowther A. Intraosseous access and adults in the emergency department. *Nurs Stand* 2011;25(48):35-8** 887
This is a review article describing intraosseous vascular access, including techniques and device used, and contraindications.
- Nagler J, Krauss B. Intraosseous catheter placement in children. *NEJM* 2011;364(8):e14-8** 491
This article provides an overview of intraosseous vascular access for pediatrics and discusses general indications, contraindications, complications, and intraosseous devices.
- Neuhaus D. [Intraossärer zugang]. *Notfall Rettungsmed* 2011;14(7):543. doi:10.1007/s10049-011-1445-9. German** 480
This article in German discusses use of IO access and its multiple applications, focusing on the EZ-IO Infusion System.
- Schexnayder SM, Storm EA, Stroud MD, et al. Chapter 15-Pediatric vascular access and centeses. *Pediatric Critical Care* 2011;4th ed:139-63. ISBN: 978-0-323-07307-3** 680
This document addresses pediatric vascular access and includes an overview of intraosseous vascular access. Indications, contraindications, supplies and equipment, technique, complications and maintenance are discussed.
- Smart RJ, Marsh S, Rosenberg M. Intraosseous access in oral and maxillofacial surgical practice. *J Oral Maxillofac Surg* 2011;69(11):2708-13. doi:10.1016/j.joms.2011.02.101** 441
This article describes IO access in terms of efficacy, indications/contraindications for use, and the IO procedure and comparison of devices to make a case for IO use in oral and maxillofacial surgical practice. In discussing IO devices citing published data, the author identified the EZ-IO device as the most accurate, efficacious, and precise system when trying to achieve IO access.
- Sommer A, Weiss M, Deanovic D, Dave M, Neuhaus D. [Einsatz der intraossaren infusion im padiatrischen notarztdienst: Analyse von notarzteinsätzen 1990-2009]. *Anaesthesist* 2011;60:125-131. German** 488
This article in German concludes that the introduction of IO in pre-hospital pediatric emergency system has markedly reduced the number of critically ill or severely injured pediatric patients without vascular access or with less reliable alternative administration routes in the last 20 years.
- Thim T, Grove EL, Krarup NJV, Løfgren B. [Intraossøs adgang]. *Ugeskr Læger* 2011;173(21):1496-8. Danish** 474
This article in Danish discusses use of the IO route for second line vascular access when peripheral IV access is difficult or impossible.
- YEAR: 2010**
- Eich C, Weiss M, Neuhaus D, et al. Intraosseous infusion in paediatric emergency medical care and anaesthesia. *Anasth Intensivmed* 2010;51:75-81. German** 972
This article, written in German, gives an overview of intraosseous access in pediatric patients especially with regard to particularly difficult vascular access in the areas of pediatric anesthesia and perioperative care. The article also gives an overview of various devices available to gain IO access, including the Cook needle and the EZ-IO device.

Intraosseous Vascular Access Bibliography

Intraosseous Overview

- Fenwick R. Intraosseous approach to vascular access in adult resuscitation. *Emerg Nurse* 2010;18(4):22-5** 456
This article reviews intraosseous vascular access and its increased use in adult resuscitation. The IO route is described, including indications, contraindications, insertion sites and devices.
- Gerardi MJ, Youngberg B. Establishing emergency vascular access: the benefits of an alternative approach. *Journal of Emergency Nursing* 2010; February:16-8** 709
This article gives an overview of IO vascular access reviewing the history, devices and complications associated with IO access.
- Kovar J, Gillum L. Alternate route: the humerus bone - a viable option for IO access. *JEMS* 2010;35(8):52-59** 505
Authors describe an early observational study (N=120) comparing intraosseous access in the humerus and the tibia, using the EZ-IO. Investigators concluded that the humerus is an acceptable IO site, which may be preferable under certain clinical conditions. This research was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.
- Lairet JR, Bebart V, Lairet K, et al. Intraosseous pressure infusion comparison using a rapid infusion device and a pressure bag in a swine model. *Ann Emerg Med* 2010;56(3):S26** 502
In an abstract presented at the 2010 ACEP Research Forum, investigators describe a swine study designed to compare IO infusion rates using the Belmont FMS 2000 rapid infusion device and a pressure bag through the proximal tibia and proximal humerus. Investigators concluded that infusion rates were highest using the pressure bag via the proximal humerus.
- Luck RP, Haines C, Mull CC. Intraosseous access. *J Emerg Med* 2010;39(4):468-75. doi:10.1016/j.jemermed.2009.04.054** 492
This article provides an overview of intraosseous vascular access and discusses general indications, contraindications, complications, and intraosseous devices.
- Miller LJ, Philbeck TE, Montez D, Spadaccini CJ. A new study of intraosseous blood for laboratory analysis. *Arch Pathol Lab Med* 2010;134:1253-60** 503
Authors describe a 10 subject volunteer study that compared intraosseous (IO) blood samples to venous blood samples for complete blood count (CBC) and chemistry profile testing. They concluded that IO blood may serve as a reliable alternate for hemoglobin and hematocrit levels, as well as for most analytes in a basic blood chemistry profile. Exceptions are CO₂ levels, platelets, and WBC. This research was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.
- Molin R, Hallas P, Brabrand M, Schmidt TA. Current use of intraosseous infusion in Danish emergency departments: a cross-sectional study. *Scand J Trauma Resusc Emerg Med* 2010;18(37). doi:10.1186/1757-7241-18-37** 433
This article describes an online questionnaire study in which the Heads of Department of 20 EDs in Denmark were asked about IO infusion within their institution. Nineteen responses were received; 14 hospitals (74%) reported having IO devices available with the median number of IO procedures performed as 5. In 9 departments training had not been provided and 8 departments didn't have IO guidelines. The favored device was the EZ-IO found in 18 of the EDs, 2 had EZ-IO and Cook Surfist and 1 had the BIG.
- Navarro K. Intraosseous infusion. *Texas EMS Magazine* 2010;Nov/Dec:34-9** 447
This article provides a brief history of IO infusion and further discusses this vascular access technique in terms of anatomy and physiology, indications and contraindications, performing the manual procedure, and possible complications. A case study is discussed in which a 7-month-old male was treated under emergency circumstances with IO infusion in the lower limb and developed compartment syndrome, resulting in a below the knee amputation.
- Philbeck TE, Miller LJ, Montez D, Puga T. Hurts so good; easing IO pain and pressure. *JEMS* 2010;35(9):58-69** 504
This article describes two studies designed to compare Lidocaine's effect on pain during fluid infusion through the tibial and humeral IO routes and to determine infusion flow rates. Authors concluded that, for adequate IO infusion rates with minimal and tolerable pain, 40mg of preservative-free Lidocaine may be needed; followed by a rapid normal saline syringe flush of at least 10mL and another 20mg of Lidocaine. Additional dosing and flushing may be required. For less overall pain due to IO infusion, and greater infusion flow rates, the proximal humerus should be strongly considered, using a longer IO needleset. This research was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.
- Phillips L, Brown L, Campbell T, Miller J, Proehl J, Youngberg B. Recommendations for the use of intraosseous vascular access for emergent and nonemergent situations in various healthcare settings: a consensus paper. *J Emerg Nurs* 2010;36(6):551-6. doi:10.1016/j.jen.2010.09.001** 458
This article discusses use of IO access within the hospital setting in the emergent and non-emergent patient populations. The history of IO access, clinical situations in which IO access may be considered, devices, contraindications, and complications are discussed. Additionally, pain management, economics, education and training and risk management are explored. This article is co-published in *Journal of Infusion Nursing*, the *Journal of Pediatric Nursing*, and *Critical Care Nurse* and was produced by the Consortium on Intraosseous Vascular Access in Healthcare Practice.

Intraosseous Vascular Access Bibliography

Intraosseous Overview

Rubal BJ, Gerhardt RT, Sartin CW, et al. Medullary shear and pressure changes associated with high intraosseous infusion rates in an isolated hind limb preparation. *Ann Emerg Med* 2010;56(3):S113 501

This abstract describes an animal study, presented at the 2010 ACEP Research Forum, that examined shear and pressure changes within the medullary space during intraosseous infusion. Results suggest that resistance to flow depends of cannula placement site, IO pressure rises rapidly with infusion rates, and medullary compression and axial shear are present at high infusion rates.

Tobias JD, Ross AK. Intraosseous infusions: A review for the anesthesiologist with a focus on pediatric use. *Anesth Analg* 2010;110(2):391-401. 428

The authors describe literature that support the use of IO access for administering anesthesia in the ICU, perioperative and operating room, including a study in which IO access was used successfully for providing intraoperative anesthesia for 106 of 109 patients. Among their conclusions, the authors reported that, even though rarely reported in anesthesia literature, IO access is a technique anyone providing care to children should consider when the patient has difficult IV access. They also concluded that IO access should be a part of an algorithm that includes numbers of attempts at peripheral access, feasibility of central access and the need for continued postoperative access; and that considering that IO access may be occasionally used in the perioperative setting in both emergent and nonemergent scenarios, it may be beneficial to have appropriate IO needles in the OR.

Vegunta RK. Chapter 8-Vascular access. *Ashcraft's Pediatric Surgery* 2010;5th ed:110-6 681

This document discusses various vascular access methods available for pediatric and neonate patients, including intraosseous access.

Vizcarra C, Clum S. Intraosseous route as alternative access for infusion therapy. *J Infus Nurs* 2010;33(3):162-74 482

This article provides an overview of IO anatomy and physiology, IO access indications, care, and management; describes therapies administered via IO access; and discusses the expanding use of IO access into areas within hospitals during nonemergency clinical situations. It also includes a table addressing indications for IO access in the hospital, as well as a table addressing the general insertion procedure for IO access.

YEAR: 2009

Aguir T. Intraosseous infusion: an age-old therapy on a new frontier. *Nurs Manage* 2009;40(12):34-5 441

Article for nursing audience.

Barrett J. Adult Intraosseous infusion: "Good to the bone!" *Response* 2009;36(3):19-21 461

This article addresses adult IO infusion, primarily in the pre-hospital setting, with regard to the history of IO, anatomy and physiology, training considerations, clinical guidelines and contraindications, and financial considerations.

Bullard-Berent J. Intraosseous infusion: a instructional program for healthcare providers, revised edition (CD-ROM). *Prehosp Emerg Care* 2009;13:266 422

Instructional program on IO.

Sunde GA, Thoresen A, Heltne J-K. [Intraossøs tilgang på kritisk syke pasienter - gammel teknikk får ny heder, eller kun for spesielt interessert]? *NAForum* 2009;22(1):33-7. German 407

This article, in German, describes the technique of IO access, the introduction of two different IO devices (Cook and EZ-IO) and describes IO use in pediatric emergency care.

Toursarkissian M, Schmidbauer W, Breckwoldt J, Spies C. [Präklinischer Einsatz von intraossären Zugängen beim Erwachsenen: Überblick und Anwendungsbeispiele] *Preclinical use of intraosseous access (IO) in adults: ILterature review and case reports. Anesthesiol Intensivmed Notfallmed Schmerzther* 2009;44(1):22-7. German 416

This review article in German describes intraosseous vascular access, and includes descriptions of the Waismed Bone Injection Gun, Vidacare EZ-IO, Jamshidi and Cook Medical IO devices.

Von Hoff DD, Kuhn JG, Burris HA, Miller LJ. La perfusion intraosseuse est-elle equivalente a la perfusion intraveineuse? *Urgence Pratique* 2009;36:36-40 507

This French version of an article previously published in American Journal of Emergency Medicine describes a 25-patient clinical study that compared the pharmacokinetics of intraosseous using the Vidaport (a predecessor of the Vidacare EZ-IO) vs. intravenous administration of morphine sulfate in adults. Results showed no differences between IO and IV administration of morphine for nearly all pharmacokinetic parameters, including maximum plasma concentration, time to maximum plasma concentration, and area under plasma concentration-time curve. There was a significant difference in the volume of distribution in the central compartment, which investigators attributed to a minor deposition effect near the IO port or in the bone marrow. Investigators concluded that the results support the bioequivalence of IO and IV administration of morphine in adults.

Intraosseous Vascular Access Bibliography

Intraosseous Overview

Weiss M, Henze G, Eich C, Neuhaus D. [Intraossäre infusion: Eine wichtige technik auch für die kinderanästhesie]. Der Anaesthesist 9 2009:863-75. Norwegian 406

This article, in Norwegian, describes IO access and modern IO devices, including the Bone Injection Gun, FAST1, and EZ-IO.

Weiss M, Henze G, Eich C, Neuhaus D. Intraossare infustion: Eine wichtige technik auch fur die kinderanasthesie [Intraosseous infusion: an important technique also for paediatric anaesthesia]. Anaesthesist 2009;58(9):863-75.doi. 10.1007/s00101-009-1605-1 German 434

Discusses use of IO for pediatric anesthesia. Specifies importance of equipment, education, guidelines.

YEAR: 2008

Asaraval M, Kharasch M, Pettineo C, Voznilek JA, Wang EE. Emergent intraosseous access. Acad Emerg Med 2008; 15: 1324 414

No abstract available.

Blumberg SM, Gorn M, Crain EF. Intraosseous infusion: A review of methods and novel devices. Pediatr Emerg Care 2008;24:50-6 368

Review of IO infusion methods and devices. Devices described include Jamshidi, Cook, FAST 1, BIG, and EZ-IO.

Bosomworth NJ. The occasional intraosseous infusion. Can J of Rural Med 2008; 13: 80-3 369

Overview of intraosseous vascular access in infants; includes indications, contraindications, complications, equipment (Sur-Fast and Jamshidi), and procedure. Also, small section on IO for adults; describes the FAST-1, Bone Injection Gun, and EZ-IO.

de Caen AR, Reis A, Bhutta A. Vascular access and drug therapy in pediatric resuscitation. Pediatr Clin N Am 2008;55:909-27 363

Describes common drugs used in pediatric resuscitation and evidence supporting their use. Also describes routes of administration including intravenous, intraosseous, and intratracheal. Describes IO systems including Bone Injection Gun, FAST-1, and EZ-IO.

Gayatri J, Tobias JD T. The use of intraosseous infusions in the operating room. J Clin Anesth 2008;20:469-73 979

This article presents a case study of an IO infusion during the anesthetic care of an infant with cyanotic congenital heart disease (CHD). The article also discusses the role of the IO route in perioperative care and reviews the adverse effect profile.

Giasi W Jr. Do not waste time trying to get an intravenous (IV) line on an infant in shock when an intraosseous (IO) line will do just as well. In: Slonim AD. Avoiding Common Pediatric Errors. Philadelphia, PA: Lippincott Williams & Wilkins; 2008. ISBN: 0-7817-7489-6, 978-0-7817-7489-5 1053

Langley DM, Moran M. Intraosseous needles: They're not just for kids anymore. J Emerg Nurs 2008; 34:318-9 370

Case reports in which intraosseous (IO) vascular access was successfully used on adults. Summarizes indications for use, complications, and precautions/considerations.

Leidel BA, Kirchoff C. [Intraossäre infusion beim erwachsenen]. Der Chirurg 2008; 4:315-26. German 402

Article describing IO access.

YEAR: 2007

Beekley AC, Starnes BW, Sebesta JA. Lessons learned from modern military surgery. Surg Clin N Am 2007;87:157-84 650

Data from the largest combat trauma database was analyzed to identify how new or improved devices, dressings or drugs have impacted prehospital casualty care, how guidelines and resuscitation strategy have changed, and discusses lessons learned and how concepts have crossed back into the civilian practice. Intraosseous access, particularly the sternal site, is identified as one of the advances for vascular access in combat medicine.

Buck ML, Wiggins BS, Sesler JM. Intraosseous drug administration in children and adults during cardiopulmonary resuscitation. Ann Pharmacother 2007;41:1679-86 374

This article reviews and assesses the literature on the use of IO drug administration during cardiopulmonary resuscitation. It addresses the risks and benefits of using IO in adults and children. The article describes the FDA-cleared devices available for use including the Pyng F.A.S.T.1, Waismed Bone Injection Gun and the Vidacare EZ-IO.

Intraosseous Vascular Access Bibliography

Intraosseous Overview

- de Caen A. Venous access in the critically ill child. *Pediatr Emerg Care* 2007;23:422-4** 372
This review article states the availability of intraosseous (IO) needles for pediatric patients, outlines the limitations of traditional venous access, and discusses the various IO devices currently available, including the Vidacare EZ-IO®.
- DeBoer S, Andrews D. Infant venous access: 'Counting fingers' and 'playing baseball'. *Australasian Emerg Nurs J* 2007; 10: 46-51** 356
This article summarized the challenges and methods of providing vascular access for infants. It describes IO techniques and devices, including the Jamshidi, Cook, EZ-IO® and Bone Injection Gun (BIG) devices.
- Fowler RL. Prehospital intraosseous access: elemental to the field? *JEMS* 2007; doi:http://jems.com/print/9198** 543
Discussion of the role intraosseous vascular access can play in the prehospital setting where vascular access is often difficult or impossible to establish. The EZ-IO is named as a new IO device along with descriptions of Jamshidi, Pyng Fast 1, and BIG needles.
- Gagliardi P, Purrone G. [Il potere di salvare vite: l'infusione di liquidi e farmaci in emergenza con accesso venoso non reperibile]. *N & A Mensile Italiano del Soccorso* 2007; 177: 20-3. Italian** 376
Article in Italian describing IO access and EZ-IO
- Landes AH. Intra-osseous infusions: the current status. *Care of the Critically Ill* 2007; 23: 53-8** 361
Overview of IO access. Includes historical aspects, current status, indications for use, advantages and disadvantages, IO kinetics, insertion sites, complications and contraindications and description of available IO devices, including EZ-IO®.
- Minkler MA. Nailing down IO insertion: the whys, whens, wheres, and hows of delivering fluids and medications the intraosseous way. *EMS Mag* 2007; 36: 38-42** 405
Practical article for EMS audience.
- Scheres M. [Nieuw hulpmiddel voor intra-ossale toegang]. *Vakblad V & VN Ambulancezorg* 2007;1:16-7. Dutch** 373
Article in Dutch describing IO access and EZ-IO.
- Wayne MA. Intraosseous vascular access: devices, sites and rationale for IO use. *JEMS* 2007;32:s23-5** 375
This article reviews intraosseous vascular access in general, and summarizes the various devices available. These include the Waismed B.I.G., the Vidacare EZ-IO, and Pyng F.A.S.T.1.
- Weiss M, Gächter-Angehrn J, Neuhaus D. [Intraossäre infusionstechnik]. *German Interdisciplinary Journal of Emergency Medicine* 2007; 10: 99-116. German** 358
This article in German (with abstract in English) describes IO infusion in detail. It includes techniques, indications, complications, and recommendations. Also describes the various devices available, including Cook, Bone Injection Gun (BIG), First Access for Shock and Trauma (F.A.S.T.1), and the EZ-IO®.
- YEAR: 2006**
- Engle WA. Intraosseous access for administration of medications in neonates. *Clin Perinatol* 2006;33(1):161-8** 662
An overview of IO vascular access use in neonates, including focus on available evidence, history, technique, physiology, clinical indications, complications, and contraindications. The author closes acknowledging IO administration of resuscitation medications and fluids in neonates is an alternative when IV access is not possible.
- Isbye DL, Nielsen SL. Intraosseous access in adults-an alternative if conventional vascular access is difficulty. *Ugeskr Laeger* 2006;168(34):2793-7. Abstract** 634
This article in Danish covers an overview of intraosseous vascular access and its utility in the adult patient.
- Wayne M. [Perfusion intra osseuse chez l'adulte: il est temps d'y penser]. *Urgence Pratique* 2006; 77: 47-9. French** 371
Article in French describes IO access and IO devices, including B.I.G., F.A.S.T.1 and EZ-IO®.
- Wayne MA. Adult intraosseous access: an idea whose time has come. *Israeli J Emerg Med* 2006;6(2):41-5** 638
The author provides an overview of intraosseous vascular access discussing evolution of the practice, equipment, treatment options and contraindications.

Intraosseous Vascular Access Bibliography

Intraosseous Overview

YEAR: 2005

DeBoer S, Seaver M, Morissette C. Intraosseous infusion: not just for kids anymore. Emerg Med Serv 2005;34(54):56-63 331
Article describes intraosseous access for adults and pediatrics. Describes and discusses IO devices available including Jamshidi, Bone Injection Gun, F.A.S.T.1, and EZ-IO®.

Heightman AJ. The rebirth of adult IO: a first-hand account of recent advances in intraosseous infusion for adults, drawn from a scientific workshop and practical lab experience. JEMS 2005;30(10):s4-7 337
Editorial article highlighting recent advances in intraosseous (IO) infusion and IO devices based on the author's experience at a scientific seminar hosted by Vidacare. Makes recommendations on the efficiency and safety of the devices.

Miller LJ, Kramer GC, Bolleter S. Rescue access made easy: Intraosseous infusion, once limited to use in children, is now becoming a reliable access site for adults. JEMS 2005;30(10):Suppl 8-18 345
Overview of IO therapy. Includes 10 Myths about Adult IO and description of available IO devices, including the EZ-IO®.

Tabas JA, Rosenson J, Price DD, Rohde D, Baird CH, Dhillon N. A comprehensive, unembalmed cadaver-based course in advanced emergency procedures for medical students. Acad Emerg Med 2005;12(8):782-5 349
Describes a training course for medical students to learn advanced emergency procedures using unembalmed cadavers. The course includes clinical indications and contraindications for specific procedures, as well as techniques. Also discusses students' confidence levels in performing procedures.

YEAR: 2004

Eslami. Intraosseous access. <http://www.emedicine.com/ped/topic3053.htm> Last updated October 22, 2004 320
Web publication discussing the indications, contraindications, insertion sites and complications of IO access.

Korszun T, Raio CC, Theodoro D, et al. Can emergency physicians utilize ultrasonography to accurately confirm intraosseous needle placement? Ann Emerg Med 2004;44(4):S84 432
This abstract evaluated the use of ultrasonography to confirm proper IO placement versus improper placement using chicken bone. Results showed 6 participants were able to confirm placement with 100% sensitivity and 94% specificity, suggesting use of ultrasonography in pediatric patients may be beneficial to confirm IO placement.

YEAR: 2003

Carillo A, Lopez-Herce J. [Canalización intraósea]. An Pediatr Contin 2003;1(1):38-41. Spanish 653
This article in Spanish discusses general IO principles.

Gluckman, W, Forti RJ. Intraosseous cannulation. www.emedicine.com/ped/topic2557.htm Last Updated: Jan 14, 2003 301
Web article discusses IO cannulation procedure insertion sites, pathophysiology, risks, contraindications and complications.

LaRocco BG, Wang HE. Intraosseous infusion. Prehosp Emerg Care 2003;7:280-5 309
A comprehensive and accessible review of the history, anatomy, technique, and clinical application of intraosseous infusion.

YEAR: 2002

Laroche M. Intraosseous circulation from physiology to disease. Joint Bone Spine 2002;69:262-9 989
This article provides an indepth overview of intraosseous circulation including blood vessel anatomy, vascularization, intraosseous blood flow, angiogenesis, bone remodeling, osteonecrosis, bone infarction, and osteoporosis.

YEAR: 2001

Orgiler Uranga PE, Navarro Arnedo JM, De Haro Marin S. [The intraosseal route. When the veins have disappeared]. Enferm Intensiva 2001;12(1):31-40. Spanish 275
Literature review on intraosseous administration of drugs during pediatric emergencies. Concludes that IO is a valid alternative route for infusion of drugs and other substances into the blood stream with a low complication rate.

Intraosseous Vascular Access Bibliography

Intraosseous Overview

YEAR: 2000

Day MW. Using intraosseous access in children. *Nursing* 2000;30(1):68 253

Nursing article discussing the role of IO infusion when peripheral veins are collapsed. Describes advantages of IO, including ready availability, ability to establish vascular access without interrupting CPR.

Dubick MA, Holcomb JB. A review of intraosseous vascular access: current status and military application. *Mil Med* 2000; 165: 552-9 254

Literature review of safety and efficacy of IO infusion of drugs and fluids, with emphasis on utility for the injured soldier. Discusses insertion times and flow rates. Includes literature citations from non-military studies in pediatrics, animals, and human cadavers.

Foex BA. Discovery of the intraosseous route for fluid administration. *J Accid Emerg Med* 2000;17:136-7 270

Brief review of the discovery and evolution of IO access in emergency care.

Jun H, Haruyama AZ, Chang KS, Yamamoto LG. Comparison of a new screw-tipped intraosseous needle versus a standard bone marrow aspiration needle for infusion. *Am J Emerg Med* 2000;18(2):135-9 269

This article describes a study that compared the speed and ease of use when using a standard bone marrow needle and a Sur-Fast intraosseous access needle. Medical students inserted the needles in turkey femurs or pork ribs. Results showed, regarding success rate, procedure time, difficulty scores, the Sur-Fast needle did not show superiority over the standard bone marrow needle.

Mattera CJ. Take aim--hit your IO target. A comprehensive approach to pediatric intraosseous infusion, including site selection, needle insertion & ongoing assessment. Part 2. *JEMS* 2000;25(4):38-48 264

Overview of pediatric IO infusion targeted for an EMS/paramedic audience. Discusses anatomy of long bones, indications, advantages, contraindications, steps for insertion, fluid administration and ongoing assessment and documentation.

Vreede E, Bulatovic A, Rosseel P, Lassalle X. Intraosseous infusion. Update in *Anesthesia* 2000;12 (Article 10):1. <http://rcpals.com/downloads/2007files/may/pals/IntraosseousInfusion.html> 263

Brief overview of IO infusion for an anesthesiology audience. Discusses technique, indications, contraindications, equipment, anatomical target sites and potential complications.

YEAR: 1999

Bohn D. Intraosseous vascular access: from the archives to the ABC. *Crit Care Med* 1999; 27: 1053-4 243

Brief review of IO history, flow rates, fluids and medications.

Feillet F, Borsa A, Monin P. [Intraosseous approach, yes but...]. *Arch Pediatr.* 1999; 6: 1349-50. French 232

No abstract available.

YEAR: 1998

Stovroff M, Teague WG. Intravenous access in infants and children. *Pediatr Clin North Am* 1998;45:1373-93 227

Review article discussing techniques for venous access in the pediatric patient includes anatomical target sites, clinical indications, advantages and disadvantages.

Review

YEAR: 1996

Coggins R, Reader A, Nist R, Beck M, Meyers W.. Anesthetic efficacy of the intraosseous injection in maxillary and mandibular teeth. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 1996;81(6):634-641. doi:10.1016/s1079-2104(96)80067-9 908

This study's objective was to determine the anesthetic efficacy of the intraosseous injection as a primary technique in human maxillary and mandibular teeth. Forty subjects were enrolled and received 2 sets of intraosseous injections with 1.8ml of 2% lidocaine with 1:100,000 epinephrine on two different occasions. Authors concluded that in 75%-93% of non-inflamed teeth subjects, an intraosseous injection may provide pupal anesthesia. Authors cautioned that the duration of the anesthesia declines over an hour.

Intraosseous Vascular Access Bibliography

Intraosseous Overview

Moller JC, Tegtmeyer FK, Schaible TF, Sussmane JB. [Intraosseous puncture as vascular access in pediatric emergency and intensive care medicine]. *Anaesthesiol Reanim* 1996;21(4):103-7. German. Abstract 209

Article describing IO infusion 18 pediatric resuscitative situations. Authors conclude that 11 patients would not have survived without IO access. Complications included a minor fracture, 1 case of compartment syndrome that did not require surgical intervention and a minor fat embolism that was of no clinical significance.

YEAR: 1995

Moller JC, Reiss I, Schaible T. Vascular access in neonates and infants--indications, routes, techniques and devices, complications. *Intensive Care World* 1995;12(2):48-53 197

Suggests that intraosseous infusion is reliable alternative to peripheral vein access for rapid infusion of fluids in neonates and infants when venous access is impossible.

Abstract only

YEAR: 1994

Evans RJ, McCabe M, Thomas R. Intraosseous infusion. *Br J Hosp Med* 1994;51(4):161-4 175

Review of IO infusion in children 6 years old and younger. Recommends IO for patients with life-threatening conditions requiring immediate vascular access. Reports less than 1% complication rate.

Kruse JA, Vyskocil JJ, Haupt MT. Intraosseous infusions: a flexible option for the adult or child with delayed, difficult, or impossible conventional vascular access. *Crit Care Med* 1994;22(5):728-9 184

Discussion of IO infusion, including ease of use, low complication rates, and variety of fluids and drugs that can be administered through the IO route in children and adults.

Orlowski JP. Emergency alternatives to intravenous access. Intraosseous, intratracheal, sublingual, and other-site drug administration. *Pediatr Clin North Am* 1994;41(6):1183-99 164

Seminal article describing alternatives to intravenous cannulation including intraosseous access, intratracheal drug administration, sublingual and intralingual injection, intra-penile administration, and intracardiac injection. Concludes that the intraosseous method is an effective alternative to intravenous access in emergency situations.

Review

Sawyer RW, Bodai BI, Blaisdell FW, McCourt MM. The current status of intraosseous infusion. *J Am Coll Surg* 1994;179:353-60. Review 182

Review of the history, insertion techniques, available devices, and applications of the intraosseous infusion as well as the indications and contraindications for intraosseous infusion in all critically ill patients.

YEAR: 1992

Brickman K, Krupp K, Rega P, Alexander J, Guinness M. Typing and screening of blood from intraosseous access. *Ann Emerg Med* 1992;21(4):414-7 509

This prospective, nonrandomized, crossover study evaluated bone marrow aspiration from the posterior iliac crest and peripheral venous blood for ABO and Rh typing as well as the presence of human leukocyte activity. No differences were seen in the ABO and Rh typing, and human leukocyte activity was detected in both the marrow and venous samples.

Cilley RE. Intraosseous infusion in infants and children. *Semin Pediatr Surg* 1992;1(3):202-7 139

Article promoting increased awareness of intraosseous infusion, familiarity with IO insertion techniques, and careful use of anatomical landmarks.

Abstract only

Gut J, Karbula D. [Intraosseous infusions in children]. *Cesk Pediatr* 1992;47:726-7. Czech 133

A review of intraosseous infusion and the possible applications in pediatric emergency medicine.

Abstract only

Molyneux E. Intraosseous infusion. *Arch Dis Child* 1992;67:665 722

Letter to the editor written in response to previous article on IO access that includes sternal access as a site for children. This author states IO route for fluids and drugs is underutilized but believes sternal site to be hazardous and upper tibia, lower femur and humerus are favored.

Intraosseous Vascular Access Bibliography

Intraosseous Overview

Welch RD, Waldron MJ, Hulse DA, Johnston CE 2nd, Hargis BM. Intraosseous infusion using the osteoport implant in the caprine tibia. J Orthop Res 1992;10(6):789-99 129

Preclinical study of an implantable intraosseous infusion device (the osteoport) in a goat model. The device allowed for ready access to the vascular system through intraosseous infusion fluids and medications. IO infusion may result in fewer complications than conventional methods of vascular access.

YEAR: 1991

Clarke P. Making sense of intraosseous infusion. Nurs Times 1991;87(1):40-1 115

Article for nurses on intraosseous infusion as an alternative to intravenous vascular access presented in a question and answer format.

Driggers DA, Johnson R, Steiner JF, Jewell GS, Swedberg JA, Goller V. Emergency resuscitation in children. The role of intraosseous infusion. Postgrad Med 1991;89(4):129-32 105

Review article discussing aspects of intraosseous infusion, including indications, technique, and pharmacokinetic factors. Concludes that multiple drugs and fluids can be safely administered through the intraosseous route.

Von Hoff DD. Intraosseous infusions: an important but forgotten method of vascular access. Cancer Invest 1991;9(5):521-8 116

Review of intraosseous vascular access targeted for an oncology audience. Describes an implantable IO device with potential to make intraosseous access more convenient for the patient.

YEAR: 1990

Chameides L, Hazinski MF, eds. Intraosseous cannulation. In: Textbook of Pediatric Advanced Life Support. Chameides L, Hazinski MF, Eds.. Dallas: American Heart Association; 1990 102

Textbook chapter on IO.

Hopkins RL. Pediatric intraosseous infusion. J LA State Med Soc 1990;142(3):31-2 104

Concludes that infusion of fluids and drugs can be readily performed with the intraosseous technique.

King ML, Moses EC. Intraosseous infusion: a lifesaving technique. Nursing 1990;20:32K,32N-32P 93

Nursing article describing intraosseous infusion techniques and benefits.

Miccolo MA. Intraosseous infusion. Crit Care Nurse 1990;10(10):35-47 100

Nursing article that describes benefits of intraosseous infusion. Recommends IO for cardiopulmonary arrest and other medical

Spivey WN. Intraosseous infusion: Current concepts : The medical college of Pennsylvania, Department of Emergency Medicine, Philadelphia, PA. J Emerg Med 1990;8(3):382 743

This abstract describes a review of the literature on intraosseous pathways and reaches the conclusion that the rate of fluid administered is limited by the size of the marrow cavity and the complication is extravasation of fluids and/or drugs into the soft tissue.

YEAR: 1989

Iserson KV. Intraosseous infusions in adults. J Emerg Med 1989;7(6):587-91 75

Study of 22 cardiac arrest patients arriving at the Emergency Department with no or insufficient intravenous access. Intraosseous needle placed and flow established in less than 1 minute in all patients. Observed flow rates of 5 to 12 mL/min with pressure bag attached. IO needle placed in the medial supramalleolus.

Miner WF, Corneli HM, Bolte RG, Lehnhof D, Clawson JJ. Prehospital use of intraosseous infusion by paramedics. Pediatr Emerg Care 1989;5(1):5-7 74

Study of IO infusion by paramedics on pediatric patients (>5 years of age) in cardiac arrest. Paramedics completed a training program in IO technique. Observed 85% success rate (10 of 12 IO attempts). Discusses training methods, limitations and implications for future use.

Intraosseous Vascular Access Bibliography

Intraosseous Overview

- Schoffstall JM, Spivey WH, Davidheiser S, Lathers CM. Intraosseous crystalloid and blood infusion in a swine model. J Trauma 1989;29(3):384-7** 85
Preclinical study of IO infusion in a swine model. Concludes that IO infusion holds potential as a first line of action for fluid resuscitation in pediatric subjects.
- Wheeler CA. Pediatric intraosseous infusion: an old technique in modern health care technology. J Intraven Nurs 1989;12(6):371-6** 76
Review article for a nursing audience presenting a brief historical overview of IO technique and insertion methods, with discussion of clinical applications and nursing management aspects.
- YEAR: 1988**
- Manley L, Haley K, Dick M. Intraosseous infusion: rapid vascular access for critically ill or injured infants and children. J Emerg Nurs 1988;14(2):63-9** 66
Article for emergency nursing audience describing IO technique, anatomy, absorption rates, clinical indications and contraindications, technique, complications and training in critically ill or injured infants and children.
- Peck KR, Altieri M. Intraosseous infusions: an old technique with modern applications. Pediatr Nurs 1988;14(4):296-8** 70
Nursing article recommending IO early in the treatment of critically ill or injured children with difficult venous access. Highlights speed and ease of IO technique.
- YEAR: 1987**
- Brillman JC. Intraosseous infusion for emergency vascular access. West J Med 1987;146(5):603** 641
A brief overview of intraosseous vascular access. The author concluded that IO vascular access is a firmly established practice based on scientific fact and clinical significance.
- Spivey WH. Intraosseous infusions. J Pediatr 1987;111(5):639-43** 56
Review article on IO infusion, includes historical background, physiology, method, clinical applications and complications of the IO procedure.
- YEAR: 1986**
- Hoelzer MF. Recent advances in intravenous therapy. Emerg Med Clin North Am 1986;4(3):487-500** 55
Review of medical literature and research on the problem of difficult intravenous access.
- Iserson KV, Criss E. Intraosseous infusions: a usable technique. Am J Emerg Med 1986;4(6):540-2** 54
This article describes case reports and also a study comparing 3 types of needles for IO insertion: spinal needles, standard IV needles, and bone marrow aspiration/biopsy needles on a pediatric cadaver leg. The bone marrow aspiration needle was easiest to insert. The clinical cases described 5 adult and 10 pediatric IO patients with insertion at the "medial malleolus".* Authors conclude that IO infusion is a safe, rapid way to access the venous circulation, providing a stable, usable fluid line in dehydrated pediatric patients. *(Often referred to as distal tibia.)
- YEAR: 1985**
- Hodge D. Intraosseous infusions: a review. Pediatr Emerg Care 1985;1(4):215-8** 44
Review of IO insertion techniques of insertion, clinical indications, contraindications, and complications.
- Rosetti VA, Thompson BM, Miller J, Mateer JR, Aprahamian C. Intraosseous infusion: an alternative route of pediatric intravascular access. Ann Emerg Med 1985;14(9):885-8** 42
Discusses the historic technique of tibial intraosseous infusion as an alternative IV route in young children. Concludes from review of the medical literature that IO access is a rapid, reliable method with acceptably low complication rate. Discusses substances absorbed through the marrow, flow rates, technical difficulties, and complications.

Intraosseous Vascular Access Bibliography

Intraosseous Overview

YEAR: 1984

Orlowski JP. My kingdom for an intravenous line. Am J Dis Child 1984;138(9):803

41

Seminal article on IO infusion by the "Father of IO." Drugs and fluids infused through the IO space enter the central circulation as rapidly as through IV routes. Unlike peripheral veins, the intramedullary blood vessels will not collapse in shock.

Rosetti V, Thompson BM, Aprahamian C, Darin JC, Mateer JR. Difficulty and delay in intravascular access in pediatric arrests. Ann Emerg Med 1984;13(5):406

39

Outlines problems with conventional vascular access in emergency medicine. Discusses possible resurgence of the "old" technique of intraosseous infusion.

Turkel H. Emergency infusion through the bone. Military Medicine 1984;149:349-50

38

Article for military medicine audience concluding that the intraosseous route is more safe and effective than the intravenous route for several clinical indications, including burns and shock, circulatory collapse, uncooperative patients, patients in transit, shortage of physicians, especially under emergency conditions. States that IO infusion is an established alternative to intravenous infusion.

YEAR: 1954

Begg AC. Intraosseous venography of the lower limb and pelvis. Br J Radiol 1954;27:318-24

27

Describes a new method of ascending venography of the lower limb and pelvis in which contrast medium is injected into the IO space of the bone. Concludes that IO venography is safe, simple, flexible, and reliable for visualization of the deep, superficial, and communicating veins of the legs and pelvis.

Pillar S. Re-emphasis on bone marrow as a medium for administration of fluid. N Eng J Med 1954;251(21):846-51

26

Recommends IO for administering fluids, with the iliac crest as the preferred anatomical site.

YEAR: 1952

Tarrow AB, Turkel H, Thompson MS. Infusions via the bone marrow and biopsy of the bone and bone marrow. J Anesthesiol 1952;13(5):501-9

24

Article for an anesthesiology audience discussing the extensive blood supply within the bone marrow and the utility of IO anesthesia administration.

YEAR: 1947

Heinild S, Sondergaard T, Tudvad F. Bone marrow infusion in childhood: Experiences from a thousand infusions. J of Pediatrics 1947; 30: 400-11

21

Early study on IO. Makes strong distinction between ordinary blood transfusion or infusion of isotonic solutions (generally safe) and continuous infusion or the infusion of hypertonic solutions. The latter carries considerable risk of osteomyelitis and subsequent disturbance in growth of the bone.

YEAR: 1946

Quilligan JJ, Turkel H. Bone marrow infusion and its complications. Am J Dis Child 1946; 71: 457-65

18

Historical article discussing refinements in IO technique and analysis of IO complications. Includes case report of an infant who developed osteomyelitis subsequent to IO infusion.

YEAR: 1944

Arbeiter H I, Greengard J. Tibial bone marrow infusion in infancy. J Pediatr 1944; 25:(1):1-12

12

Early article describes technique for tibial bone marrow infusion. Reports 6 failures and 2 partial failures in 43 attempts on 34 young children. X-ray studies post IO infusion showed small bone defects and periosteal elevation with new bone formation.

Bailey H. Bone marrow as a site for the reception of infusions, transfusion and anesthetic agents. Br Med J 1944;1:181-2

15

Recommends IO cavity of the manubrium as useful as IV for anesthetic infusion.

Intraosseous Vascular Access Bibliography

Intraosseous Overview

Bailey H. Bone marrow as a site for the reception of infusions, transfusions and anaesthetic agents: a review of the present position. *Anesthesiology* 1944;5(5):545-6 649

This abstract describes one physician's summary of experience using the sternum as an intraosseous vascular access site for 60 cases. Discusses potential benefits and complications compared to intravenous access.

Meola F. Bone marrow infusions as a routine procedure in children. *J Pediatr* 1944;25(1):13-6 13

Early observational study on IO infusion at the Children's Hospital of Akron, OH.

YEAR: 1943

Macht D. Studies on intraosseous injections of epinephrine. *Am J Physiol* 1943;138(2):269-72 9

Study of the clinical effects of intraosseous, intramuscular and intravenous injections of aqueous versus oil solutions of epinephrine.

Meyer LM, Perlmutter M. The absorption rate from the bone marrow. *Am J Med Sci* 1943;205(2):187-90 10

Early study finding comparable circulation times between IV and IO infusions in 21 subjects.

YEAR: 1942

Doud E, Tysell, J. Massive intramedullary infusions *JAMA* 1942;120(15):1212. doi:10.1001/jama.1942.82830500006010c 914

This article discusses use of the medullary route for massive replacement therapy when the usual methods of administration and not available or practical. The article also reviews a case study of a man in receipt of a sternal puncture needle inserted into the medullary cavity where he received the infusions through this needle of whole blood and fluids.

Papper EM. The bone marrow route for injecting fluids and drugs into the general circulation. *Anesthesiology* 1942;3(3):307-13 8

Discusses IO infusion, pioneered by Tocantins, as a viable route for parenteral fluids, drug therapy, and anesthesia. Includes case reports.

YEAR: 1941

Tocantins LM, O'Neill JF, Jones H. Infusion of blood and other fluids via the bone marrow: Application in pediatrics. *JAMA* 1941a; 117(5):1229-34 7

Describes emergency IO infusion of citrated blood and saline into the tibia or femur of 9 infants. IV access was impossible. Found no complications upon clinical or x-ray examination post-infusion.

Tocantins LM, O'Neill JF, Price AH. Infusions of blood and other fluids via the bone marrow in traumatic shock and other forms of peripheral circulatory failure. *Ann Surg* 1941;114:1085-92 4

Early study of 4 patients with acute failure of the peripheral circulation. IO infusion of blood, fluids, or drugs via the bone marrow resulted in a prompt recovery from the state of collapse. Recommends IO route when peripheral veins are not available and a fluids are urgently needed.

Tocantins LM, O'Neill JF. Infusions of blood and other fluids into the general circulation via the bone marrow. *Surg Gynecol Obstet* 1941;73:281-7 5

Clinical study of 52 IO infusions of fluids in 40 patients (33 adults and 7 infants). Found no local, constitutional, immediate, or delayed reactions accompanying or following any infusion.

YEAR: 1940

Tocantins LM, O'Neill JF. Infusion of blood and other fluids into the circulation via the bone marrow. *Proc Soc Exp Biol Med* 1940;45(3):782-3 3

Clinical study finding that IO infusion for parenteral therapy was successful in 16 of 17 trials in 14 patients. Found that citrated blood, plasma, glucose and salt solutions could be infused with no complications.

Tocantins LM. Rapid absorption of substances injected into the bone marrow. *Proc Soc Exp Biol Med* 1940; 45: 292-6 2

Seminal study demonstrating that substances injected into the IO cavity of the tibia of the rabbit and the sternum of man immediately appeared in the central circulation, similar to IV administration.

Intraosseous Vascular Access Bibliography

Intraosseous Overview

YEAR: 1922

Drinker C, Drinker K, Lund C. The circulation in the mammalian bone marrow. Am J Physiol 1922;62(1):1-92

1

Seminal article on blood circulation in the IO space. Demonstrates movement of red blood cells from the bone marrow into the circulating blood by perfusion of the tibia of the dog and by injections into the bone marrow in the rabbit and cat.

Intraosseous Vascular Access Bibliography

Medications

YEAR: 2019

Burgert JM, Johnson AD, O'Sullivan JC, et al. Pharmacokinetic effects of endotracheal, intraosseous, and intravenous epinephrine in a swine model of traumatic cardiac arrest. *Am J Emerg Med* 2019;(in press). doi: 10.1016/j.ajem.2019.02.035 1046

This pre-clinical study compared various PK parameters, return of spontaneous circulation (ROSC), time to ROSC, and odds of ROSC after epinephrine was administered via endotracheal (ETT), IO, and IV routes in a swine traumatic cardiac arrest model (TCA). IO groups included sternal IO (SIO), humeral IO (HIO), and tibial IO (TIO). CPR only and CPR plus defibrillation (CPRD) groups were included for analyzing ROSC. The Cmax of the IV epinephrine group was significantly higher than that of the IO group (p=0.049). The tmax of the TIO group was significantly longer than that of all other groups (p=0.008). There were significant differences in mean plasma concentrations over time between the IV and TIO groups at 90, 120, 150, and 180 seconds (p<0.05) with the TIO group having an unexpectedly prolonged absorption phase. There was no difference in the rate of ROSC between ETT, TIO, HIO, SIO, IV and CPRD groups. The PK findings relative to ROSC support the concept that neither epinephrine nor the route of administration influenced the outcome. All IO insertions were performed using the EZ-IO device.

Farrokh S, Cho SM, Lefebvre AT, Zink EK, Schiavi A, Puttgen HA. Use of intraosseous hypertonic saline in critically ill patients. *J Vasc Access* 2019;20(4):427-32. doi: 10.1177/1129729818805958. Epub 2018 Oct 17 1052

Retrospective case report of six patients describing the use of intraosseous (IO) administration for 23.4% saline administration to treat intracranial hypertension. In all six cases sodium levels were increased and there were no IO complications.

Mansfeld A, Radafshar M, Thorgeirsson H, Hoijer CJ, Segerlantz M. Palliative sedation via intraosseous vascular access: A safe and feasible way to obtain a vascular access end of life. *J Palliat Med* 2019;22(1):109-111. doi: 10.1089/jpm.2018.0398 1056

This is a case report of IO access for palliative sedation with propofol in a 56-year-old man with no venous access. IO access was gained using an EZ-IO driver and the patient was successfully treated with propofol for 4 days to manage intractable pain and agitation.

Sampson CS. Extravasation from a misplaced intraosseous catheter. *Clin Pract Cases Emerg Med* 2019;3(3):303-4 1068

A 75-year old female presented by EMS to the Emergency Department (ED) after a ventricular fibrillation cardiac arrest. EMS defibrillated the patient and placed a right proximal tibial EZIO intraosseous (IO) catheter which multiple medications (epinephrine, magnesium, amiodarone, and calcium chloride) were administered; and she had return of spontaneous circulation prior to ED arrival. The IO catheter wasn't patent upon arrival in the ED and was removed. The patient was discharged on day four with ecchymosis near the insertion site. Three weeks post discharge the patient presented with tissue necrosis in an area surrounding the initial proximal tibial IO insertion site. The patient's leg was debrided and grafting was performed; the author reported "good healing" three months post-event.

Schindler P, Helfen A, Wildgruber M, et al. Intraosseous contrast administration for emergency computed tomography: A case-control study. *PLoS ONE* 2019;14(5): e0217629. <https://doi.org/10.1371/journal.pone.0217629> 1067

Retrospective case-control feasibility study comparing proximal tibial intraosseous (PTIO) and peripheral intravenous (PIV) delivery of contrast media in 24 patients receiving emergent CT scans as part of trauma diagnostics (n=4 PTIO, n=20 PIV). Delivery of contrast media was by power injection with rates of 5cc/sec for CT images of the head and neck, chest, abdomen and leg vessels. There were no significant differences in ability to complete imaging protocols or image quality. There were no complications. The study was limited by low patient numbers.

Wang J, Fang Y, Ramesh S, et al. Intraosseous Administration of 23.4%NaCl for Treatment of Intracranial Hypertension. *Neurocrit Care* 2019;30(2):364-71. <https://doi.org/10.1007/s12028-018-0637-2> 1070

Retrospective analysis of 76 patients exhibiting clinical symptoms of intracranial hypertension (ICH) that received 23.4% NaCl via the central venous catheter (CVC, n=38) or intraosseous (IO, n=38) access. IO insertion success was 97%; 33 were placed in the proximal humerus and 5 in proximal tibia. Transient hypotension was noted in 10 patients with IO devices and 3 with CVCs, an insignificant difference. No IO specific complications were noted. Time to delivery of 23.4% NaCl was faster with IO access; outcomes for CVC and IO were similar. Limitations include retrospective data, no ICP monitors, small numbers of patients.

YEAR: 2018

Akman N, Braunschweig T, Honickel M, et al. Reversal of dabigatran by intraosseous or intravenous idarucizumab in a porcine polytrauma model. *Br J Anaesth* 2018;120(5):978-87. doi: 10.1016/j.bja.2018.01.027 956

This study compared the efficacy and safety of IO versus IV idarucizumab for dabigatran reversal in a porcine polytrauma model. Twenty-one male pigs received oral dabigatran for 3 days and on the 4th day received dabigatran infusion while another 7 received a sham treatment. The treated pigs were then randomized to one of three groups; IO saline, IV idarucizumab, IO idarucizumab while the other 7 comprised the sham group. The pigs were subjected to polytrauma (femur fracture and blunt liver injury). Blood loss, hemodynamic values, and blood samples were measured and recorded. Blood loss was highest in the control group, followed by the two idarucizumab groups, and lowest in the sham group. Survival to 240 minutes was 100% in the sham group and both idarucizumab groups, and 14% in the control group. IO and IV idarucizumab promptly normalized global coagulation assays and thrombin generation and were comparable for reversing dabigatran.

Intraosseous Vascular Access Bibliography

Medications

- Burgert J, Martinez A, O'Sullivan M, Blouin D, Long A, Johnson A. Sternal route more effective than tibial route for intraosseous amiodarone administration in a swine model of ventricular fibrillation. *Prehosp Emerg Care* 2018;22(2):266-75. doi:10.1080/10903127.2017.1358782** 903

This study examined the measured mean plasma concentration, maximum plasma concentration (Cmax), and time to maximum concentration (Tmax) of amiodarone administered by 3 different routes, sternal IO (SIO), tibial IO (TIO), and IV over a time period of 5 minutes in 21 swine who were randomly assigned to one of the 3 routes. The swine were under general anesthesia and ventricular fibrillation was induced and CPR initiated. After 4 minutes in ventricular fibrillation the swine were administered 300 mg of amiodarone and blood samples were taken at 30 second intervals over 300 seconds. Authors concluded that the SIO and IV routes of amiodarone were comparable. The TIO group took almost 3 times longer to reach Tmax than the SIO and IV groups. In the swine model used in this study, the authors concluded that SIO route was more effective than the TIO route for the amiodarone delivery in a swine with VF and ongoing CPR.

- Chin SJ, Moore GA, Zhang M, et al. The AAHKS clinical research award: Intraosseous regional prophylaxis provides higher tissue concentrations in high BMI patients in total knee arthroplasty: A randomized trial. *J Arthroplasty* 2018;33(7S):S13-8. doi:10.1016/j.arth.2018.03.013.** 966

This study compared tissue concentrations of low-dose vancomycin via intraosseous regional administration (IORA) vs actual body weight-adjusted IV dosing in total knee arthroplasty (TKA) in obese patients (BMI>35). The obese patient population has an increased risk of periprosthetic joint infection after TKA. 22 patients were randomized to receive either 15mg/kg (max 2 g) of systemic vancomycin or 500 mg vancomycin via IORA. Fat and bone samples were taken and antibiotic concentrations measured. The overall mean tissue concentration in the subcutaneous fat was 39.3 µg/g in the IORA group vs 4.4 µg/g in the IV group (P<0.01). Mean tissue concentrations in bones were 34.4 µg/g in the IORA group vs 6.1 µg/g in the IV group (P<0.01). Low-dose IORA vancomycin was effective in providing tissue concentrations 5-9 times higher than IV administration in this high risk patient population.

- Symonds T, Parkinson B, Hazratwala K, McEwen P, Wilkinson M, Grant A. Use of regional administration of prophylactic antibiotics in total knee arthroplasty. *ANZ J Surg* 2018;88:848-53** 1025

This paper discusses prosthetic joint infection (PJI) after total knee arthroplasty (TKA) and the use of prophylactic antibiotics to prevent PJI. Current literature recommends IV administration of cephalosporins, however, rising resistance rates limit the effectiveness of IV cephalosporins. Alternatives include clindamycin, teicoplanin, and vancomycin. The author reviews alternative routes of administration to increase time dependent or concentration dependent antibiotic killing including intravenous regional administration (IVRA) and intraosseous regional administration (IORA). Supporting literature is reviewed. The author concludes that IVRA and IORA of prophylactic antibiotics in TKA is a novel way to increase tissue concentrations of prophylactic antibiotics and the current literature supports changing guidelines (after further research) to allow IVRA and IORA in TKA. The EZ-IO device was utilized for IORA of prophylactic antibiotics in the reviewed studies.

- Young SW, Zhang M, Moore GA, Pitto RP, Clarke HD, Spangehl MJ. The John N. Insall Award: Higher tissue concentrations of vancomycin achieved with intraosseous regional prophylaxis in revision TKA: A randomized controlled trial. *Clin Orthop Relat Res.* 2018;476:66-74** 1066

This is a prospective, randomized, controlled trial of patients undergoing revision total knee arthroplasty (TKA). Twenty patients were randomized to receive systemic IV or IO regional administration (IORA) of vancomycin as prophylaxis. Higher tissue and bone concentrations were consistently achieved in the IORA group with tissue concentrations during the procedure 5 to 20 times higher in the IORA group versus the IV group. The EZ-IO device was used to gain IO access in this study.

YEAR: 2017

- Boysen SR, Pang JM, Mikler JR, Knight CG, Semple HA, Caulkett NA. Comparison of tranexamic acid plasma concentrations when administered via intraosseous and intravenous routes. *Am J Emerg Med* 2017;35(2):227-33. doi:http://dx.doi.org/10.1016/j.ajem.2016.10.054** 867

Swine study comparing pharmacokinetic (pK) parameters of TXA given by the IO vs IV route. For the 4 min and 5 min results Cmax plasma concentrations were higher in the IV group but similar from injection completion onwards. Other pK parameters were not significantly different. Limitations included swine model, normotensive animals and proximity of sampling site (jugular vein) to the IV infusion site (auricular). Investigators concluded this study supports the pharmacokinetic bioequivalence of IO and IV administration of TXA in this animal model.

- Budach NM, Niehues SM. CT angiography of the chest and abdomen in an emergency patient via humeral intraosseous access. *Emerg Radiol* 2017;24(1):105-8. doi:10.1007/s10140-016-1438-6. (Germany)** 823

This case report describes a CT angiography of the chest and abdomen done via an EZ-IO catheter placed in a critically ill patient's proximal humerus. The contrast media was infused at a rate of 4 mL/s and the infusion pressure never exceeded 300 mmHg. No immediate or short term complications were observed. The authors describe the overall image quality and vessel contrast observed as excellent.

- Burgert JM, Johnson AD, Garcia-Blanco J, Fulton LV, Loughren MJ. The resuscitative and pharmacokinetic effects of humeral intraosseous vasopressin in a swine model of ventricular fibrillation. *Prehosp Disaster Med* 2017;32(3):305-10. doi:10.1017/S1049023X17000140** 940

This preclinical study reported data evaluating the pharmacokinetics of HIO and IV vasopressin and the ROSC in a swine model of ventricular fibrillation cardiac arrest. For the parameters of occurrence of ROSC, odds of ROSC, time to ROSC, Cmax, Tmax, and plasma concentrations over time, the IO and IV routes results were comparable.

Intraosseous Vascular Access Bibliography

Medications

- Clemency B, Tanaka K, May P, et al. Intravenous vs. intraosseous access and return of spontaneous circulation during out of hospital cardiac arrest. *Am J Emerg Med* 2017;35:222-6. doi:10.1016/j.ajem.2016.10.052** 943
- A retrospective chart review was done to analyze data of three EMS agencies over an 18 month timespan. Analysis was done on charts from adults who suffered OOHCA and received epinephrine through EMS established IV or IO access. An IO first approach was found non-inferior to an IV first approach based on the end point ROSC at time of emergency department arrival.
- Elliott A, Dubé P, Cossette-Côté A, et al. Intraosseous administration of antidotes-a systematic review. *Clin Toxicol* 2017; 55(10):1025-54. doi:10.1080/15563650.2017.1337122** 917
- This study reviews current IO administration of antidotes for patients that have presented to the emergency department with serious poisoning and IV access is not available. The study concluded that the evidence supporting the use of IO route for administering antidotes for poisoning patients is rare. Most evidence of IO access administration of antidotes has occurred in animal studies and case reports. Per author, despite lack of evidence, IO access is a potential option for antidotal treatments for resuscitation for patients where IV access is not available.
- Feinstein B, Stubbs B, Rea T, Kudenchuk P. Intraosseous compared to intravenous drug resuscitation in out-of-hospital cardiac arrest. *Resuscitation* 2017;117:91-6. doi:10.1016/j.resuscitation.2017.06.014** 922
- This retrospective cohort study evaluated emergency medical services (EMS) that treated adult patients with atraumatic out of hospital cardiac arrest (OHCA) in order to compare drug administration via intraosseous(IO) versus intravenous (IV) and the effectiveness. Study endpoints were survival to hospital discharge, return of spontaneous circulation (ROSC), and survival to hospital admission. The study included 1,800 patients, 1,525 of whom received IV access and 275 who received IO access. The practice for OHCA management in the EMS system from which the data was obtained was to attempt tibial IO access after failed IV attempts. The authors concluded that use of IO access was associated with a lower likelihood of ROSC and hospitalization; and acknowledged that further study of how vascular access routes affect OHCA patient outcomes is warranted.
- Helleman K, Kirpalani A, Lim R. A novel method of intraosseous infusion of adenosine for the treatment of supraventricular tachycardia in an infant. *Pediatr Emerg Care* 2017;33(1):47-8. doi: 10.1097/PEC.0000000000000966** 871
- This article describes a case in which adenosine was administered to a 2-week old patient with supraventricular tachycardia, which was successfully terminated following intraosseous administration of the drug.
- Lee E. The first time. *Ann Emerg Med* 2017;70(1):99-100. DOI: <https://doi.org/10.1016/j.annemergmed.2017.01.021>** 883
- This case study describes a resident's experience treating an infant in respiratory arrest. Among the interventions were tibial intraosseous vascular access using the Arrow® EZ-IO and administration of epinephrine. The baby did not survive.
- Pamplin J, Fisher AD, Penny A, et al. Analgesia and sedation management during prolonged field care. *J Spec Oper Med* 2017;17(1):106-20** 1009
- These are guidelines for prolonged field care (PFC) intended to be used after Tactical Combat Casualty Care (TCCC) when evacuation to higher level of care is not immediately possible. The intent of these guidelines is to identify potential issues to consider when providing analgesia with or without sedation for an extended time period (4-72 hours). IO is listed as an optional route of administration.
- Winkler M, Talley C, Woodward C, et al. The use of intraosseous needles for injection of contrast media for computed tomographic angiography of the thoracic aorta. *J Cardiovasc Comput Tomogr* 2017;11(3):203-7. doi: 10.1016/j.jcct.2017.03.001** 825
- This retrospective study of a quality and safety database compared procedures performed by use of intraosseous vascular access for contrast media infusion to a control group of the studies in the database performed with antecubital intravenous access. The quality metrics of the two groups were similar, with the intraosseous needle group being slightly better. There were no complications related to IO use in general or specifically associated with the procedures. Limitations included this was a single-center study with small sample size and possible selection bias due to unfamiliarity with IO access.
- Wolfson DL, Tandoh MA, Jindal M, Forgione PM, Harder VS. Adult intraosseous access by advanced EMTs: A statewide non-inferiority study. *Prehosp Emerg Care* 2017;21(7):7-13. doi:10.1080/10903127.2016.1209262** 816
- This retrospective non-inferiority study examined EMS data extracted from a statewide EMS data system over a two year period. IO insertions performed by advanced EMTs (AEMT) and Paramedics were compared for insertion success rates. The majority of IO placements were with the EZ-IO®. The investigators concluded successful IO access was not different among AEMTs and Paramedics lending evidence in support of expanding the scope of practice of AEMTs to include establishing IO access in adults.
- Young SW, Zhang M, Moore GA, Pitto RP, Clarke HD, Spangehl MJ. Higher tissue concentrations of vancomycin with intraosseous regional prophylaxis in revision TKA- A randomized controlled trial. *Manuscript submitted for publication*** 930
- A randomized controlled study comparing antibiotic tissue concentrations when vancomycin is administered for total knee arthroscopy via IO and IV access. Ten subjects were randomized to each group. The IO group received 500 mg vancomycin injected directly into the proximal tibia IO insertion site below an inflated thigh tunicate, and the IV group received 1 gram vancomycin, both were given before skin incision. Results showed IO tissue concentrations of vancomycin were 5-20 times higher than systemic IV despite the lower dose. This study was sponsored by Teleflex Incorporated.

Intraosseous Vascular Access Bibliography

Medications

YEAR: 2016

- Adams TS, Blouin D, Johnson D. Effects of tibial and humerus intraosseous and intravenous vasopressin in porcine cardiac arrest model. Am J Disaster Med 2016;11(3):211-8. doi:10.5055/ajdm.2016.0241** 896
- This study compared maximum concentration time (Cmax) to maximum concentration mean (Tmax) of mean serum concentration of vasopressin, return of spontaneous circulation (ROSC), time to ROSC, with odds of survival to vasopressin administration by tibial intraosseous, proximal humerus intraosseous (PHIO), and intravenous (IV) routes in a cardiac arrest model. Authors concluded TIO and PHIO provide rapid and reliable access in administration of life-saving medications during cardiac arrest and may be faster due to IV difficulty.
- Beaumont D, Baragchizadeh A, Johnson C, Johnson D. Effects of tibial and humerus intraosseous administration of epinephrine in a cardiac arrest swine model. Am J Disaster Med 2016;11(4):243-50. doi:10.5055/ajdm.2016.0246** 898
- This study examined the differences of pharmacokinetics and pharmacodynamics of epinephrine via of tibial intraosseous access and IV access. Interruptions in CPR in order to obtain vascular access reduces the flow of blood to vital organs. Study results showed that TIO access may be a faster alternative to IV access for delivery of vasoactive medications.
- Blouin D, Gegel BT, Johnson D, Garcia-Blanco JC. Effects of intravenous, sternal, and humerus intraosseous administration of hextend on time of administration and hemodynamics in a hypovolemic swine model. Am J Disaster Med 2016;11(3):183-92. doi:10.5055/ajdm.2016.0238** 900
- This study was to determine if there were any significant differences between humerus intraosseous (PHIO), sternal intraosseous(SIO) and intravenous (IV) administration of Hextend on the hemodynamics or administration time in a hypovolemic swine model. Time of administration of the Hextend on effects on systolic and diastolic blood pressure, mean arterial pressure, heart rate, cardiac output and stroke volume. After administration of Hextend, data was collected every 2 minutes for 8 minutes total. Results found no significant difference in these measures among the PHIO, SIO or IV groups.
- Bramlett E, Fales W, West B, LaBond V. Rate of return of spontaneous circulation in relation to primary vascular access during out-of-hospital adult cardiac arrest. Ann Emerg Med 2016;68(4S):S120** 912
- Investigators conducted a retrospective prehospital study over a 3 month time period comparing IV vs. IO access for return of spontaneous circulation (ROSC). With approximately 800 cases of out-of-hospital cardiac arrest (OOHCA) they found a significantly greater success rate for IO access but no difference between IO and IV for ROSC or time to first epinephrine.
- Burgert J. A primer on intraosseous access: History, clinical considerations, and current devices. Am J Disaster Med 2016;11(3):167-73. doi:10.5055/ajdm.2016.0236** 901
- This journal article literature review was written to provide information about the history, clinical considerations, and devices associated with intraosseous access to administer resuscitative drugs when IV access can't quickly or easily obtained.
- Burgert J. Intraosseous vascular access in disasters and mass casualty events: A review of the literature. Am J Disaster Med 2016;11(3):149-66. doi:10.5055/ajdm.2016.0235** 902
- This literature review examined the increase in use of intraosseous access for administration of resuscitative fluids and drugs to patients where intravenous access could not quickly or easily obtained during disasters and mass casualty events. The review also included a comparison of IO route to other routes for establishing vascular access in patients that have been involved in mass casualty or disasters.
- Celik T, Ozturk C, Balta S, Demirkol S, Iyisoy A. A new route to life in patients with circulatory shock: Intraosseous route. Am J Emerg Med 2016;34(5):922-23. doi:10.1016/j.ajem.2016.02.035** 906
- In this letter to the editor authors discuss the importance of establishing access to circulatory system during CPR. The authors referenced the study "The effects of proximal and distal routes of intraosseous epinephrine administration on short-term resuscitative outcome measures in an adult swine model of ventricular fibrillation: a randomized controlled study" and the study "Intraosseous versus intravenous vascular access during out-of-hospital cardiac arrest: a randomized controlled trial". Authors concluded that intraosseous access seems reasonable for patients in cardiopulmonary arrest or severe shock that do not have available and quick IV access for administration of medications and fluids.
- Chin YX, Kiat Tan KB, Koh ZX, et al. Comparing intraosseous and intravenous access for out-of-hospital cardiac arrest in Singapore. Resuscitation 2016;106(S1):e25** 813
- The objective of this study was to determine if there would be a difference in rates of vascular access and ROSC if paramedics were able to use IO access after two initial IV attempts failed. Investigators found higher vascular access success and prehospital epinephrine administration rates with the addition of IO access but no significant difference for ROSC.
- Singapore
- Cornell M, Kelbaugh J, Todd B, et al. Pharmacokinetics of sternal intraosseous atropine administration in normovolemic and hypovolemic swine. Am J Disaster Med 2016;11(4):233-6. doi:10.5055/ajdm.2016.0244** 911
- This prospective, experimental study was to characterize and compare the pharmacokinetics of atropine that is administered via sternal intraosseous (IO) route in hypovolemic and non-hypovolemic swine. Main outcomes PK parameters, maximum concentration (Cmax) and time to reach maximum concentration (Tmax). Authors concluded sternal IO route is effective for administration of atropine and data gained from this study was found to be similar to previous information reported on tibial IO and IV administration even in situations of significant hemorrhage.

Intraosseous Vascular Access Bibliography

Medications

- Davis J, Bates L. Rapid sequence induction via an intraosseous needle. J Intensive Care Society 2016;17(2):178-9** 788
This article presents a case study of rapid sequence intubation via intraosseous (IO) access with a review of relevant literature. The authors describe a case of an adult male patient, peri-arrest with cardiogenic shock, cyanosed with un-recordable oxygen saturations and blood pressure. IO access was established in the proximal tibia and rapid sequence induction was performed using fentanyl, ketamine and suxamethonium. After 30 seconds direct laryngoscopy was attempted and intubation was secured on first attempt. The authors concluded that use of IO access for RSI can be useful in cases of difficult vascular access and rapid intubating conditions can be achieved which are comparable to using IV drug delivery.
- EMEDHOME.com. Clinical Pearl: Getting a CTA for PE if the IV is inadequate Emerg Med News 2016;38(12):19. doi:10.1097/01.EEM.0000511109.41978.1a** 931
Online article that briefly discusses use of intraosseous access to obtain a CTA study for pulmonary vasculature imaging when intravenous access is difficult.
- Fulkerson J, Lowe R, Anderson T, Moore H, Craig W, Johnson D. Effects of intraosseous tibial vs. intravenous vasopressin in a hypovolemic cardiac arrest model. West J Emerg Med 2016;17(2):222-8. doi:10.5811/westjem.2015.12.28825** 777
Randomized, prospective preclinical study that examined the differences in pharmacokinetics and pharmacodynamics of tibial IO (TIO) and IV-delivered vasopressin during cardiac arrest and CPR until ROSC was achieved. No difference was noted for ROSC between TIO and IV delivered vasopressin. Authors concluded the use of IO access could avoid the time delay associated with IV access, and that it is effective for treatment of hypovolemic cardiac arrest and should be first line for rapid vascular access.
- Greenstein YY, Koenig SJ, Mayo PH, Narasimhan M. A serious adult intraosseous catheter complication and review of the literature. Crit Care Med 2016;44(9):e904-9. doi: 10.1097/CCM.0000000000001714** 775
This article includes a case study of an adult patient who received an intraosseous (IO) catheter, that may have extravasated, resulting in vascular compromise. The patient was treated with pharmacologic intervention and the status was reversed. A review of the literature on adult IO complications is also described.
- Hampton K, Wang E, Argame JI, Bateman T, Craig W, Johnson D. The effects of tibial intraosseous versus intravenous amiodarone administration in a hypovolemic cardiac arrest porcine model. Am J Disaster Med 2016;11(4):253-60** 829
This study compared IV to tibial IO administration of amiodarone. Investigators found no significant differences for the endpoints of Cmax, Tmax and time to/ rate of ROSC between IO and IV.
- Holloway MM, Jurina SL, Orszag JD, et al. Effects of humerus intraosseous versus intravenous amiodarone administration in a hypovolemic porcine model. Am J Disaster Med 2016;11(4):261-9** 828
In a swine study comparison of the humeral IO and IV amiodarone administration routes investigators found no difference in time to ROSC or rate, time to maximum concentration (Tmax) p = 0.501) or in maximum plasma drug concentration (Cmax) (p = 0.232).
- Hughes J, Isaacson J, Stavos J. Percutaneous intraosseous doxycycline injections for aneurysmal bone cysts: A minimally invasive treatment option performed by interventional radiology. J Vasc Interv Radiol 2016;27(3):S261-2** 873
This abstract describes indications, techniques and mechanism of percutaneous intraosseous doxycycline injections for the treatment of aneurysmal bone cysts.
- Ilicki J, Scholander J. Lidocaine can reduce the pain of intra-osseous flush infusion. Crit Care 2016;20:192. doi: 10.1186/s13054-016-1359-5** 875
This letter to the editor expresses support for the practice of injecting lidocaine into the intraosseous (IO) space prior to IO infusion in order to mitigate the pain associated with IO infusion.
- Johnson M, Inaba K, Byerly S, et al. Intraosseous infusion as a bridge to definitive access. Am Surg 2016;82(10):876-80** 826
This retrospective study examined indications and outcomes associated with IO use at a Level 1 trauma center from 2008-2015. All 68 IO placements were with the EZ-IO device; most patients had trauma diagnoses. Most IO placements were successful on first attempt within 3 minutes of arrival. Non-serious extravasation was the most common complication. Authors concluded IO access "should be considered as a rapid, low risk, high yield aid to long-term IV access in both adults and children, and is an important bridge to definitive access in resuscitation".
- Kudenchuk PJ, Brown SP, Daya M, et al. Amiodarone, lidocaine, or placebo in out-of-hospital cardiac arrest. N Engl J Med 2016;274:1711-22** 880
Authors described a randomized, double-blind trial, comparing parenteral amiodarone, lidocaine, and saline placebo, along with standard care, in adults who had non-traumatic out-of-hospital cardiac arrest, shock-refractory ventricular fibrillation or pulseless ventricular tachycardia after at least one shock, and vascular access (N=3026). The focus of the study was not intraosseous access, but eligible patients had intravenous or intraosseous access (n=661).

Intraosseous Vascular Access Bibliography

Medications

- Montez D, Puga T, Davlantes C, Philbeck T. IO infusion pain mitigation in the sternum and proximal humerus: Establishing a regimen. Crit Care Med 2016;44(12 Suppl):154** 822
- A prospective study with 30 evaluable healthy volunteers receiving PH and sternal IO access (Arrow® EZ-IO® Vascular Access System and T.A.L.O.N.™, Teleflex, Wayne, PA) was conducted to determine if there is a significant difference between pain after a total of 60mg or 40mg of 2% preservative-free and epinephrine-free lidocaine. Endpoints were subject reported pain scores during 5 minutes of rapid infusion at 300 mmHg and 15 and 30 minutes at a rate of 125 mL/hour per pump. Authors concluded infusion pain through a PH IO may be managed with a single 40mg lidocaine prior to infusion, but a total of 60mg may be considered for sternal IO infusion. This study was sponsored by Teleflex Incorporated.
- Montez DF, Puga TA, Davlantes C, Higgins R, Miller LJ, Philbeck TE. Blood transfusion via intraosseous access: A pre-clinical study. J Vasc Access 2016;17(4):e5-6** 783
- A preclinical study evaluating blood transfusion via IO vascular access in anesthetized swine. Results showed pressurized blood transfusion through IO vascular access resulted in acceptable flow rates and did not result in appreciable hemolysis as indicated by free hemoglobin values. This study was sponsored by Teleflex Incorporated.
- Puga TA, Montez DF, Davlantes C, Miller LJ, Philbeck TE. Swine study shows no intramedullary effects of power-injected contrast media using intraosseous access. J Vasc Access 2016;17(4):e16** 785
- A preclinical study evaluating the immediate effects of power injected contrast media on the medullary space of anesthetized swine. Contrast media (150 mL) was administered at a rate of 5 mL/second. For each limb receiving power injection a control limb was submitted for evaluation. The pathologist was blinded to which limb received power injection. Results showed no histological difference in limbs receiving and not receiving power injection. This study was sponsored by Teleflex Incorporated.
- Savell S, Mora AG, Perez CA, Bebart VS, Maddry JK. En route intraosseous access performed in the combat setting. Am J Disaster Med 2016;11(4):225-31. doi:10.5055/ajdm.2016.0243** 847
- A retrospective study evaluating vascular access routes used for US Military personnel injured in combat and transported by MEDEVAC. Medical records were reviewed for intravenous (IV) and intraosseous (IO) use including, number of attempts and rates of success; along with events occurring in transit, hospital and ICU stays and 30 day outcomes. Results showed IV and/or IO access was attempted in 832 patients. PIV was first line of attempt in 758 cases with 93% success; IO access was first line of attempt in 74 cases with 85% success. There were 25 attempts to establish IO as the second line of access with 100% successful placement. Success rates were 100% with tibia (29); 94% with humerus (21/22); and 89% with the sternum (41/46). The overall IO success rate was 88% for all attempts made.
- Smith S, Borgkvist B, Kist T, Annelin J, Johnson D, Long R. The effects of sternal intraosseous and intravenous administration of amiodarone in a hypovolemic swine cardiac arrest model. Am J Disaster Med 2016;11(4):271-7. doi:10.5055/ajdm.2016.0249** 830
- A pre-clinical study comparing the effects of IV and sternal IO administered amiodarone in a swine cardiac arrest model. Following 2 minutes of cardiac arrest, CPR was initiated and after an additional 2 minutes, amiodarone was administered via sternal IO or IV access. Blood samples were collected over 5 minutes. Results showed no statistical difference between routes for return of spontaneous circulation (ROSC), time to ROSC, T-max, or C-max. The authors concluded sternal IO route provides rapid and reliable access to administer life-saving medications during cardiac arrest.
- Strong D, Powell E, Tilney PVR. A 20-year-old-male with hemorrhagic shock. Air Med J 2016;35(1):8-11. http://dx.doi.org/10.1016/j.amj.2015.10.003** 803
- This case study describes the medical management of a 20 year old male post high-speed motor vehicle crash with multitrauma and in shock upon air medical team arrival. Care entailed aggressive airway support, bilateral chest decompressions, management of potential pelvic bleeding with a pelvic binder, one peripheral IV through which packed red blood cells and plasma were given and one proximal humerus IO through which 1 g tranexamic acid (TXA) was given.
- Uwaydah NI, Hoskins SL, Bruttig SP, et al. Intramuscular versus intraosseous delivery of nerve agent antidote pralidoxime chloride in swine. Prehosp Emerg Care 2016;20(4):485-92. doi:10.3109/10903127.2014.942479** 842
- A preclinical study comparing delivery of nerve agent antidote when administered via intramuscular (IM) and proximal tibia intraosseous (IO) routes, in normovolemic and hypovolemic swine. IO and IV administration of the antidote achieved and surpassed therapeutic levels in normovolemic groups; time to therapeutic level with IM was 2 minutes versus 15 seconds with IO access. Combined administration via IO route initially, followed by IM injection 60 minutes post IO injection resulted in therapeutic levels for a prolonged time, most closely mimicking standard hospital care of poisoned patients. The authors concluded the rapid increase in plasma concentrations, coupled with the sustainability of the drug in plasma supported advantages of IO over IM delivery.
- Vallier DJ, Torrence AD, Stevens, III R, Arcinue PN, Johnson D. The effects of sternal and intravenous vasopressin administration on pharmacokinetics. Am J Disaster Med 2016;11(3):203-9. doi:10.5055/ajdm.2016.0240** 841
- A preclinical study comparing the maximum concentration (Cmax), time to maximum concentration (Tmax) when administering vasopressin via intravenous (IV) and sternal intraosseous (SIO) access in a cardiac arrest swine model. Anesthetized swine were put into cardiac arrest, after 2 minutes CPR was initiated for 2 minutes, then 40 units of vasopressin was administered via IV or SIO route. Results showed no significant difference in SIO and IV groups for Cmax or Tmax.

Intraosseous Vascular Access Bibliography

Medications

Wilson J, Passmore A, Leger S, Lannan J, Bentley M, Johnson D. Effects of tibial intraosseous and intravenous administration of Hextend on time of administration and hemodynamics in a hypovolemic swine model. *Am J Disaster Med* 2016;11(3):193:201. doi:10.5055/ajdm.2016.0239

836

A preclinical study comparing administration of Hextend via IV and tibial intraosseous (IO) access routes for time for administration and hemodynamic measures in a hypovolemic swine model. Following exsanguination, 500 mL of Hextend was administered via both routes; a control group received no Hextend. Hemodynamic measures data were collected every 2 minutes for 8 minutes. The mean time for administration in the IV group was 10 minutes 16 seconds (\pm 2 minutes 47 seconds), and for the IO group it was 10 minutes 12 seconds (\pm 1 minutes 36 seconds). There was no significant difference in systolic blood pressure, diastolic blood pressure, mean arterial pressure, cardiac output, and stroke volume.

Wimmer MH, Heffner K, Smithers M, et al. The comparison of humeral intraosseous and intravenous administration of vasopressin on return of spontaneous circulation and pharmacokinetics in a hypovolemic cardiac arrest swine model. *Am J Disaster Med* 2016;11(4):237-42. doi:10.5055/ajdm.2016.0245

827

A preclinical study comparing IV and humeral intraosseous (IO) access administration of vasopressin in a hypovolemic swine model in cardiac arrest. Following exsanguination, the swine were placed in cardiac arrest for 2 minutes, then resuscitated for 2 minutes in accordance with ACLS guidelines. Vasopressin was administered. Blood samples were collected at various time points following vasopressin injection and analyzed for maximum concentration (Cmax) and time to maximum concentration (Tmax) between groups; return of spontaneous circulation was also captured. ROSC was achieved for all HIO subjects (n=7) and in seven out of eight IV subjects; mean time to ROSC was 9.8 minutes for HIO and 10.7 for the IV group. However, statistically there was no significant difference between HIO and IV administration of vasopressin for achievement of ROSC, time to ROSC, Cmax, Tmax, concentration over time, survivability, or odds ratio.

YEAR: 2015

Douma M, Bara G, O'Dochartaigh D, Brindley P. Double-barrelled resuscitation: a feasibility and simulation study of dual-intraosseous needles into a single humerus. *Injury* 2015;46(11):2239-42. doi:10.1016/j.injury.2015.08.029

915

This study examined whether the use of dual-intraosseous needles to deliver fluid and medication when vascular access is insufficient. The study used a single porcine humerus. The authors concluded that dual intraosseous needles are feasible and may help the rapid resuscitation of patients.

Ewy G, Bobrow B, Chikani V et al. The time dependent association of adrenaline administration and survival from out-of-hospital cardiac arrest. *Resuscitation* 2015;96:180-85. doi:10.1016/j.resuscitation.2015.08.011

919

This article discusses a retrospective analysis of data collected to investigate the possible time-dependent outcomes associated with adrenaline administration by personnel with Emergency Medical Services (EMS). Primary endpoint was survival to hospital discharge and positive neurological outcome. The study included 3,469 patients with out of hospital cardiac arrest (OHCA). Study concluded patients with OHCA that had been treated early with adrenaline and had a shockable rhythm had a survival rate to hospital discharge.

Hill SL, Thomas SHL, Flecknell PA, et al. Rapid and equivalent systemic bioavailability of the antidotes HI-6 and dicobalt edetate via the intraosseous and intravenous routes. *Emerg Med J* 2015;32(8):626-31. doi: 10.1136/emermed-2014-204171

751

A preclinical study evaluating the bioavailability of antidotes HI-6 oxime and dicobalt edetate when given via proximal tibia intraosseous (IO) access, established via the EZ-IO, compared to intravenous administration via central access in minipigs. Results showed rapid and similar systemic bioavailability of the antidotes when given by both routes and that IO access is an appropriate access route when IV access is impractical.

Montez DF, Puga T, Miller L, et al. Intraosseous infusions from the proximal humerus reach the heart in less than 3 seconds in human volunteers. *Ann Emerg Med* 2015;66(4s):S47. http://dx.doi.org/10.1016/j.annemergmed.2015.07.165

771

In a healthy adult volunteer study contrast media was injected through the proximal humerus site and captured under fluoroscopy as it entered the heart. The mean time it took from injection at the insertion site to visualize contrast entry into the superior vena cava and the right atrium was 2.42 seconds. Abstract presented at ACEP 2015. This study was sponsored by Teleflex Incorporated.

Sampson CS, Bedy S-M. Lipid emulsion therapy given intraosseously in massive verapamil overdose. *Am J Emerg Med* 2015;33(12):1844.e1.doi: 10.1016/j.ajem.2015.04.061

767

A case study report of a 24-year old female who presented to the emergency department after consuming an over dose amount of verapamil. Central and peripheral venous access were obtained for delivery of vasopressors and intravenous fat emulsion 20% (IFE). IFE was initiated via peripheral IV (PIV) access but access was lost; administration through central access was not possible due to the potential drug interaction. Intraosseous (IO) access was established using the Arrow EZ-IO system in the proximal tibia without complication and IFE administration was resumed. The patient reported some pain with infusion. After half the bolus administration was delivered, the infusion pump alarmed due to inadequate flow. PIV access was obtained and IFE administration was resumed using the newly obtained access route. The authors suggested that the viscosity of the medication may have caused the delivery failure by infusion pump through the IO route and recommend slowing down the bolus rate of infusion for clinicians attempting this route for IFE administration in the future.

Seghatchian J, Putter JS. Advances in transfusion science for shock-trauma: optimizing the clinical management of acute haemorrhage. *Transfus Apher Sci* 2015;53(3):412-22. http://dx.doi.org/10/1016/j.transci.2015.11.012

852

This review article describes various protocols for haemorrhage control, specifying routes of access, including intraosseous vascular access infusion rates and volumes of various transfusion fluids.

Intraosseous Vascular Access Bibliography

Medications

Strandberg G, Larsson A, Lipcsey M, Michalek J, Eriksson M. Intraosseous and intravenous administration of antibiotics yields comparable plasma concentrations during experimental septic shock. *Acta Anaesthesiol Scand* 2015;doi: 10.1111/aas.12454

738

Preclinical study using a porcine model to determine whether there were differences in intraosseous (IO) and intravenous (IV) antibiotic (cefotaxime and gentamicin) concentrations during septic shock. Both methods of administration yielded comparable concentrations. Authors concluded in an emergency, IO administration of these antibiotics may be considered in severe infections when venous access is difficult

Sweden

Ventura AMC, Shieh HH, Bousso A, et al. Double-blind prospective randomized controlled trial of dopamine versus epinephrine as first-line vasoactive drugs in pediatric septic shock. *Crit Care Med* 2015;43(11):2292-302. doi:10.1097/CCM.0000000000001260

840

This article describes a prospective double-blind randomized controlled study evaluating the difference between use of dopamine and epinephrine as first-line vasoactive drug in pediatric septic shock patients. This study conducted in the pediatric intensive care unit (PICU) of Hospital Universitario da Universidade de Sao Paulo, Brazil. One hundred twenty-one patients aged 1 month to 15 years who met criteria were randomized to receive either epinephrine (n=57) or dopamine (n=63) via IV or intraosseous (IO) vascular access (via EZ-IO). The authors concluded dopamine was associated with an increased risk of death and healthcare-associated infection; whereas administration of epinephrine via IV or IO routes was associated with increased survival.

YEAR: 2014

Borovnik-Lesjak V, Whitehouse K, Baetiong A, et al. Effects of intraosseous erythropoietin during hemorrhagic shock in swine. *PLoS One* 2014;9(11):e110908. doi: 10.1371/journal.pone.0110908

1044

This preclinical study investigated whether erythropoietin (EPO) given during hemorrhagic shock improved resuscitation and increased survival in a swine model. Swine were randomized to one of three groups: loss of 50% blood volume, loss of 65% blood volume, or loss of 65% blood volume plus vasopressin. Within each group half of the swine also received intraosseous EPO. EPO failed to improve initial resuscitability and 72 hour survival, however, EPO did attenuate acute organ injury. Additionally, vasopressin proved effective in improving survival.

Burgert J, Mozer J, Williams T, et al. Effects of intraosseous transfusion of whole blood on hemolysis and transfusion time in a swine model of hemorrhagic shock: a pilot study. *AANA Journal* 2014;82(3):198-202

733

Preclinical study using a porcine model to determine whether there were differences in intraosseous (IO) and intravenous (IV) whole blood transfusion relative to hemolysis and transfusion time. IO transfusion does not significantly increase hemolysis (using free hemoglobin as outcome measure) or transfusion time compared with IV transfusion. Authors concluded transfusion of whole blood through an IO device is an effective transfusion method that may be used until other vascular access is obtained.

Cooper IF, Siadat MS. Organic chemicals associated with injection intraosseous: top publications. *BioMedLib Review* 2014;<http://bmlreview.com/bld/WakgYU2Picf/BML-review-organcichemical-injectionintraosseous-706014831.html>

732

This literature review article sought to identify organic chemicals associated with intraosseous injection within the published literature. The top 31 articles identified in the search are cited within the article.

YEAR: 2013

Verma PK, Srivastava R, Ramesh KM. Anesthetic efficacy of X-tip intraosseous injection using 2% lidocaine with 1:80,000 epinephrine in patients with irreversible pulpitis after inferior alveolar nerve block: a clinical study. *J Conserv Dent* 2013;16(2):162-66. doi:10.4103/0972-0707.108202

839

A study evaluating the use of X-tip intraosseous injection of 2% lidocaine with 1:80,000 epinephrine in dental patients with irreversible pulpitis in whom inferior alveolar nerve block has failed. Thirty patients were included and 93% of X-tip injections were successful. Ninety-six percent of patients had subjective/objective increase in heart rate. Results showed X-tip intraosseous injection of 2% lidocaine was effective in achieving pulpal anesthesia in patients with irreversible pulpitis.

YEAR: 2011

Eich C, Weiss M, Neuhaus D, et al. Handlungsempfehlung zur intraossären Infusion in der Kinderanästhesie [Recommended action for intraosseous infusion in children's anesthesia]. *Anästhesiologie Intensivmedizin* 2011;52:S46-52. German

770

German Society of Anaesthesiology and Intensivmedizin eV" (DGAI), includes a general discussion of intraosseous (IO) as vascular access, overview of devices and recommendations for pediatric anesthesia with indications for intraosseous infusion in pediatric anesthesia and perioperative care in children. Early or primary IO indications are respiratory and circulatory arrest; critical hemodynamic instability before or during anesthesia induction; severe laryngospasm; anesthesia induction in respiratory bleeding. Urgent indications (decision based on each case is necessary) include urgent induction of anesthesia in non-fasted children (Ileus, RSI); induction of anesthesia in children with unstable circulation or severe cardiac insufficiency. Semi-elective indications (decision based on each case is necessary) after mask induction of anaesthesia (if vascular access required); mandatory induction of "intravenous" anaesthesia (as in malignant hyperthermia). This article is in German.

Intraosseous Vascular Access Bibliography

Medications

YEAR: 2010

Mosier JM, Hiller K, Franke H, Degan J, Boyer LV. Scorpion antivenom administered via alternative infusions. J Med Toxicol 2010;6:249

799

A case study describing administration of scorpion antivenom via intraosseous (IO) vascular access in a 16-month old female. Following failure to obtain IV access in pre-hospital and upon arrival at the ED, IO vascular access was established in the proximal tibia and 3 vials of antivenom in 50 mL saline were administered over 10 minutes. Within 5 minutes, the patients respiratory status improved, intubation was averted, and vital signs stabilized immediately; nystagmus and writhing resolved. The patient was discharged home after a short observation period. The authors concluded that when IV access is difficult, IO access may be a rapid and reasonable rescue maneuver for patients requiring scorpion antivenom.

YEAR: 2009

Fortin JL, Capellier G, Manzon C, Giocanti J, Gall O. Intraosseous administration of hydroxocobalamin in the acute treatment of cyanide poisoning. Burns 2009;35(S1):S15-6. doi: 10.1016/j.burns.2009.06.061. France

801

Case study of a 9- month old treated with IO hydroxocobalamin for suspected smoke inhalation cyanide poisoning. The patient was discharged from the ICU without neurological sequelae. Authors stated the IO route for hydroxocobalamin warrants further exploration to improve ease and speed of treatment.

YEAR: 1997

Reisman D, Reader A, Nist R, Beack M, Weaver J. Anesthetic efficacy of the supplemental intraosseous injection of 3% mepivacaine in irreversible pulpitis. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 1997;84(6):676-82

856

A dental study evaluating use of supplemental intraosseous injection of 3% mepivacaine in mandibular posterior teeth following application of an alveolar nerve block. Results showed supplemental injections increased anesthetic effect and a second injection was sometimes necessary.

Replogle K, Reader A, Nist R, Beck M, Weaver J, Meyers WJ. Anesthetic efficacy of the intraosseous injection of 2% lidocaine (1:100,000 epinephrine) and 3% mepivacaine in mandibular first molars. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 1997;83(1):30-7

855

A dental study comparing the anesthetic effect of 2% lidocaine (1:100,000 epinephrine) and 3% mepivacaine when injected in the mandibular first molars. The results showed the lidocaine to be more successful with a longer duration of pupal anesthesia than mepivacaine.

YEAR: 1996

Coggins R, Reader A, Nist R, Beck M, Meyers W.. Anesthetic efficacy of the intraosseous injection in maxillary and mandibular teeth. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 1996;81(6):634-641. doi:10.1016/s1079-2104(96)80067-9

908

This study's objective was to determine the anesthetic efficacy of the intraosseous injection as a primary technique in human maxillary and mandibular teeth. Forty subjects were enrolled and received 2 sets of intraosseous injections with 1.8ml of 2% lidocaine with 1:100,000 epinephrine on two different occasions. Authors concluded that in 75%-93% of non-inflamed teeth subjects, an intraosseous injection may provide pupal anesthesia. Authors cautioned that the duration of the anesthesia declines over an hour.

YEAR: 1995

Leonard MS. The efficacy of an intraosseous injection system of delivering local anesthetic. JADA 1995;126(1):81-6

884

This article describes a device used for the intraosseous delivery of local anesthesia during dental procedures.

Intraosseous Vascular Access Bibliography

Military Application

YEAR: 2018

Auten J, Mclean JB, Kemp JD, et al. A pilot study of four intraosseous blood transfusion strategies. J Spec Oper Med 2018;18(3):50-6 1042

This pilot study compares four different IO blood transfusion strategies with varying degrees of transfusion pressure in a swine model with similar bone density to that of an adult military servicemember. Animals were randomly assigned to one of four transfusion strategies: 1) gravity, 2) pressure-bag, 3) rapid-transfusion device, or 4) manual push-pull. Hemorrhage was simulated then IO access was obtained with the EZ-IO device. Gravity transfusion was the slowest with a flow rate 5 mL/min, followed by rapid transfusion device (31 mL/min), single site pressure bag (78 mL/min), double site pressure bag (103 mL/min), and push-pull technique (109 mL/min). Single site or double site pressure bag was determined to be the best option for IO infusion because of the high flow rate and no associated incidences of overpressure or death.

Gendron B, Cronin A, Monti J, Brigg A. Military medic performance with employment of a commercial intraosseous infusion device: A randomized, crossover study. Mil Med 2018;183(5-6):e216-22. doi:10.1093/milmed/usx078 933

Randomized crossover prospective study in which 77 of U.S. Army Combat Medics naive to the EZ-IO system were trained and then attempted IO access using the EZ-IO in bone models of the proximal tibial (PT) and proximal humerus (PH) sites. Success rate was the primary outcome with no significant differences in results between sites; and no significant learning or design confounding effects. Secondary outcomes of mean procedural time demonstrated a significant mean time advantage of 17.1 s ($p < 0.05$) in PT placement. There was no significant difference between sites for mean participant comfort level utilizing the EZ-IO® System. Authors concluded the overall first-attempt success rates with the EZ-IO® System are similar to the success rates of the FAST1® device.

Sulava EF, Bianchi W, Krepela A, et al. Performance of single versus double site intraosseous blood transfusion strategies in a swine (sus scrofa) model of hemorrhagic shock. Ann Emerg Med 2018;72(4s):S3-4 1023

This abstract describes interim results of a study in a swine model that discusses the utility of intraosseous blood transfusions for treating hypovolemic battlefield injuries, compares advantages and complications of humeral versus sternal IO access for resuscitation, and identifies flow rates, degree of intravascular hemolysis, and occurrence of coagulopathy in single versus double site intraosseous blood transfusion. The study found that in an animal model of hemorrhagic shock, double site IO transfusion appears to confer a significant advantage in flow rates without significant complications

YEAR: 2017

Butler F. Two decades of saving lives on the battlefield: Tactical combat casualty care turns 20. Mil Med 2017;182(3):1563-68. doi:10.7205/milmed-d-16-00214 905

The author discusses tactical combat casualty (TCCC), which has evolved over the past the past 20 years into a set of evidence-based, best practice prehospital trauma care guidelines for use in combat. TCCC has become a standard of trauma care in the US military and many other militaries of our allied nations. The Committee on TCCC and the Joint Trauma System are working with civilian trauma colleagues to advance prehospital trauma care into civilian trauma care in situations such as shooter events, terrorist bombings, motor vehicle accidents, household accidents and criminal violence.

Hodgetts JM, Johnston A, Kendrew J. Long-term follow-up of two patients with retained intraosseous sternal needles. J R Army Med Corps 2017;163(3):221-2. doi: 10.1136/jramc-2016-000699 872

This article describes two cases in which FAST1 intraosseous needle tips were retained in the sternal manubrium of patients following device removal. In each case, there were no long-term complications.

Mercer SJ, Jones CL, Round J, et al. Military anaesthesia in contingencies: What skill sets are required and how will we prepare our trainees? J R Army Med Corps 2017;163(4):226-32. doi: 10.1136/jramc-2016-000722. (United Kingdom) 993

This paper describes skill sets and training for the Defence Medical Services in the UK, specifically the revised Military Higher Module and how it will be implemented in the future either during deployment or times of peace. IO devices as a means to control catastrophic haemorrhage is listed as a competency.

Shina A, Baruch EN, Shlaifer A, et al. Comparison of two intraosseous devices: The NIO versus the EZ-IO by novice users- a randomized cross over trial. Prehosp Emerg Care 2017;21(3):315-21. doi:10.1080/10903127.2016.1247201 817

Using a porcine hind leg model authors compared the success rate and ease-of-use ratings of an IO device, the NIO® in comparison to the Arrow® EZ-IO by novice users. NIO success rates were comparable to those of EZ-IO; 54% of the participants preferred using the EZ-IO over the NIO.

Sotomayor T, Maraj C, Mott J, et al. Humeral head intraosseous access: Filling the military gap. J Def Model Simul 2017;14(4):361-9. doi: 10.1177/1548512916646888 1022

This article assesses the usability of the Partial Task Trainer (PTT) to train certain military medical providers on the technique of humeral head intraosseous infusion (HHIO). The PTT consists of an arm with functional structures and characteristics that allow trainees hands on practice locating anatomical landmarks, inserting the IO needle, and introducing the catheter into the humerus. Currently the US Army utilizes the EZ-IO Intraosseous Infusion System for HHIO infusions.

Intraosseous Vascular Access Bibliography

Military Application

U.S. Army, CoTCCC, TCCC Working Group. Tactical combat casualty care: Lessons and best practices. Tactical combat casualty care (TCCC): Lessons and best practices. Handbook. No. 17-13: Version 5. May 2017

1072

The CoTCCC handbook was created as a guide to best practices created by the Committee on Tactical Combat Casualty Care (CoTCCC) which includes representatives from all the U.S. Armed Services that are part of the Tactical Combat Casualty Care (TCCC) Working Group. The recommendations are based on input from the battlefield as well as evidence in the civilian literature, examined and put together to provide guidelines for care. The recommendations and required skill sets include IO access as an alternative to IV access in multiple sections. The TCCC- Medical provider skill set specifically includes the ability to demonstrate the use of IV/IO blood product administration (medical officers and operating room special operations medics) and the use of IV/IO tranexamic acid (TXA).

YEAR: 2016

Edwards S, Smith J. Advances in military resuscitation. Emerg Nurse 2016;24(6):25-9. doi:10.7748/en.2016.en1630

818

This journal article discusses lessons learned from treatment of severe traumatic injury in combat situations and how they can be applied in the civilian environments when treating the same type injuries.

Maddry JK, Savell S, Mora A, Perez C, Bebart V. En route intraosseous access performed in the combat setting. Ann Emerg Med 2016;68(4):S106

889

This abstract describes a study designed to describe and compare the use of intraosseous (IO) catheters by military MEDEVAC providers during recent conflicts. There were 12 patients that receive IO catheters following failed intravenous cannulation with an 83% success rate, and 74 patients for whom IO access was the first access attempted with an 85% success rate. Researcher concluded that IO access can be used successfully in the combat setting and accounted for approximately 12% of vascular access in the MEDEVAC population they studied.

Philbeck TE, Montez DF, Puga TA, Davlantes C, Miller LJ. Infusion flow rates and insertion success through the sternum using a multi-site intraosseous device. J Vasc Access 2016;17(4):e131

784

This abstract describes the results of a healthy volunteer study evaluating use of the EZ-IO TALON in the sternal IO insertion site. IO infusion flowrate was measured and reported for gravity infusion, as well as pressured infusions at 100, 200, and 300 mmHg. The authors concluded the TALON device may be used safely and successfully in the sternum with excellent infusion flow rates. This study was sponsored by Teleflex Incorporated.

Savell S, Mora AG, Perez CA, Bebart VS, Maddry JK. En route intraosseous access performed in the combat setting. Am J Disaster Med 2016;11(4):225-31. doi:10.5055/ajdm.2016.0243

847

A retrospective study evaluating vascular access routes used for US Military personnel injured in combat and transported by MEDEVAC. Medical records were reviewed for intravenous (IV) and intraosseous (IO) use including, number of attempts and rates of success; along with events occurring in transit, hospital and ICU stays and 30 day outcomes. Results showed IV and/or IO access was attempted in 832 patients. PIV was first line of attempt in 758 cases with 93% success; IO access was first line of attempt in 74 cases with 85% success. There were 25 attempts to establish IO as the second line of access with 100% successful placement. Success rates were 100% with tibia (29); 94% with humerus (21/22); and 89% with the sternum (41/46). The overall IO success rate was 88% for all attempts made.

Uwaydah NI, Hoskins SL, Bruttig SP, et al. Intramuscular versus intraosseous delivery of nerve agent antidote pralidoxime chloride in swine. Prehosp Emerg Care 2016;20(4):485-92. doi:10.3109/10903127.2014.942479

842

A preclinical study comparing delivery of nerve agent antidote when administered via intramuscular (IM) and proximal tibia intraosseous (IO) routes, in normovolemic and hypovolemic swine. IO and IV administration of the antidote achieved and surpassed therapeutic levels in normovolemic groups; time to therapeutic level with IM was 2 minutes versus 15 seconds with IO access. Combined administration via IO route initially, followed by IM injection 60 minutes post IO injection resulted in therapeutic levels for a prolonged time, most closely mimicking standard hospital care of poisoned patients. The authors concluded the rapid increase in plasma concentrations, coupled with the sustainability of the drug in plasma supported advantages of IO over IM delivery.

Wong MR, Reggio MJ, Morocho FR, et al. Effects of intraosseous epinephrine in a cardiac arrest swine model. J Surg Res 2016;201(2):327-33. doi:10.1016/j.jss.2015.11.015

776

Preclinical study that examined the differences in pharmacokinetics and pharmacodynamics of tibial IO (TIO) and IV-delivered epinephrine during cardiac arrest and CPR. There were no significant differences between IV versus TIO epinephrine in achieving ROSC, time to ROSC, and Cmax. In the context of ROSC, epinephrine delivered via TIO route was a clinically relevant alternative to IV administration. The authors concluded that when IV access cannot be immediately obtained in cardiac arrest patients, TIO access should be considered.

Intraosseous Vascular Access Bibliography

Military Application

YEAR: 2015

Chatfield-Ball C, Boyle P, Autier P, van Wees SH, Sullivan R. Lessons learned from the casualties of war: Battlefield medicine and its implication for global trauma care. J R Soc Med. 2015;108(3):93-100. doi: 10.1177/0141076815570923 965

This analysis examines the current state of military trauma in high-income countries and how these developments could be applied to low/middle-income countries to help deliver affordable trauma care there. Intraosseous needles are identified as a key technology especially when working in a moving environment or on a bumpy road which would likely be encountered in a low/middle-income country. Under such circumstances normal cannulation would likely fall out, whereas an IO needle would remain in place.

Chico-Fernández M, Terceros-Almanza L, Mudarra-Reche C. Innovation and new trends in critical trauma disease. Med Intensiva (English Edition) 2015;39(3):179-88. doi:10.1016/j.medine.2015.03.002 907

This article discusses the trends in management of critical trauma disease (CTD) in the military combat and civilian setting. Authors of the article discuss the need in ongoing innovations in the management of trauma patients in ICUs. In order to achieve more innovations there is a need for improvement in the following areas: methodology in emergency care medicine, increased knowledge in resuscitation strategies, study of epidemiology of trauma disease and its effect on patient outcomes, application of methodologies for ensuring correct trauma care team performance.

Haider AH, Piper LC, Zogg CK, et al. Military-to-civilian translation of battlefield innovations in operative trauma care. Surgery 2015;158(6):1686-95. doi: 10.1016/j.surg.2015.06.026 870

This paper describes a survey of trauma military directors that suggested that military data supporting damage control resuscitation has altered civilian practice. Among those practices are the use of intraosseous vascular access

Philbeck TE, Puga T, Montez DF, Miller LJ, Saussy J, Davlantes C. Sternal flow rates and insertion success using a multisite intraosseous device. Ann Emerg Med 2015;66(4s):s48 787

A healthy volunteer study evaluating use of the EZ-IO TALON in the sternal IO insertion site. Military trained medics performed all device insertions. IO infusion flowrate was measured and reported for gravity infusion, as well as pressured infusions at 100, 200, and 300 mmHg. The authors concluded the TALON device may be used by military and tactical medicine personnel to safely and successfully establish IO access in the sternum with excellent infusion flow rates. This study was sponsored by Teleflex Incorporated.

Rottenstreich M, Malka I, Glassberg E, Schwartz O, Tarif B. Pre-hospital intra-osseous freeze dried plasma transfusion: a case report. Disaster and Military Medicine 2015;1(8):1-3 935

Case report of a 13 year old girl suffering from severe hemorrhagic shock due to blast injuries and gun shot wounds that received freeze-dried plasma via IO access as part of prehospital resuscitative efforts. Her vital signs improved upon arrival to the hospital; and she was released after 3 weeks of hospitalization.

YEAR: 2014

Barnard EBG, Moy RJ, Kehoe AD, Bebart VS, Smith JE. Rapid sequence induction of anesthesia via the intraosseous route: a prospective observational study. Emerg Med J 2014;32(6):449-52. doi:10.1136/emmermed-2014-203740 702

A prospective observational study that evaluated use of intraosseous vascular access for delivery of rapid sequence intubation (RSI) drugs. Data was collected between January and May 2012 at a combat hospital in Afghanistan. Thirty-four (34) patients underwent RSI with drug delivery via the IO route. Access was established in the proximal humerus and tibia using the EZ-IO and in the sternum using the FAST-1. All placements were successful on first attempt; first pass intubation success rate was 97%; a Cormack-Lehane (C-L) laryngoscopic grade view of 1 was reported 91%. Authors concluded that IO access is a safe and feasible route for delivery of anesthetic drugs for RSI.

Dobson GP, Letson HL, Tadaki D. The Bellamy challenge: it's about time. J R Army Med Corps 2014;160(1):9-15.doi: 10.1136/jramc-2013-000145 1071

Authors briefly review clinical literature and discuss the historical development and research of pharmacological and procedural adjuncts such as Hextend, hypertonic saline, permissive hypotension and adenosine-lidocaine-magnesium cardioplegia to support restoration of hemostasis in the pre-hospital environment, especially in far-forward military scenarios. Properties of a proposed "ideal" fluid solution for hemorrhagic shock are listed and include easy delivery (IV or IO), protection from secondary brain damage, effective in small volumes amongst other attributes.

Johnson D, Dial J, Ard J, et al. Effects of intraosseous and intravenous administration of Hextend on time of administration and hemodynamics in a swine model. J Spec Oper Med 2014;14(1):79-85 713

A preclinical study comparing intraosseous (IO) and intravenous (IV) administration of Hextend in 27 swine for time of administration and hemodynamics. IO access was established in the proximal humerus using the EZ-IO. Results showed time for administration was not significant; there were no significant differences between IV and IO relative to hemodynamics. The author concluded that the IO route is an effective method of administering Hextend

Intraosseous Vascular Access Bibliography

Military Application

Lewis P, Wright C. Saving the critically injured trauma patient: a retrospective analysis of 1000 uses of intraosseous access. *Emerg Med J* 2014;31(9):784. doi:10.1136/emermed-2014-203588

714

This retrospective study reported IO use over a 7-year period during combat operations in Afghanistan by the UK Defence Medical Services. The EZ-IO and FAST1 IO devices were available for use; IO use data was collected from the front line, during helicopter evacuation and at the combat hospital. A total of 1014 IO devices were inserted into 830 adult patients; various medications infused via IO access are listed. Across all cases there were no serious IO complications and 14 minor complications. The author concluded that in the pre-hospital setting in particular and in severely injured trauma patients, IO access should be considered a primary method of obtaining vascular access.

Nadler R, Gendler S, Chen J, Lending G, Abramovitch A, Glassberg E. The Israeli Defense Force experience with intraosseous access. *Military Medicine* 2014;179(11):1254-7

740

Retrospective study of the Israeli Defense Force (IDF) registry from January 1999 through October 2012 to identify all cases in which IO access was attempted. The Bone Injection Gun (B.I.G.) was the device used for IO access. A total 37 attempts were made in 30 patients. First attempt success was 53% with an overall success rate 49% when factoring subsequent attempts. Most frequent cause for failure related to providers skill level, and due to the device design allowing little room for error. This study prompted the IDF to seek an alternative for the B.I.G.

Israel

Pasley J, Miller C, Dubose J, et al. Intraosseous infusion rates under high pressure: a cadaveric comparison of anatomic sites. 2014 Annual Scientific Assembly for the Eastern Assoc for the Surgery of Trauma meeting. <http://www.dtic.mil/cgi-bin/GetTRDoc?AD=ADA597324>. Published January 2014. Accessed May 12, 2014

728

This report describes a study conducted by the Air Force Research Laboratory comparing intraosseous infusion rates between IO sites in a cadaveric model to determine if there is a site that is most effective for volume resuscitation. Using 16 cadavers procured within 72 hours of death, IO access was established in the proximal tibia and proximal humerus using the EZ-IO and in the sternum using the FAST1. Results showed the mean flow rate in the sternum was 1.6 times greater than the humerus and 3.1 times greater than the tibia. An abstract describing this report was presented by oral presentation at the 2014 annual scientific assembly for the Eastern Association for the Surgery of Trauma meeting.

Rush S, D'Amore J, Boccio E. A review of the evolution of intraosseous access in tactical settings and a feasibility study of a human cadaver model for a humeral head approach. *Mil Med* 2014;179(8 Suppl):24-8. doi: 10.7205/MILMED-D-13-00484

726

This article explores use of IO vascular access in combat and tactical settings through a brief review of the literature describing this practice. A small feasibility study is discussed that evaluated the use of cadavers for training 26 U.S. Air Force Pararescuemen (PJs) on establishing IO access in the humeral head (proximal humerus is the descriptor used by EZ-IO for this site) using the EZ-IO powered driver and needle set system (pictured in the article) and needles inserted with a manual driver without power. First attempt placement success with the EZ-IO powered driver system was achieved in 25 of 26 attempts; first attempt placement success using the manual driver and needle set occurred in 19 of 21 attempts. The authors concluded that the humeral head (proximal humerus) IO site is the most appropriate site within the tactical setting; and that use of a human cadaver model for training is an appropriate model.

Sontgerath JS, Rubal BJ, DeLorenzo RA, Morgan TL, Ward JA. Variability in intraosseous flush practices of emergency physicians. *Am J Emerg Med* 2014;<http://dx.doi.org/10.1016/j.ajem.2014.03.001>

719

This prospective study sought to evaluate intraosseous flush practices of emergency physicians. Using cadavers, 15 emergency physicians were asked to flush an IO catheter placed in the proximal tibia and proximal humerus IO insertion sites with 10 mL normal saline as they would in clinical practice; IO pressure measurements were recorded using an IO catheter inserted in the diaphysis of the target bones. Results showed the median IO pressure generated was 903 mmHg and the median flush duration was 5.2 seconds. Result showed significant interoperator variability with greater than 35-fold difference in flush forces. The authors concluded that it may be prudent practice for providers to extend the flush over several seconds to limit the maximal pressures.

Vassallo J, Horne S, Smith JE. Intraosseous access in the military operational setting. *J R Nav Med Serv* 2014;100(1):36-9

794

This article describes a prospective, observational study conducted March – July 2011 at the emergency department, Camp Bastion, Afghanistan evaluating use of IO access in 117 patients established using the EZ-IO and the FAST1 devices (76% EZ-IO).

YEAR: 2013

Barratt JW. Re: reasons for not using intraosseous access in critical illness. *Emerg Med J* 2013;30(6):516-7. doi:10.1136/emermed-2012-202120

703

This article describes a questionnaire study that was given to UK Role One military clinicians deployed to Afghanistan to assess the level of experience and confidence rating with use of IO access, using the FAST-1 and EZ-IO, and IV access. Thirty-three responses were received; clinicians felt more confident with IV access over IO access; clinicians felt more confident with FAST-1 IO access than EZ-IO IO access.

UK

Intraosseous Vascular Access Bibliography

Military Application

- Morton R, Krakover B, Hudson T, Alexander B. Casualty evacuation: an innovative role for emergency nurses. J Emerg Nurs 2013;39(6):576-80** 677
- This article describes the role of the casualty evacuation nurse role within the military. One case study briefly notes the use of proximal tibia IO access and the administration of packed red blood cells in a 22-year-old woman. No further follow up is provided other than noting the patients were expected to survive.
- Plancade D, Millot I, Fetisssof H, et al.. Sternal perforation with an intraosseous device and hemomediastinum infusion Ann Fr Anesth Reanim 2013;<http://dx.doi.org/10.1016/j.annfar.2013.01.009>** 616
- A 45-year-old woman in hemorrhagic shock with multiple injuries to the limbs, secondary to a war wound, received sternal IO access using the Jamshidi trocar (not specifically intended for sternal use). After initiating a blood transfusion through the IO line a contrast CT scan revealed sternal perforation and hemomediastinum, secondary to the transfusion, as well as drainage into the left pleural cavity. The catheter was removed, right thoracic drainage was performed, and the patient was released from ICU 48 hours later. The authors conclude this case report demonstrates the difficulty in selecting emergency insertion sites and the necessity of choosing an appropriate IO catheter.
- Pozza M, Lunardi F, Pflipsen M. Emergency intraosseous access: a useful, lifesaving device use in Afghanistan. J Spec Oper Med 2013;13(1):25-8** 684
- A case study describing use of the EZ-IO in Afghanistan by US military on 5 patients with traumatic injury including one pediatric patient. Access was obtained in the proximal tibia on first attempt and was used to administer crystalloids in all patients along with opioids, analgesics and antibiotics. All ultimately received central venous access and peripheral access was established in one patient. There were no IO complications.
- Stranden G, Skogrand H, Spinella PC, Hervig T, Rein EB. Donor performance of combat readiness skills of special forces soldiers are maintained immediately after whole blood donation: A study to support the development of a prehospital fresh whole blood transfusion program. Transfusion 2013; 53(3):526-30. doi:10.1111/j.1537-2995.2012.03767.x** 570
- This study conducted by the Norwegian Navy evaluated the ability of 25 soldiers to perform buddy transfusion by starting phlebotomy, establishing sternal IO access using the FAST1, and infusing 1 unit of whole blood. Physical performance was evaluated pre and post blood donation and lactate levels were recorded. The authors concluded that physical and combat performances are preserved within limits post whole blood donation and that soldiers are able to learn the phlebotomy and sternal reinfusion with only a short lecture on the procedure.
- YEAR: 2012**
- Berger E. Innovations from a decade of war: soldiers' final sacrifice has improved emergency care. Ann Emerg Med 2012;60(6):14A-5A. <http://dx.doi.org/10/1016/j.annemergmed.2012.10.012>** 611
- This article takes a look at the emergency medicine advances that result from war, including intraosseous resuscitation.
- Carness JM, Russell JL, Lima RM, Navarro LHC, Kramer GC. Fluid resuscitation using the intraosseous route: Infusion with lactated ringers and hetastarch. Mil Med 2012;177(2):222-8.** 529
- This pre-clinical study evaluated IO flow rates obtainable with infusion of lactated Ringer's and hetastarch 6% through the proximal tibia and sternum IO insertion sites, using a swine model. The EZ-IO 25mm was used to facilitate tibial IO access; sternal access was established using a Jamshidi needle. Results showed that hetastarch flow rates were lower than lactated Ringer's flow rates at both insertion sites; sternal infusion of hetastarch is likely to provide greater estimated intravascular volume expansion than lactated Ringer's, despite the lower infusion rates; resuscitation using the IO rate is likely to benefit from pressure bag or high-pressure pump delivery. This study was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.
- Helm M, Goller R, Hackenbroch C, Hossfeld B. A complication of the use of an intra-osseous needle. Emerg Med J 2012;29:923. doi: 10.1136/emered-2011-200139** 1054
- This is a case report of needle sheering associated with the use of the FAST-1 intraosseous infusion system. A soldier successfully placed a FAST-1 needle in the sternum of a healthy volunteer soldier during a training session. Upon completion of the training session, the soldier was unable to remove the needle. The retained needle was later removed surgically at a field hospital.
- Lairet J, Lairet K, Burns C, et al. Prehospital interventions performed in a combat zone- A prospective multicenter study. Prehosp Emerg Care 2012;16(1):174. doi:10.3109/10903127.2011.624676** 512
- This abstract described a prospective observational study evaluating lifesaving interventions performed in a combat zone, including those that were incorrectly used. The use of intraosseous access in the study cohort of 449 patients was very low with only 26 IO lines established.

Intraosseous Vascular Access Bibliography

Military Application

Rush S, Bremer J, Foresto C, Rubin AM, Anderson PI. A magnetic resonance imaging study to define optimal needle length for humeral head IO devices. J Spec Oper Med 2012;12(2):77-82 577

This article describes a retrospective study in which 50 consecutive MRI images were evaluated of the humerus for the purpose of determining the optimal needle length necessary for successful proximal humerus IO insertion. Results showed the cortical thickness was 4mm in all cases and that an IO needle length ranging between 40-50mm should be used via the anterior approach. The EZ-IO is specifically discussed in relation to the proximal humerus IO insertion site; and a 24 patient post mortem review of the EZ-IO placed in the proximal humerus is discussed.

Vassallo J, Horne ST, Smith JE. Intraosseous access on military operations: a 4 month review. Poster presentation at International Conference on Emergency Medicine, Dublin, Ireland. June 27-30, 2012 593

This poster presented at the 2012 International Conference of Emergency Medicine described a 4 month review of intraosseous access in UK military operations in Afghanistan. During the timeframe the EZ-IO was used to establish IO access in the proximal humerus and tibia sites; the FAST1 was used to establish sternal IO access. Of the 87 EZ-IO applications there were 12 functional issues and the placement success rate for both sites combined was 86.3%. In 24 FAST1 applications there were 4 functional issues and the placement success rate was 83.4%.

YEAR: 2011

Borron SW, Arias JC, Bauer CR, et al. Intraosseous line placement for antidote injection by first responders and receivers wearing personal protective equipment. Am J Emerg Med 2011;29(4):373-81.doi:10.1016/j.ajem.2009.10.009 424

This article describes a preclinical trial with a caprine model that assessed the ability of protected, experienced first responders and limited-experience first receivers to place IO lines for antidote administration using the EZ-IO device. First responders placed IO lines successfully in 100% of cases, and first receivers placed IO lines successfully in 91% of the cases. Investigators concluded that IO lines may facilitate earlier administration of antidotes to hazardous material victims.

Brisson M. Trauma and the military medic. EMS1.com 12/01/2011 528

This article describes use of IO access along with other prehospital interventions in a traumatically wounded soldier in a combat zone. The IO site used was the proximal humerus as the patient had 3 of 4 limbs traumatically amputated.

Harcke T, Crawley G, Ritter B, Mazuchowski E. Feedback to the field: an assessment of sternal intraosseous (IO) infusion. J Spec Oper Med 2011;11(1):23-6 544

This article summarizes the case-based observations made by the Armed Forces Medical Examiner System on soldiers killed in action/died of wounds who had evidence of sternal intraosseous access. The Pyng Fast-1 is noted in the article as the sternal IO device most widely distributed by the department of defense (DOD); the EZ-IO is listed as another device that may be seen in emergency care facilities within the DOD. Of 98 cases, 78 (80%) showed proper placement; 20% were unsuccessful. It should be noted that the article incorrectly states that the EZ-IO using the powered driver is indicated for sternal placement.

Navarro Suay R, Bartolome Cela E, Hernandez Abadía de Barbará A, Tamburri Barriain R, Rodriguez Moro C, Olivera Garcia J. [Intraosseous access for fluid therapy in combat situations: use by Spanish military medical staff in Afghanistan]. Rev Esp Anestesiol Reanim 2011;58(2):85-90 645

This article in Spanish describes the Spanish military medical staff's experience with the use of intraosseous lines for fluid therapy in a combat zone from March 2007 to June 2008. Twenty-five patients had an IO placed with the Bone Injection Gun (BIG). Placement success rates were 76% for the 19 pre-hospital placements and 100% for the 6 in-hospital placements. There were no complications during insertion. Conclusion was intraosseous access can provide an alternative to venous access for treating trauma patients in combat zones.

YEAR: 2010

Hulse EJ, Thomas GOR. Vascular access on the 21st century military battlefield. J R Army Med Corps 2010;156(4 Suppl 1):s385-90 629

An article evaluating various methods of obtaining vascular access in the management of 21st century battlefield trauma including, peripheral IV access, intraosseous access, venous cut-down, and central venous access. The authors conclude that IO access should be the first line vascular access in casualties with severe trauma to avoid delay initiating resuscitation in pre-hospital or hospital setting.

YEAR: 2009

Fenton P, Bali N, Sargeant I, Jeffrey SLA. A complication of the use of an intra-osseous needle. J R Army Med Corps 2010;155(2):110-1 450

This case report describes a complication of use of a sternal IO device (FAST-1, Pyng Medical Corporation, Richmond, Canada) in a 21-year-old soldier who suffered multiple soft tissue fragmentation injuries, in which the needle tip broke in situ. The author concluded the complication resulted from the IO needle being placed when the patient was lying in a lateral position with the skin over the manubrium displaced from the midline.

Intraosseous Vascular Access Bibliography

Military Application

- Plancade D, Ruttimann M, Boulland P, et al. [Evaluation d'un nouveau catheter pour perfusion intra-osseuse en OPEX]. La Revue du CARUM-Réanoxyo 2009;25(2):49-50. French** 410
- This article describes an observational study performed by the French military air surgical team in Chad. There were 11 patients with no insertion failures. For 7 patients, the insertion site was the proximal tibia and for the remainder the site was the proximal humerus. The authors concluded that the EZ-IO is a device that is simple, reliable and which gives satisfaction for the administration of drugs.
- Sarkar D, Philbeck T. The use of multiple intraosseous catheters in combat casualty resuscitation. Mil Med 2009;174:106-8** 418
- This case study describes injuries sustained in Iraq by an American soldier, and the concurrent use of 4 IO devices to resuscitate and stabilize him.
- YEAR: 2008**
- Borron S, Arias J, Sanchez M Bauer C. Hemodynamics following intraosseous administration of hydroxocobalamin in the goat. Ann Emerg Med 2008;52(4):S96** 421
- Animal (goat) study to determine if IO administration of hydroxocobalamin for antidotal treatment for exposure to cyanide and other poison agents would be faster and require less fine motor coordination and sensitivity; and would result in similar hemodynamic changes compared to IV administration. Using the EZ-IO device, researchers concluded that hemodynamic effects of hydroxocobalamin given by the IO route in non-poisoned goats are mild and similar in magnitude to those of saline control animals.
- Borron S, Arias J, Sanchez M, et al. Intraosseous line placement by hazardous materials responders and receivers for hydroxocobalamin administration. Ann Emerg Med 2008;52(4):S97** 420
- Animal (goat) study to determine the capacity and time required for protected hazardous materials responders and receivers to accomplish vascular access and hydroxocobalamin administration for antidotal treatment for exposure to cyanide and other poison agents. Using the EZ-IO device, researchers concluded that the time required for IO administration of the drug was shorter than intravenous administration; and that IO placement is readily accomplished wearing all levels of chemical protective garments and equipment.
- YEAR: 2007**
- Beekley AC, Starnes BW, Sebesta JA. Lessons learned from modern military surgery. Surg Clin N Am 2007;87:157-84** 650
- Data from the largest combat trauma database was analyzed to identify how new or improved devices, dressings or drugs have impacted prehospital casualty care, how guidelines and resuscitation strategy have changed, and discusses lessons learned and how concepts have crossed back into the civilian practice. Intraosseous access, particularly the sternal site, is identified as one of the advances for vascular access in combat medicine.
- Cooper BR, Mahoney PF, Hodgetts TJ, Mellor A. Intra-osseous access (EZ-IO®) for resuscitation: UK military combat experience. J R Army Med Corps 2007;153(4):314-6** 379
- Describes the experience of the UK Defence Medical Service using the EZ-IO for emergency vascular access in Afghanistan. They used the device for 26 patients, including 10 children. Of the 26 EZ-IO placements, 23 were made in the emergency department. There was a 97% insertion success rate with no infection. Significant infusion pain was felt by three patients.
- Suyama J, Knutsen C, Northington W, Hahn M, Hostler D. Intraosseous vs. intravenous access while wearing personal protective equipment in a simulated HazMat scenario. Acad Emerg Med 2007;14(5):s128** 360
- Study investigating time difference in obtaining IO vs. IV access while wearing personal protective equipment (PPE) in simulated HazMat scenarios. With provider in PPE and mannequin not in PPE, vascular access was faster with IO (14 seconds vs. 46 seconds; $p < 0.001$); also, fluid infusion time (28 seconds vs. 46 seconds; $p < 0.001$). With provider and mannequin in PPE, all the following favored IO: needle to skin time (13 seconds vs. 25 seconds, $p < 0.001$), vascular access time (17 seconds vs. 63 seconds; $p < 0.001$), and fluid infusion time (30 seconds vs. 66 seconds; $p < 0.001$). Investigators conclude that EZ-IO under HazMat conditions provides vascular access and fluid more quickly than IV access.
- Suyama J, Knutsen CC, Northington WE, Hahn M, Hostler D. IO versus IV access while wearing personal protective equipment in a HazMat scenario. Prehosp Emerg Care 2007;11(4):467-72** 401
- Article describes a controlled study in which the time difference between IV and IO access was compared while providers and simulated patients (mannequins) were wearing personal protective equipment (PPE). Twenty-two EMT-P providers measured the times to skin access, vascular access and fluid infusion in three scenarios: no PPE for providers or mannequins; providers only in PPE; and both providers and mannequins in PPE. In all scenarios, there was a statistically significant difference in vascular access and fluid infusion time, in favor of the EZ-IO. Investigators concluded that, overall, the EZ-IO provides vascular access and fluid more quickly than standard IV access, and that donning PPE does not hinder providers' use of the EZ-IO.

Intraosseous Vascular Access Bibliography

Military Application

YEAR: 2005

Butler FK, Holcomb JB. The tactical combat casualty care transition initiative. Army Medical Department Journal PB 8-0504/5/6 Apr/May/Jun 2005 -33-37 348

Article for a military audience describing strategies employed as part of the Tactical Combat Casualty Care Transition Initiative, including phased levels of battlefield care, more aggressive use of tourniquets, battlefield antibiotics, IV vs IM battlefield analgesia, hypotension resuscitation strategies, small volume colloid as a resuscitation fluid, cricothyrotomy vs intubation for a definite airway in maxillofacial trauma, and more aggressive use of needle decompression for suspected tension pneumothoraces. Advocates IO infusion devices over cutdowns for fluid replacement.

Tabas JA, Rosenson J, Price DD, Rohde D, Baird CH, Dhillon N. A comprehensive, unembalmed cadaver-based course in advanced emergency procedures for medical students. Acad Emerg Med 2005;12(8):782-5 349

Describes a training course for medical students to learn advanced emergency procedures using unembalmed cadavers. The course includes clinical indications and contraindications for specific procedures, as well as techniques. Also discusses students' confidence levels in performing procedures.

Timboe HL, Bruttig SP, Ruemmler MW. Adult IO in the combat zone: the past, present and future use of intraosseous infusion by the U.S. military. JEMS 2005; 30: 27-8 329

Article discussing the use of IO in the combat zone. Highlights newer medical devices that make IO access and infusion safer.

YEAR: 2004

Gawande A. Casualties of war-military care for the wounded from Iraq and Afghanistan. NEJM 2004; 351: 2471-5 317

Article describing the military medical system's strategies and systems of battle care.

Vardi A, Berkenstadt H, Levin I, Bentencur A, Ziv A. Intraosseous vascular access in the treatment of chemical warfare casualties assessed by advanced simulation: proposed alteration of treatment protocol. Anesth Analg 2004;98(6):1753-8 325

Evaluation of the BIG in a chemical warfare mass casualty scenario. Found 73.4% simulated survival in the IO group and 3.3% in the control group (no IO). Average treatment goals obtained in 3.5 minutes for IO group and 10 minutes for control group. Concludes that IO has great potential for early treatment of chemical.

Walls RM. Adult intraosseous device aids terrorism response. Journal Watch Emergency Medicine July 28, 2004 318

Evaluation of the B.I.G. in a simulated mass casualty attack with 88.9% of IO attempts successful.

<http://emergency-medicine.jwatch.org/content/vol2004/issue728/>

YEAR: 2003

Ben-Abraham R, Gur I, Vater Y, Weinbroum AA. Intraosseous emergency access by physicians wearing full protective gear. Acad Emerg Med 2003;10:1407-10 305

Study evaluating the ability of physicians to establish IO access in patients while wearing full protective gear. Concludes that IO insertion of the BIG needle is rapid, but the protective gear increased insertion time 50%.

Berkenstadt H, Ziv A, Barsuk D, Levine I, Cohen A, Vardi A. The use of advanced simulation in the training of anesthesiologists to treat chemical warfare casualties. Anesth Analg 2003;96:1739-42 303

This article describes the development of a simulation-based training program for anesthesiologists to treat nerve gas intoxication in mass casualty scenarios. As part of the program, the Bone Injection Gun was used for vascular access for delivery of fluids and medications. Most participants (22 of 25) concluded that the training program was an effective means to prepare for nerve gas intoxication in mass casualty situations.

Dubick MA, Atkins JL. Small-volume fluid resuscitation for the far-forward combat environment: current concepts. J Trauma 2003; 54: S43-5. 314

Review article asserting that IO administration of hypertonic saline dextran is consistent with the concept of permissive hypotension. Calls for innovative techniques in resuscitating patients from severe hemorrhage.

Holcomb JB. Fluid resuscitation in modern combat casualty care: lessons learned from Somalia. J Trauma 2003; 54: S46-51 308

Historical perspective on combat casualty care perspectives, differences in combat and civilian trauma cases, hypotensive resuscitation and hemorrhage control. Recommends instituting an algorithm for fluid resuscitation in combat casualties.

Intraosseous Vascular Access Bibliography

Military Application

YEAR: 2000

Dalenius E. [Reduced but better health care for armed forces]. *Lakartidningen* 2000; 97: 3624-8. Swedish. Abstract 265
Report on reorganization of the medical capacity of the Swedish Armed Forces focusing on new treatment modalities such as intraosseous infusion.

Dubick MA, Holcomb JB. A review of intraosseous vascular access: current status and military application. *Mil Med* 2000; 165: 552-9 254
Literature review of safety and efficacy of IO infusion of drugs and fluids, with emphasis on utility for the injured soldier. Discusses insertion times and flow rates. Includes literature citations from non-military studies in pediatrics, animals, and human cadavers.

YEAR: 1997

Dubick MA, Kramer GC. Hypertonic saline dextran (HSD) and intraosseous vascular access for the treatment of haemorrhagic hypotension in the far-forward combat arena. *Ann Acad Med Singapore* 1997;26(1):64-9 218
Review article highlighting preclinical data and 1 clinical study. Demonstrates that IO administration can be used for safe and rapid infusion of hypertonic saline dextran with the hemodynamic effect as IV administration.

YEAR: 1996

Shoemaker WC, Peitzman AB, Bellamy R, et al. Resuscitation from severe hemorrhage. *Crit Care Med* 1996;24(2S):12S-23S 215
Discusses research directions for resuscitation from trauma-induced acute hemorrhagic shock, particularly uncontrolled hemorrhagic shock, with emphasis on fluid resuscitation.

YEAR: 1984

Turkel H. Emergency infusion through the bone. *Military Medicine* 1984;149:349-50 38
Article for military medicine audience concluding that the intraosseous route is more safe and effective than the intravenous route for several clinical indications, including burns and shock, circulatory collapse, uncooperative patients, patients in transit, shortage of physicians, especially under emergency conditions. States that IO infusion is an established alternative to intravenous infusion.

Intraosseous Vascular Access Bibliography

Non-Emergency Applications

YEAR: 2019

- Mansfeld A, Radafshar M, Thorgeirsson H, Hoijer CJ, Segerlantz M. Palliative sedation via intraosseous vascular access: A safe and feasible way to obtain a vascular access end of life. *J Palliat Med* 2019;22(1):109-111. doi: 10.1089/jpm.2018.0398** 1056

This is a case report of IO access for palliative sedation with propofol in a 56-year-old man with no venous access. IO access was gained using an EZ-IO driver and the patient was successfully treated with propofol for 4 days to manage intractable pain and agitation.

YEAR: 2018

- Crawford SB. Intraosseous vascular access device as a transarticular k-wire alternative in mallet finger laceration. *Clin Pract Cases Emerg Med* 2018;2(1):71-4. doi:10.5811/cpcem.2017.7.34811** 969

This case study discusses the use of an IO vascular access device (EZ-IO) as a substitute for k-wire stabilization of mallet finger in a patient with distal fracture and tendon exposure of the third and fourth phalange. The needle driver of the EZ-IO was placed in a sterile glove and was then used to place the inner stylet of the device through the tip of the finger to achieve splint fixation in extension. The patient had a favorable outcome.

- Han K, Kim J. Intraosseous anesthesia using a computer-controlled system during non-surgical periodontal therapy (root planning): Two case reports. *J Dent Anesth Pain Med* 2018;18(1):65-9. doi: 10.17245/jdapm.2018.18.1.65** 983

This paper presents two case reports of IO anesthesia using a computer-controlled intraosseous system (CIAS) for non-surgical periodontal therapy (root planing). CIAS-based induction of local anesthesia during non-surgical periodontal therapy was more comfortable for both patients relative to previous conventional local infiltration anesthesia (CLIA) treatment.

- Rodda LN, Volk JA, Moffat E, et al. Evaluation of intraosseous fluid as an alternative biological specimen in postmortem toxicology. *J Anal Toxicol* 2018;42(3):163-9. doi: 10.1093/jat/bkx096** 1014

This article investigates intraosseous fluid (IOF) as an alternative matrix for drug testing in deceased patients, especially in cases where the cadaver is severely compromised following death. IO access was obtained at 4 sites, bilateral proximal tibia and bilateral proximal humerus, using the EZ-IO device. Samples in 29 subjects were collected and screened for a host of illicit substances. Study results support the possible use of IOF as an alternative postmortem specimen for toxicological investigations when necessary.

- Symonds T, Parkinson B, Hazratwala K, McEwen P, Wilkinson M, Grant A. Use of regional administration of prophylactic antibiotics in total knee arthroplasty. *ANZ J Surg* 2018;88:848-53** 1025

This paper discusses prosthetic joint infection (PJI) after total knee arthroplasty (TKA) and the use of prophylactic antibiotics to prevent PJI. Current literature recommends IV administration of cephalosporins, however, rising resistance rates limit the effectiveness of IV cephalosporins. Alternatives include clindamycin, teicoplanin, and vancomycin. The author reviews alternative routes of administration to increase time dependent or concentration dependent antibiotic killing including intravenous regional administration (IVRA) and intraosseous regional administration (IORA). Supporting literature is reviewed. The author concludes that IVRA and IORA of prophylactic antibiotics in TKA is a novel way to increase tissue concentrations of prophylactic antibiotics and the current literature supports changing guidelines (after further research) to allow IVRA and IORA in TKA. The EZ-IO device was utilized for IORA of prophylactic antibiotics in the reviewed studies.

- Young SW, Zhang M, Moore GA, Pitto RP, Clarke HD, Spangehl MJ. The John N. Insall Award: Higher tissue concentrations of vancomycin achieved with intraosseous regional prophylaxis in revision TKA: A randomized controlled trial. *Clin Orthop Relat Res*. 2018;476:66-74** 1066

This is a prospective, randomized, controlled trial of patients undergoing revision total knee arthroplasty (TKA). Twenty patients were randomized to receive systemic IV or IO regional administration (IORA) of vancomycin as prophylaxis. Higher tissue and bone concentrations were consistently achieved in the IORA group with tissue concentrations during the procedure 5 to 20 times higher in the IORA group versus the IV group. The EZ-IO device was used to gain IO access in this study.

YEAR: 2017

- Young S, Zhang M, Moore GA, et al. Higher tissue concentrations of vancomycin with low-dose intraosseous regional versus intravenous systemic prophylaxis in revision total knee arthroplasty: A randomized trial. Paper presented at: American Academy of Orthopaedic Surgeons Annual Meeting; March 14-18, 2017; San Diego, CA. Abstract P118** 1036

This is an abstract of a study that compared tissue concentrations of vancomycin administered intravenously (IV) versus intraosseous regional administration (IORA) in revision TKA. Twenty patients were randomized to 2 groups: 1 g IV vancomycin or 500 mg IORA vancomycin. Overall geometric mean tissue concentrations in fat samples were 3.7 µg/g in the IV group vs 49.3 µg/g in the IORA group (P<0.001) while mean tissue concentrations in the femoral bone were 6.4 µg/g in the IV group vs 77.1 µg/g in the IORA group (P<0.001). IORA of low-dose vancomycin provided tissue concentrations 5-20 times higher than IV administration. IO access was obtained using the EZ-IO device. This study was sponsored by Teleflex Incorporated.

Intraosseous Vascular Access Bibliography

Non-Emergency Applications

Young SW, Clarke HD, Moore GA, Zhang M, Spangehl MJ. Higher tissue concentrations of vancomycin are achieved with intraosseous versus intravenous administration in revision TKA. The Knee 2017;24(6):XIV (Abstract 0018). <https://doi.org/10.1016/j.knee.2017.08.045>.

1038

This abstract describes a study that compared tissue concentrations of vancomycin administered intravenously (IV) versus intraosseous regional administration (IORA) in revision TKA. Twenty patients were randomized to 2 groups: 1 g IV vancomycin or 500 mg IORA vancomycin. Mean tissue concentrations in fat samples were 4.1 µg/g in the IV group vs 115 µg/g in the IORA group (P<0.001) while tissue concentrations in the femoral bone were 7.2 µg/g in the IV group vs 101 µg/g in the IORA group (P<0.001). IORA of low-dose vancomycin provided tissue concentrations 5-20 times higher than IV administration. IO access was obtained using the EZ-IO device. This study was sponsored by Teleflex Incorporated.

Young SW, Clarke HD, Pitto R, et al. Higher tissue concentrations of vancomycin with low-dose intraosseous regional versus intravenous systemic prophylaxis in revision TKA. ePoster presented at: International Society of Arthroscopy, Knee Surgery and Orthopaedic Sports Medicine Biennial Congress; June 4-8,2017; Shanghai, China. ePoster 1230

1037

This e-poster describes a study that compared tissue concentrations of vancomycin administered intravenously (IV) versus intraosseous regional administration (IORA) in revision TKA. Twenty-two patients were randomized to 2 groups: 1 g IV vancomycin or 500 mg IORA vancomycin with 20 patients analyzed. Mean tissue concentrations in fat samples were 4.1 µg/g in the IV group vs 115 µg/g in the IORA group (P<0.001) while tissue concentrations in the femoral bone were 7.2 µg/g in the IV group vs 101 µg/g in the IORA group (P<0.001). IORA of low-dose vancomycin provided tissue concentrations 5-20 times higher than IV administration. IO access was obtained using the EZ-IO device. This study was sponsored by Teleflex Incorporated.

Young SW, Zhang M, Moore GA, Pitto RP, Clarke HD, Spangehl MJ. Higher tissue concentrations of vancomycin with intraosseous regional prophylaxis in revision TKA- A randomized controlled trial. Manuscript submitted for publication

930

A randomized controlled study comparing antibiotic tissue concentrations when vancomycin is administered for total knee arthroscopy via IO and IV access. Ten subjects were randomized to each group. The IO group received 500 mg vancomycin injected directly into the proximal tibia IO insertion site below an inflated thigh tunicate, and the IV group received 1 gram vancomycin, both were given before skin incision. Results showed IO tissue concentrations of vancomycin were 5-20 times higher than systemic IV despite the lower dose. This study was sponsored by Teleflex Incorporated.

YEAR: 2016

Hunsaker SK, Heaston S. The development of a difficult intravenous access algorithm in Guayaquil, Ecuador: Trials and triumphs. Ann Glob Health 2016;82(3):473-4

874

This abstract describes how students and professors from the Brigham Young University (BYU) College of Nursing traveled to Ecuador to perform a qualitative study related to the process of managing difficult intravenous (IV) access. Among the objectives of the study were determining the need for a difficult IV access algorithm and if the need existed, to donate intraosseous (IO) equipment and training materials to the hospital.

Martinez AM, Pardo ML, Ricarcho JH.. Perception of discomfort during injection and the need for supplemental anesthesia in the intraosseous technique using 4% articaine. Acta Odontol Latinoam 2016;29(3):214-8.

953

This article describes an experimental study to determine patient perception of discomfort during IO injection for dental procedures involving the mandibular molars. Subjects (N=70) received either IO injection (N=35) or inferior alveolar nerve block (N=35) with articaine/epinephrine. Both groups reported similar rates of supplemental injection (P=0.80) while the IO group reported less perceived discomfort (P=0.00), differing statistically.
(Colombia)

Miao CH. Hemophilia A gene therapy via intraosseous delivery of factor VIII-lentiviral vectors. Thromb J 2016;14(Suppl1):93-9

995

This paper discusses a recently developed novel approach of IO delivery of lenti-viral vectors to correct hemophilia A. Ex vivo hematopoietic stem cell (HSC) transduction/transplantation has been shown to successfully deliver Factor 8 (FVIII) into HemA mice but the procedure requires pre-conditioning using potentially toxic, myelosuppressive agents. IO delivery to transduce HSCs bypasses this step and potential thrombocytopenia associated with pre-conditioning. When compared to IV infusion of LVs, IO delivery directly introduced LVs into the bone marrow significantly enhancing transduction efficiency of HSCs. In mice, a single infusion of G-F8-LVs produced long-term stable expression of hFVIII in platelets and corrected hemophilia phenotype for the long term.

Puga T, Montez D, Philbeck T, Davlantes C. Adequacy of intraosseous vascular access insertion sites for high-volume fluid infusion. Crit Care Med 2016;44(12 Suppl):143

821

This study was completed on 30 healthy subjects to evaluate infusion rates via the sternum (SIO) and proximal humerus (PH) sites under 300 mmHg via pressure bag. The mean SIO infusion rate was 9,587±2,706mL/hr (n=27); mean PH infusion rate was 6,292 ±3,277mL/hr (n=52). There were no serious complications; minor complications were 5 cases of excess pain, 2 cases vagal response, and mammary tissue engorgement. The mean PH flow rate was significantly lower than that of SIO, but placing IO catheters in each humeri with simultaneous infusion could result in fluid delivery of 13,000mL/hr, surpassing that of the sternum. This study was sponsored by Teleflex Incorporated.

Intraosseous Vascular Access Bibliography

Non-Emergency Applications

YEAR: 2015

Anson JA, Sinz EH, Swick JT. The versatility of intraosseous vascular access in perioperative medicine: a case series. *J Clin Anesth* 2015;27(1):63-7.<http://dx.doi.org/10.1016/j.jclinane.2014.10.002>

729

This article presents a 5-case series describing use of IO vascular access by anesthesiologists in the perioperative and critical care settings. All insertions were made in the proximal tibia and there were no adverse events reported. The devices cited as being used were the EZ-IO and the Cook Surfast manual needle. A proposed perioperative vascular access algorithm incorporating IO access is presented. The authors address key topics around IO access including use of same drug dosing as IV administered drugs, frequent palpation and monitoring of the insertion site for extravasation, low complication rate and actual risks associated with fat emboli and bone injury, pain and anxiety management in the awake patient and clinician-perceived pain. Administration of blood products, ACLS drugs, Lactated Ringer's solution and anesthetics are noted without complication. Use of IO aspirate for laboratory testing is noted, however use of the initial aspirate is indicated. Several patients in the case series were reported to find the discomfort of IO insertion preferable to multiple intravenous attempts. The authors concluded: IO lines can be placed quickly and safely in emergency situations or in elective surgical patients with difficult intravenous access; IO access can be useful in a wide variety of clinical settings; and is an important skill for anesthesiologist to learn.

Salzman J, Burnett A, Frascione R, et al. Intraosseous pressure monitoring in critically ill and injured patient. *Crit Care Med* 2015;43(12 Suppl):abstract 183:47. doi: 10.1097/01.ccm.0000474011.25695.a8

848

A pilot study evaluating the relationship between intraosseous (IO) pressure measurements and blood pressure obtained via external blood pressure cuff in ICU patients. Patients with IO access established by EMS or in the emergency department with planned admission to the ICU or surgical ICU were included in the study. External pressures were recorded every 15 minutes and IO pressure was monitored via a transducer for 12 continuous hours. Results showed IO pressures were approximately 30% of external blood pressure cuff readings.

Salzman JG, Frascione RJ, Zagar AE et al. Intraosseous pressure monitoring in critical care patients. *Ann Emerg Med* 2015;66(4s):S148

755

The authors described a proof of concept pilot study conducted to determine intraosseous (IO) pressure measures and their relationship to blood pressure obtained using an external blood pressure cuff in ICU patients. The average IO systolic blood pressure, IO diastolic blood pressure, and IO mean were 39.5±12.7 mm Hg, 31.5±7.6 mmHg, and 35.0±8.8 mm Hg respectively. The ratio of IO systolic blood pressure to cuff systolic blood pressure, IO diastolic blood pressure to cuff diastolic blood pressure, and IO mean to cuff mean are 34.5±13.4%, 40.5±22.3%, and 40.1±17.1% respectively. There were no adverse events reported. Investigators concluded that in their convenience sample of severely ill and injured patients, IO pressure was reliably obtained and appeared to be 35% to 40% of blood pressure readings obtained via external blood pressure cuff; and that this method of pressure monitoring may be an appropriate alternative to invasive monitoring option in the future. This study was sponsored by Teleflex Incorporated.

YEAR: 2014

Hagglund H, Remberger M, Ringden O. Twenty-year follow-up of a randomized trial comparing intraosseous and i.v. BM transplantation [letter to the editor]. *Bone Marrow Transplant* 2014;49(12):1541-2. doi: 10.1038/bmt.2014.184

982

This letter to the editor reports the 20 year follow-up of a randomized study comparing IO and IV transplantation of allogeneic hematopoietic stem cells from sibling donors conducted in 1998. At the 20 year follow-up the probability of graft versus host disease, treatment related mortality, and relapse probability were similar between the two groups. None of the patients in the trial developed a secondary malignancy.

Montez D, Puga T, Garcia M, et al. Lactate levels in venous and intraosseous blood correlate; prothrombin time/INR levels do not. *Aca Emerg Med* 2014;21(5)Suppl:S304.

773

In a series of studies using healthy adult volunteers the objective was to add to available data comparing IO marrow/blood (initial 1 mL aspirate), IO blood (subsequent aspirate), and venous and capillary blood to determine if there is a correlation between samples for serum lactate and PT/INR levels. Two point-of-care analysers were used. Conclusions were lactate levels obtained from IO blood appear comparable to lactate levels from venous blood; the PT/INR levels did not correlate. This study was sponsored by Teleflex Incorporated.

Young SW, Zhang M, Freeman JT, Mutu-Grigg J, Pavlou P, Morre GA. The Mark Coventry Award: Higher tissue concentrations of vancomycin with low-dose intraosseous regional versus systemic prophylaxis in TKA. *Clin Orthop Relat Res* 2014;472(1):57-65. doi:10.1007/s11999-013-3038-z

620

This randomized, controlled study compared tissue concentrations at the surgical site of regionally and systemically administered prophylactic vancomycin, in 30 patients undergoing total knee arthroscopy. The antibiotic was administered using three methods: 250mg through IO regional administration in the proximal tibia (IORA); 500mg through IORA; and 1g administered systemically through IV. Results showed the tissue concentration of vancomycin was greater in the 250mg IORA group than the systemic IV group, and the 500mg IORA group had higher concentrations than both groups.

Intraosseous Vascular Access Bibliography

Non-Emergency Applications

YEAR: 2013

Frascone RJ, Salzman JG, Bliss P, Adams A, Wewerka SS, Dries DJ. Intraosseous pressure tracings mimics arterial pressure tracings in timing and contour. *Ann Emerg Med* 2013;62(4S):S13 - 4 665

A pre-clinical study that compared intraosseous (IO), central venous and arterial pressure tracings in a porcine model. Results showed that IO pressure was approximately 25% of arterial pressure. A sampling of IO blood gases revealed oxygenation levels of venous blood. This study was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.

Frascone RJ, Salzman JG, Ernest EV, Burnett AM. Use of an intraosseous device for invasive pressure monitoring in the ED. *Am J of Emerg Med* 2014;32(6):692.e3-692.e4.doi:10.1016/j.ajem.2013.12.029 667

A case study describing intraosseous pressure monitoring, through tibial IO access, using a standard arterial pressure monitoring transducer during resuscitation of a 31-year-old male in cardiac arrest. Pressure readings were recorded for approximately 53 minutes and were compared to non-invasive blood pressure cuff monitoring at the same time points. IO systolic, diastolic and mean IO pressures were approximately 40% of arterial pressures. This is the first case report demonstrating IO space has a measureable blood pressure and it correlates with pressure obtained through conventional techniques.

Larsson T, Strandberg G, Eriksson M, Bondesson U, Lipcsey M, Larsson A. Intraosseous samples can be used for opioid measurements- and experimental study in the anesthetized pig. *Scand J Clin Lab Invest* 2013;73(2):102-6. doi:10.3109/00365513.2012.744088 605

In this preclinical swine study, investigators sought to evaluate whether intraosseous blood samples can be used to measure opioids, and if so, to determine the level of accuracy of those measurements. Blood samples were drawn from bilateral tibial IO catheters and from a central venous catheter for six hours. Authors concluded that IO blood samples can be used for the analysis of opioids if an IV route is not available.

Lee H, Park JB, Lee S, Baek S, Kim H, Kim SJ. Intra-osseous injection of donor mesenchymal stem cell (MSC) into the bone marrow in living donor kidney transplantation; a pilot study. *J Transl Med* 213;11:96. doi: 10.1186/1479-5876-11-96 881

Authors described a study in which adult living donor kidney transplantation recipients (N=7) were given mesenchymal stem cells (MSC) derived from the donor bone marrow to evaluate the safety and the feasibility of immunological changes related to the intraosseous injection of MSC into the bone marrow. They concluded that donor MSC injection into the iliac bone at the time of transplant was feasible and safe.

Montez DF, Puga TA, Garcia MR, et al. Intraosseous blood correlates with venous blood in healthy subjects using point-of-care analyzers. *Ann Emerg Med* 2013;62(4S):S40 676

A clinical study evaluating the relationship between IO blood and peripheral venous blood lactate levels analyzed using the i-STAT point-of-care analyzer in healthy volunteers. Results showed IO blood lactate levels were comparable to venous blood lactate levels with a positive statistical correlation. This study was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.

Verma PK, Srivastava R, Ramesh KM. Anesthetic efficacy of X-tip intraosseous injection using 2% lidocaine with 1:80,000 epinephrine in patients with irreversible pulpitis after inferior alveolar nerve block: a clinical study. *J Conserv Dent* 2013;16(2):162-66. doi:10.4103/0972-0707.108202 839

A study evaluating the use of X-tip intraosseous injection of 2% lidocaine with 1:80,000 epinephrine in dental patients with irreversible pulpitis in whom inferior alveolar nerve block has failed. Thirty patients were included and 93% of X-tip injections were successful. Ninety-six percent of patients had subjective/objective increase in heart rate. Results showed X-tip intraosseous injection of 2% lidocaine was effective in achieving pulpal anesthesia in patients with irreversible pulpitis.

Young SW, Zhang M, Freeman JT, Vince KG, Coleman B. Higher cefazolin concentrations with intraosseous regional prophylaxis in TKA. *Clin Orthop Relat Res* 2013;471(1):244-9. doi:10.1007/s11999-012-2469-2 576

A clinical study comparing Cefazolin concentrations found at the operation site following total knee arthroscopy when prophylactic antibiotics are administered systemically, through IV administration, and regionally, through IO injection directly at the site using the EZ-IO. Subcutaneous fat and bone samples were collected for evaluation from 22 subjects. Authors concluded that regional IO administration of prophylactic antibiotics can achieve tissues levels higher than with systemic administration.

YEAR: 2012

Abrams-Ogg AC, Defarges A, Foster RA, Bienzle D. Comparison of canine core bone marrow biopsies from multiple sites using different techniques and needles. *Vet Clin Pathol* 2012;41(2):235-42. doi: 10.1111/j.1939-165X.2012.00422.x 664

A pre-clinical study that compared the EZ-IO 15 gauge 25mm needle set and the 13 gauge Jamshidi aspiration/biopsy needle when used to obtain core biopsy specimens in canines.

Canada

Intraosseous Vascular Access Bibliography

Non-Emergency Applications

- Barker LT.** *In the child with gastroenteritis who is unable to tolerate oral fluids, are there effective alternatives to intravenous hydration?* *Ann Emerg Med* 2012;60(5):607-8. doi: 10.1016/j.annemergmed.2012.04.003 534
- This article, part of a Review Snapshot series in Annals summarizes a literature review (Rouhani et al in Pediatrics 2011) for evidence of alternatives to traditional IV hydration in a dehydrated child. Thirty-eight articles were included for the analysis with five of them randomized controlled trials; and one of those comparing IO to IV rehydration. (Banerjee et al, which found IO placement faster with no therapeutic outcome differences). The focus of this review was on nasogastric tube rehydration as effective when IV fails and as less invasive than IO or CVC placement.
- Crowley M, Brim C, Proehl J, et al.** *Emergency nursing resource: difficult intravenous access.* *J of Emerg Nursing* 2012;38(4):335-43 602
- Manuscript of a literature review and critical analysis done to develop the Emergency Nurse's Association (ENA) December 2011 Emergency Nursing Resource (ENR) which focused on the clinical issue of difficult IV access. Graded recommendations and decision options are provided for alternatives to IV access, including IO.
- Ibrahim M, Cairney K.** *Intraosseous (IO) infusion as a means of vascular access.* *Br J Resuscitation* 2012;Autumn:23-6 599
- This article provides an overview of intraosseous vascular access, including applicable patient population, IO access sites, pain management, IO education and compares IO access to central venous access.
- Mazaheri-Khameneh R, Sarrafzadeh-Rezaei F, Asri-Resaei S, Dalir-Naghadeh B.** *Evaluation of clinical and paraclinical effects of intraosseous vs intravenous administration of propofol on general anesthesia in rabbits.* *Vet Res Forum* 2012;3(2):103-9 614
- A preclinical study evaluating the effects of propofol on selected blood parameters and physiological variables during general anesthesia in rabbits when administered via intraosseous and intravenous routes. Results showed the IO route was as effective as the IV route for propofol administration at doses inducing general anesthesia. The authors concluded that use of IO propofol could be recommended as a safe method of anesthesia in small animals with limited vascular access.
- Miller L, Montez DF, Philbeck TE, Puga TA, Morgan J.** *Infusing chilled saline via the Intraosseous route is equivalent to infusion via the intravenous route in reducing the core temperature in swine.* *Prehosp Emerg Care* 2012;16(1):152. doi:10.3109/10903127.2011.624676 513
- This abstract presented at the 2012 NAEMSP scientific assembly described a randomized, cross-over study in which 8 swine were administered chilled saline via IV and IO routes to determine if the two routes were equivalent. The results suggested no clinical or statistical difference between IV and IO routes for infusion of chilled saline for therapeutic hypothermia. This study was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.
- Paxton JH.** *Intraosseous vascular access: A review.* *Trauma* 2012;14(3):195-232. DOI:10.1177/1460408611430175 690
- An overview of IO vascular access including a review of currently available literature. The author discusses various IO devices available and their performance metrics, IO access sites, flow rates, advantages and disadvantages of IO access compared to conventional access methods, complications and recommendations on use of the approach. The author concludes that while IO access may not be appropriate for all patients, it deserves a place in the modern provider's armamentarium.
- Rush S, Bremer J, Foresto C, Rubin AM, Anderson PI.** *A magnetic resonance imaging study to define optimal needle length for humeral head IO devices.* *J Spec Oper Med* 2012;12(2):77-82 577
- This article describes a retrospective study in which 50 consecutive MRI images were evaluated of the humerus for the purpose of determining the optimal needle length necessary for successful proximal humerus IO insertion. Results showed the cortical thickness was 4mm in all cases and that an IO needle length ranging between 40-50mm should be used via the anterior approach. The EZ-IO is specifically discussed in relation to the proximal humerus IO insertion site; and a 24 patient post mortem review of the EZ-IO placed in the proximal humerus is discussed.
- Severyn FA.** *Complication after intraosseous needle removal following successful systemic thrombolysis for a massive pulmonary embolism.* *Resuscitation* 2012;83(11):e207. doi:10.1016/j.resuscitation.2012.07.014 575
- This letter to the editor is written in response to the case report by Landy titled, Complication of intraosseous administration of systemic thrombolysis for a massive pulmonary embolism with cardiac arrest. The author suggests that the tissue necrosis described by Landy may have been due to the removal of the IO needle while there was still significant fibrinolytic activity at the needle insertion site. The author suggests a change in medical care after return of spontaneous circulation (ROSC) in patients following thrombolytic administration through IO access to convert the functioning IO line to a non-flowing saline lock. The EZ-IO was used to provide IO access in the case report by Landy.

Intraosseous Vascular Access Bibliography

Non-Emergency Applications

Seymour CW, Cooke CR, Hebert PL, Rea TD. Intravenous access during out-of-hospital emergency care of noninjured patients: a population-based outcome study. *Ann Emerg Med* 2012;59(4):296-303. doi:10.1016/j.annemergmed.2011.07.021

465

The objective of this study was to retrospectively evaluate the relationship between out-of-hospital IV access and mortality among non-injured, non-cardiac arrest patients transported by 4 advanced life support agencies between January 1, 2002 and December 31, 2006. A total of 56,332 patients were included in the study. The author concludes that efforts to establish IV access in the out-of-hospital setting is was associated with reduction in hospital mortality among non-injured, non-cardiac arrest patients.

Wampler D, Manifold C. Changes in end-tidal carbon dioxide during hypothermia in a swine model. *Prehosp Emerg Care* 2012;16(1):155-6. doi:10.3109/10903127.2011.624676

521

This abstract presented at the 2012 NAEMSP scientific assembly evaluated end-tidal carbon dioxide (ETCO2) levels under initial induction of hypothermia, rewarming, and a second induction of hypothermia, via IO and IV infusion in the swine model. The authors concluded that there was no demonstrated association of ETCO2 with brain temperature during the initial induction. However, during rewarming and second induction of hypothermia the association of ETCO2 and brain temperature had a direct and proportional association. This research was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.

YEAR: 2011

Aliman AC, Piccioni Mde A, Piccioni JL, Oliva JL, Auler Junior JO. Intraosseous anesthesia in hemodynamic studies in children with cardiopathy. *Rev Bras Anesthesiol* 2011;61(1):41-9

654

A comparative study evaluating the effectiveness of IO access in relation to IV access for infusion of anesthetics (ketamine, midazolam, and fentanyl) and fluids during hemodynamic studies in 21 infants with congenital heart disease. IO access was established in the proximal tibia (n=11). Results showed, time to access was significantly shorter with IO access (3.6 vs 9.6 minutes); anesthetic onset was shorter with IV access (56.3 vs 71.3 seconds); and no significant difference between groups for hydration volume and anesthesia recovery time. The authors concluded that due to its easy manipulation and efficiency, hydration and anesthesia by IO access was satisfactory without necessity of other infusion access.

Brazil

de Vogel J, Heydanus R, Mulders AGM, Smalbrack DJC, Papatsonis DNM, Gerritse BM. Lifesaving intraosseous access in a patient with a massive obstetric hemorrhage. *Am J Perinatol Rep* 2011;1(2):119-122. doi: <http://dx.doi.org/10.1055/s-0031-1293514>

541

Case study of a 42 year-old woman with massive obstetric hemorrhage ultimately resulting in postpartum hysterectomy. Massive blood loss and inability to stop bleed prevented sufficient resuscitation via established PIV lines. IO access was established with the EZ-IO and used for fluid replacement and administration of cardiac resuscitation drugs. Fluid administered through IO access was 75% of the total infusion volume.

Eich C, Weiss M, Neuhaus D, et al. Handlungsempfehlung zur intraossären Infusion in der Kinderanästhesie [Recommended action for intraosseous infusion in children's anesthesia]. *Anästhesiologie* 2011;52:S46-52. German

770

German Society of Anaesthesiology and Intensivmedizin eV" (DGAI), includes a general discussion of intraosseous (IO) as vascular access, overview of devices and recommendations for pediatric anesthesia with indications for intraosseous infusion in pediatric anesthesia and perioperative care in children. Early or primary IO indications are respiratory and circulatory arrest; critical hemodynamic instability before or during anesthesia introduction; severe laryngospasm; anesthesia induction in respiratory bleeding. Urgent indications (decision based on each case is necessary) include urgent induction of anesthesia in non-fasted children (Ileus, RSI); induction of anesthesia in children with unstable circulation or severe cardiac insufficiency. Semi-elective indications (decision based on each case is necessary) after mask induction of anaesthesia (if vascular access required); mandatory induction of "intravenous" anaesthesia (as in malignant hyperthermia). This article is in German.

Emergency Nurses Association (ENA). Emergency nursing resource: Difficult intravenous access. Des Plaines, IL: Emergency Nurses Association; December 2011

603

The Emergency Nurse's Association (ENA) published a series of Emergency Nursing Resources with emphasis on clinical or practice based issues. This issue focused on difficult IV access and provides a summary of the literature review, with graded recommendations and decision options for practice for IO access, ultrasound guidance, subcutaneous rehydration therapy and several other alternatives. IO access is graded as having a high level of evidence supporting use of IO access when difficult IV access is known or suspected for high success rates and rapid time to insertion.

Harcke HT, Crawley G, Mabry R, Mazuchowski E. Placement of tibial intraosseous infusion devices. *Mil Med* 2011;176(7):824-7

469

This article describes a military study in which post-mortem preautopsy multidetector CT was used to assess placement of tibial IO needles in battlefield trauma deaths where IO was used as part of the medical intervention. Results showed 58 of 61 (95%) tibial IO needles were correctly placed. In this study, the device used for IO placement was not recorded, but may have been the manual device or EZ-IO as the Army has access to both.

Intraosseous Vascular Access Bibliography

Non-Emergency Applications

- Howarth D. Adult intraosseous access: experiences in a remote emergency department. *Australian Family Physician* 2011;40(7):510-1** 483
- In this article, the author makes a supporting case for remote emergency departments to stock adult intraosseous kits by referencing two adult septic shock cases in which IO access was used for rapid IV fluid replacement as well as IV antibiotics and inotrope support.
- Kehrl T, Broderick E. Relationship of body mass index and increased difficulty with intraosseous needle placement: assessment of tissue depth using ultrasound. *Ann Emerg Med* 2011;54(4s):S263** 531
- In this abstract the authors attempted to establish a relationship in obese patients (BMI >30) between BMI, ability to palpate the tibial tubercle, and tissue depth at the IO insertion sites. Results showed that in obese patients, IO placement with a 25mm catheter is feasible at the proximal and distal tibial sites if the tibial tubercle is palpable and that insertion into the proximal humerus in this population is not recommended.
- Abstract only*
- Neuhaus D. [Intraossärer Zugang]. *Notfall Rettungsmed* 2011;14(7):543. doi:10.1007/s10049-011-1445-9. German** 480
- This article in German discusses use of IO access and its multiple applications, focusing on the EZ-IO Infusion System.
- Schexnayder SM, Storm EA, Stroud MD, et al. Chapter 15-Pediatric vascular access and centeses. *Pediatric Critical Care* 2011;4th ed:139-63. ISBN: 978-0-323-07307-3** 680
- This document addresses pediatric vascular access and includes an overview of intraosseous vascular access. Indications, contraindications, supplies and equipment, technique, complications and maintenance are discussed.
- Sheehan C, Sodhi V, Esler M. Intraosseous needles on the delivery suite. *Int J Obstet Anesth* 2011;20(3):272-3. doi:10.1016/j.ijoa.2011.01.003.** 553
- This article discusses how a group of obstetricians and anesthesiologists prepared for what they expected to be a difficult delivery with limited venous access. The EZ-IO was brought into the delivery suite as a back-up option if they were unable to achieve venous access in an emergency situation. The authors did note their concern with the pain associated with IO infusion. Ultimately, the IO device was not needed for the delivery in question, but it has been added to their resuscitation kit within the delivery suites.
- Smart RJ, Marsh S, Rosenberg M. Intraosseous access in oral and maxillofacial surgical practice. *J Oral Maxillofac Surg* 2011;69(11):2708-13. doi:10.1016/j.joms.2011.02.101** 441
- This article describes IO access in terms of efficacy, indications/contraindications for use, and the IO procedure and comparison of devices to make a case for IO use in oral and maxillofacial surgical practice. In discussing IO devices citing published data, the author identified the EZ-IO device as the most accurate, efficacious, and precise system when trying to achieve IO access.
- YEAR: 2010**
- Neuhaus D, Weiss M, Engelhardt T, et al. Semi-elective intraosseous infusion after failed intravenous access in pediatric anesthesia. *Pediatr Anesth* 2010;20(2):168-71. doi: 10.1111/j.1460-9592.2009.03244.x** 425
- Authors report an observational study of 14 children in whom semi-elective IO infusion was performed under anesthesia after peripheral IV had failed. IO infusion was successful for all 14 patients, using the EZ-IO system for 8 patients and the Cook system for 6 patients.
- Phillips L, Brown L, Campbell T, Miller J, Proehl J, Youngberg B. Recommendations for the use of intraosseous vascular access for emergent and nonemergent situations in various healthcare settings: a consensus paper. *J Emerg Nurs* 2010;36(6):551-6. doi:10.1016/j.jen.2010.09.001** 458
- This article discusses use of IO access within the hospital setting in the emergent and non-emergent patient populations. The history of IO access, clinical situations in which IO access may be considered, devices, contraindications, and complications are discussed. Additionally, pain management, economics, education and training and risk management are explored. This article is co-published in *Journal of Infusion Nursing*, the *Journal of Pediatric Nursing*, and *Critical Care Nurse* and was produced by the Consortium on Intraosseous Vascular Access in Healthcare Practice.
- Rahman O, Willis L. Vascular procedures in the critically ill obese patient. *Crit Care Clin* 2010;26(4):647-60. doi:10.1016/j.ccc.2010.08.003** 451
- This article discusses vascular access procedures in critically ill obese patients. Anatomic considerations, general procedural considerations such as location of the procedure and patient positioning, catheter insertion technique, ultrasound guided insertion, intraosseous insertion, and other various considerations are evaluated.

Intraosseous Vascular Access Bibliography

Non-Emergency Applications

- Tobias JD, Ross AK. Intraosseous infusions: A review for the anesthesiologist with a focus on pediatric use. *Anesth Analg* 2010;110(2):391-401.** 428
- The authors describe literature that support the use of IO access for administering anesthesia in the ICU, perioperative and operating room, including a study in which IO access was used successfully for providing intraoperative anesthesia for 106 of 109 patients. Among their conclusions, the authors reported that, even though rarely reported in anesthesia literature, IO access is a technique anyone providing care to children should consider when the patient has difficult IV access. They also concluded that IO access should be a part of an algorithm that includes numbers of attempts at peripheral access, feasibility of central access and the need for continued postoperative access; and that considering that IO access may be occasionally used in the perioperative setting in both emergent and nonemergent scenarios, it may be beneficial to have appropriate IO needles in the OR.
- Vegunta RK. Chapter 8-Vascular access. *Ashcraft's Pediatric Surgery* 2010;5th ed:110-6** 681
- This document discusses various vascular access methods available for pediatric and neonate patients, including intraosseous access.
- Vizcarra C, Clum S. Intraosseous route as alternative access for infusion therapy. *J Infus Nurs* 2010;33(3):162-74** 482
- This article provides an overview of IO anatomy and physiology, IO access indications, care, and management; describes therapies administered via IO access; and discusses the expanding use of IO access into areas within hospitals during nonemergency clinical situations. It also includes a table addressing indications for IO access in the hospital, as well as a table addressing the general insertion procedure for IO access.
- YEAR: 2009**
- Bangerter C, Mines P, Sweet M. The use of intraosseous anesthesia among endodontists: results of a questionnaire. *J Endod* 2009;35:15-8** 415
- Survey of 833 endodontists. 95% report using IO anesthesia.
- Burgert JM. Intraosseous infusion of blood products and epinephrine in an adult patient in hemorrhagic shock. *AANA J* 2009; 77: 359-63** 435
- Case report of IO infusion in 79-year old woman with hematemesis after intestinal surgery.
- Weiss M, Henze G, Eich C, Neuhaus D. Intraossare infusion: Eine wichtige technik auch fur die kinderanasthesie [Intraosseous infusion: an important technique also for paediatric anaesthesia]. *Anaesthesist* 2009;58(9):863-75.doi. 10.1007/s00101-009-1605-1 German** 434
- Discusses use of IO for pediatric anesthesia. Specifies importance of equipment, education, guidelines.
- YEAR: 2008**
- Joseph G, Tobias JD. The use of intraosseous infusions in the operating room. *J Clin Anesth* 2008;20:469-73** 412
- Case report of anesthetic use of IO infusion in a 8-month old infant during surgery.
- YEAR: 2006**
- Zaidi SZ, Sahovic EA, Al-Shangeeti AS, et al. Can intra-osseous transplantation improve results of umbilical cord blood transplantation in adult patients? *Bone Marrow Transplant* 2006;37(3):335** 1039
- This letter to the editor discusses umbilical cord blood (UCB) transplantation in adults and proposes that IO transplantation of UCB is a way of overcoming the problem of delayed engraftment. Further study would be needed.
- YEAR: 2005**
- Tabas JA, Rosenson J, Price DD, Rohde D, Baird CH, Dhillon N. A comprehensive, unembalmed cadaver-based course in advanced emergency procedures for medical students. *Acad Emerg Med* 2005;12(8):782-5** 349
- Describes a training course for medical students to learn advanced emergency procedures using unembalmed cadavers. The course includes clinical indications and contraindications for specific procedures, as well as techniques. Also discusses students' confidence levels in performing procedures.

Intraosseous Vascular Access Bibliography

Non-Emergency Applications

YEAR: 2003

Nusstein J, Kennedy S, Reader A, Beck M, Weaver J. Anesthetic efficacy of the supplemental x-tip intraosseous injection in patients with irreversible pulpitis. J Endo 2003;29(11):724-8 299

Dental study finding successful injections of 2% lidocaine with epinephrine in 27 of 33 (82%) X-tip IO injections (82%) for anesthesia in mandibular teeth.

YEAR: 2002

Ichioika N, Inaba M, Kushida T, Esumi T, Takahara K, Inaba K, Ogawa R, Iida H, Ikehara S. Prevention of senile osteoporosis in SAMP6 mice by intrabone marrow injection of allogeneic bone marrow cells. Stem Cells 2002; 20: 542-51 292

Preclinical study in mice demonstrating that transplantation of bone marrow from normal allogenic mice injected directly into the bone marrow cavity of irradiated recipient mice can prevent and treat osteoporosis.

Ivanova TA, Skoromets AA, Tikhodeev SA. [Intravenous spondylo-infusion in the treatment of lumbar osteochondrosis]. Zh Nevrol Psikhiatr Im S S Korsakova 2002;102(2):40-4. Russian. Abstract 291

Study describing IO infusion in patients with neurological symptoms of osteochondritis of lumbosacral intervertebral disks. Found relief and prompt regression of neurological symptoms after IO infusion.

Manggold J, Sergi C, Becker K, Lukoschek M, Simank HG. A new animal model of femoral head necrosis induced by intraosseous injection of ethanol. Lab Anim 2002; 36: 173-80 295

Basic research study in sheep demonstrating that intraosseous injection of ethanol directly into the center of the femoral head produced necrotic changes similar to the early stages of osteonecrosis. The model holds potential for evaluating new therapeutics for the disease.

YEAR: 2001

Hancock SW, Knight G. Intraosseous needles: an essential emergency adjunct in paediatric anaesthesia. Paediatr Anaesth 2001;11(4):505-6 284

Review of the use of IO in anesthesiology. Advocates that IO needles be available in all clinical areas where IV access is required.

YEAR: 2000

Hurren JS. Can blood taken from intraosseous cannulations be used for blood analysis? Burns 2000; 26: 727-30 262

Study comparing IO blood samples to IV samples for blood chemistry values. For many parameters, IO and IV levels were similar. Authors caution that potassium and glucose levels should be interpreted with care. Also found that white cell and platelet counts in the IO samples were very different from those measured in IV blood samples.

Pan'ko SV, Antipov IuG, Semenido IuN, Sosnovskaia Olu, Golovanova TA, Sanin AV. [Suppression of graft versus host reaction by depositing a magnet-controlled adriamycin dosage form in bone marrow allotransplantation in animal experiments]. Vestnik Rossiiskoi Akademii Meditsinskikh Nauk 2000;(3): 10-5. Russian. Abstract 251

Intraosseous transplantation of bone marrow in combination with long-acting Adriamycin may inhibit acute and chronic graft versus host reactions.

Stabile P, Reader A, Gallatin E, Beck M, Weaver J. Anesthetic efficacy and heart rate effects of the intraosseous injection of 1.5% etidocaine (1; 200,000 epinephrine) after an inferior alveolar nerve block. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2000;89(4):407-11 258

Dental study in 48 volunteers finding IO injection of etidocaine resulted in a significant increase in anesthetic effect. The majority of subjects receiving IO etidocaine solution experienced a transient increase in heart rate.

Yankovskis G, Beldava I, Livina B. Osteoreflexory treatment of alcohol abstinence syndrome and craving for alcohol in patients with alcoholism. Acupunct Electrother Res 2000;25:9-16 255

Osteoreflexory therapy (intraosseous injection of 0.5 to 1.0 ml of 0.9% saline solution) reduced alcohol craving in patients treated for alcoholism.

Abstract only

Intraosseous Vascular Access Bibliography

Non-Emergency Applications

YEAR: 1998

Bennett RA, Schumacher J, Hedjazi-Haring K, Newell SM. Cardiopulmonary and anesthetic effects of propofol administered intraosseously to green iguanas. J Am Vet Med Assoc 1998;212(1):93-8 230

Veterinary study in 14 iguanas were finding that IO propofol resulted in a significant decrease in heart rate that appeared 35 minutes after induction of anesthesia and persisted for 120 minutes. Serum pO₂ values decreased after induction of anesthesia.

Abstract only

YEAR: 1997

Cambay EJ, Donaldson JS, Shore RM. Intraosseous contrast infusion: efficacy and associated findings. Pediatr Radiol 1997;27:892-3 222

Pediatric article detailing use of an IO line for bolus infusion of nonionic contrast material for CT contrast enhancement; a radiographic band may occur as a result of retained contrast material within the marrow.

YEAR: 1995

Leonard MS. The efficacy of an intraosseous injection system of delivering local anesthetic. JADA 1995;126(1):81-6 884

This article describes a device used for the intraosseous delivery of local anesthesia during dental procedures.

Waisman M, Roffman M, Bursztein S, Heifetz M. Intraosseous regional anesthesia as an alternative to intravenous regional anesthesia. J Trauma 1995;39(6):1153-6 200

Clinical study of IO anesthesia during orthopedic surgery. Satisfactory anesthesia was obtained in 106 of 109 patients. Concludes that IO regional anesthesia is a valuable technique when IV anesthesia fails or is not feasible.

YEAR: 1994

Takada M, Yamamoto I, Morita R. Chronic intramedullary infusion of interleukin-1 alpha increases bone mineral content in rats. Calcif Tissue Int 1994; 55: 103-8 181

Preclinical study in rats examining bone mineral content following IO infusion of IL-1.

YEAR: 1991

Islam A. New sternal puncture needle. Journal of Clinical Pathology 1991;44(8):690-1 107

Describes the design of a larger and more user friendly sternal intraosseous needle for bone marrow aspiration.

YEAR: 1989

Orlowski JP, Porembka DT, Gallagher JM, Van Lente F. The bone marrow as a source of laboratory studies. Ann Emerg Med 1989;18(12):1348-51 640

This article describes a pre-clinical study comparing bone marrow, venous blood, and arterial blood specimen results when used for blood electrolytes, blood chemistries, blood gases and hemoglobin; and a clinical evaluation of bone marrow and venous blood used for cultures.

YEAR: 1983

Turkel H. Intraosseous infusion. Am J Dis Child 1983;137(7):706 37

Case report of 3-year-old child permanently blinded and brain damaged because of inability to administer anesthetic intravenously. Patient was on oxygen following an inhalation anesthetic. Concludes that IO administration of anesthesia would have prevented this poor outcome.

YEAR: 1982

Hedley DW, Joshua DE, Tattersall MH, Taylor IW. Fine-needle aspiration of bone marrow from sternum. Lancet 1982;2:415-16 35

Study finding that 23-gauge needle is less painful and yields purer bone marrow sample from the sternum.

Intraosseous Vascular Access Bibliography

Non-Emergency Applications

YEAR: 1980

Knowles S, Hoffbrand AV. Bone-marrow aspiration and trephine biopsy (1). Br Med J 1980; 281(6234):204-5 34
Discusses clinical indications, needle types, and anatomical sites for bone marrow aspiration and Trephine biopsy.

Knowles S, Hoffbrand AV. Bone-marrow aspiration and trephine biopsy (2). Br Med J 1980; 281(6235):280-1 33
Describes aspiration technique, preparation of bone marrow slides, Jamshidi-Swain trephine, as well as risks and aftercare involved in bone marrow aspiration and trephine biopsy.

YEAR: 1978

Lempert RK, Arnoldi CC. The significance of intraosseous pressure in normal and diseased states with special reference to the intraosseous engorgement-pain syndrome. Clin Orthop Relat Res 1978;136:143-56 30
Intraosseous angiography and intraosseous pressure measurement can be useful for diagnosing bone pain and treatment site.

YEAR: 1977

Valdes MM. Intraosseous fluid administration in emergencies. Lancet 1977;1(8024):1235-6 29
Observational study of 15 patients needing emergency fluids and in whom IV's were difficult to establish. Patients received drugs and fluids via IO. Concludes that IO therapy is effective with no serious complications.

YEAR: 1956

Bennike T, Gormsen H, Moller B. Comparative studies of bone marrow punctures of the sternum, the iliac crest, and the spinous process. Acta Med Scand 1956;155(5):377-96 28
Study finding sternal puncture superior to iliac crest and spinous process punctures for bone marrow sampling. Cautions that inexperienced practitioners should use iliac crest or spinal process in the absence of training in sternal puncture.

YEAR: 1954

Begg AC. Intraosseous venography of the lower limb and pelvis. Br J Radiol 1954;27:318-24 27
Describes a new method of ascending venography of the lower limb and pelvis in which contrast medium is injected into the IO space of the bone. Concludes that IO venography is be safe, simple, flexible, and reliable for visualization of the deep, superficial, and communicating veins of the legs and pelvis.

YEAR: 1944

Bailey H. Bone marrow as a site for the reception of infusions, transfusions and anaesthetic agents: a review of the present position. Anesthesiology 1944;5(5):545-6 649
This abstract describes one physician's summary of experience using the sternum as an intraosseous vascular access site for 60 cases. Discusses potential benefits and complications compared to intravenous access.

YEAR: 1942

Doud E, Tysell, J. Massive intramedullary infusions JAMA 1942;120(15):1212. doi:10.1001/jama.1942.82830500006010c 914
This article discusses use of the medullary route for massive replacement therapy when the usual methods of administration and not available or practical. The article also reviews a case study of a man in receipt of a sternal puncture needle inserted into the medullary cavity where he received the infusions through this needle of whole blood and fluids.

YEAR: 1934

Josefson A. A new method of treatment-Intraossal injections. Acta Medica Scandinavica 1934;81(5-6):550-64 687
This article describes one clinician's use of sternal IO access for infusion of campolon to treat anemia in 1930. The author performed over 50 injections without serious complications.
Sweden

Intraosseous Vascular Access Bibliography

Pediatric

YEAR: 2019

Itoh T, Lee-Jayaram J, Fang R, Hong T, Berg B. Just-in-time training for intraosseous needle placement and defibrillator use in a pediatric emergency department. *Pediatr Emerg Care* 2018;35(10):712-15. doi:10.1097/PEC.0000000000001516.

984

This article describes a study comparing medical students' comfort level in performing IO needle placement and defibrillator use in a pediatric ED before and after just-in-time training (JITT). JITT sessions were facilitated by ED attending physicians. Sessions for IO placement included group discussion of the location of IO needle set, indications, contraindications, locations on the body for placement, confirmation of placement, and selection of appropriate needle size. Participants then had hands-on practice using the EZ-IO task trainer for the humerus and tibia. The comfort level increased from pre survey 0% to post survey 48% (P<0.0001).

Sørgjerd R, Sunde GA, Heltne JK. Comparison of two different intraosseous access methods in a physician-staffed helicopter emergency medical service - A quality assurance study. *Scand J Trauma Resusc Emerg Med* 2019;27(1):15 doi: 10.1186/s13049-019-0594-6

1062

This study compared IO insertions with the EZ-IO device (tibial/humeral insertions) to the FAST-R device (sternal insertions only) in a physician-staffed helicopter emergency medical service. Insertion time, insertion site, flow, indication for IO access, and complications were compared. Median insertion time was 15 seconds for EZ-IO and 20 seconds for FAST-R. Overall, 35.1% of EZ-IO insertions resulted in poor flow and required a pressure bag while 85.7% of FAST-R insertions had good or very good flow. EZ-IO complications included extravasation (2.4%), aspiration failure (11.9%), and insertion time >30 seconds (4.8%). Complications associated with FAST-R included user failure (12.5%) and insertion time >30 seconds (12.5%). The authors suggest that although EZ-IO is faster the FAST-R device may be more useful when high-flow infusion rates are required. The authors indicate that a low number of insertions were made with the FAST-R device and many outliers were observed in the data. However, the article does not present the total number of insertions per device.

YEAR: 2018

El-Nawawy AA, Omar OM, Mona Khalil M. Intraosseous versus intravenous access pediatric septic shock patients admitted to Alexandria University Pediatric Intensive Care Unit. *J Trop Pediatr* 2018;64(2):132-40. doi:10.1093/tropej/fmx061

932

Prospective randomized clinical trial in which IO access was compared to peripheral intravenous access (PIV) in pediatric patients with septic shock. Children's ages ranged from 1 month to 36 months old and weights ranged from 4 to 14 kg with similar characteristics in both groups; 30 patients in each subset. The IO group had significantly shorter vascular access insertion times, shorter length of stay and reduced mortality. IO access was achieved in the proximal tibia on first attempt for all insertions; 50% of PIV attempts failed on first attempt. There were no complications for the IO subset compared to 26.7 % for PIV. There was a reduced ability to aspirate for labwork via the IO access. This study supports existing literature that early use of IO insertion is safe and effective with minimal complications.

Fuchs Z, Scaal M, Haverkamp H, Koerber F, Persigehl T, Eifinger F. Anatomical investigations on intraosseous access in stillborns - Comparison of different devices and techniques. *Resuscitation* 2018;127:79-82

978

This article investigates the success rate of IO access in preterm and term stillborns using two different needles (21G butterfly and 15G EZ-IO) inserted manually and one battery-powered semi-automatic drill (EZ-IO). All insertions were performed on the tibia. Estimated success rates were 61.1% for the butterfly needle, 43.0% for the hand twisted EZ-IO, and 39.7% for the EZ-IO drill. The authors conclude that IO access in premature and term neonates is best achieved by manual access with a twisted butterfly needle.

Markic J, Polic B, Mestrovic J, Kovacevic T, Zanchi I. Successful intraosseous therapy using EZ-IO system in a preterm neonate below 2 kg. *Minerva Pediatr* 2018;70(1):104-5. doi:10.23736/S0026-4946.16.04707-1. (Croatia)

928

This paper is a letter to the editor describing successful insertion of EZ-IO in a neonate weighing less than 2 kg with respiratory failure, signs of sepsis, and shock. After successful insertion the patient was resuscitated and later stabilized. The authors advise that IO access is safe, effective, and attainable in all age groups despite FDA approval only in patients greater than 3 kg.

Molacek J, Houdek K, Opatrný V, et al. Serious complications of intraosseous access during infant resuscitation. *Eur J Pediatr Surg Rep* 2018;6:e59-e62

1057

This case reports a serious compartment syndrome in a 2.5 year old infant which resulted in a left leg partial amputation. The IO device was placed to administer treatment following a respiratory arrest and extravasated.

Nishida O, Ogura H, Egi M, et al. The Japanese clinical practice guidelines for management of sepsis and septic shock 2016 (J-SSCG 2016). *Acute Med Surg* 2018;5(1):3-89. doi: 10.1002/ams2.322

1059

These guidelines are a Japanese-specific set of guidelines for sepsis and septic shock created by the Japanese Society of Intensive Care Medicine and the Japanese Association for Acute Medicine. The IO route for administration of fluid resuscitation and circulatory inotropes when treating septic shock in pediatric patients is discussed. The authors conclude there is insufficient evidence to make a recommendation for this use.

Intraosseous Vascular Access Bibliography

Pediatric

Pifko E, Price A, Busch C, et al. Observational review of paediatric intraosseous needle placement in the paediatric emergency department. J Paediatr Child Health 2018;54(5):546-50. doi:10.1111/jpc.13773

1011

This study compared the success rates and time to placement for Manual IO versus EZ-IO needles in pediatric emergency department (PED) patients ≤ 8 kg and > 8 kg at a single institution. It was a retrospective, cross-sectional, descriptive study. All identified patients with an IO attempted in the PED were included. Fifty patients were identified. In patients ≤ 8 kg, overall success rates were 55% (17/31) for Manual IO and 47% (8/17) for EZ-IO. In patients > 8 kg, Manual IO success rates were 100% (2/2) and EZ-IO success rates were 93% (14/15) for overall attempts. Time (minutes) to successful placement in patients ≤ 8 kg was 4.5 for Manual IO vs 12.8 for EZ-IO ($P=0.02$). In patients > 8 kg, time to successful placement was 8.5 for Manual IO vs 10.2 for EZ-IO ($P=0.70$). Overall success rates in this study were poor in both groups, most likely due to lack of experience at IO insertion or inadequate device training. Access in smaller patients was more difficult and required greater time to insertion.

Rideout M, Raszka W. Hypovolemic shock in a child: A pediatric simulation case. MedEdPORTAL 2018;14:10694. doi: 10.15766/mep_2374-8265.10694

1060

This is a learning module for fourth year medical students to learn about fluid management and IO needle placement. The module simulates hypovolemic shock in a 3 year old patient using a child mannequin. An IO kit, including an EZ-IO driver, is supplied for obtaining IO access. A pilot study was conducted in 2017 with 16 subinterns on a pediatric service. Perceived competence in management of volume depletion and procedural skills were high following the training session and students felt the case was a beneficial learning experience.

Sawyer T, Nishisaki A. Intraosseous access during newborn resuscitation: It may be fast, but is it safe? Pediatr Crit Care Med 2018;19(5):499-501. doi:10.1097/PCC.0000000000001513

1017

This article examines emergency vascular access during newborn resuscitation. It discusses the time needed to place an emergency umbilical vein catheter (eUVC) and intraosseous kits (EZ-IO) in a series of simulated newborn resuscitations across 4 studies. In all 4 studies IO placement was significantly faster than eUVC placement. An additional study found eUVC placement to be significantly faster with real human umbilical cords than with simulated umbilical cords as used in the aforementioned studies. While IO access in newborns appears faster than eUVC in simulated models, to date, no randomized trials or large case-cohort studies have systematically evaluated the short and long-term safety of IO placement during newborn resuscitation. Current guidelines still support eUVC as the preferred method of obtaining vascular access during newborn resuscitation. The authors suggest further studies are needed to determine short and long-term safety of IO access in newborns before widespread adoption of the process can be recommended.

Schwindt EM, Hoffmann F, Deindl P, Waldhoer TJ, Schwindt JC. Emergency vascular access and how to accelerate it: A simulation-based study performed in real-life neonatal resuscitation rooms. Pediatr Crit Care Med 2018;19(5):468-76. doi:10.1097/PCC.0000000000001508

934

In neonatal training events in 16 hospitals over two years, clinicians with neonatal experience simulated resuscitation of an asphyxiated newborn and were recorded for retrospective analysis. Clinicians could choose either umbilical venous catheter (UVC) or intraosseous access (IO), using the EZ-IO device for vascular access. Delays for both procedures were related to equipment availability and lack of familiarity; training and prepackaged kits may decrease this variable. IO access was more than twice as fast to obtain than eUVC access.

Szarpak L, Ladny JR, Dabrowski M, et al. Comparison of 4 pediatric intraosseous access devices: A randomized simulation study. Pediatr Emerg Care 2018;00:1-5. doi:10.1097/PEC.0000000000001587. [Epub ahead of print]

1026

This study aimed to compare the success rates of 4 commonly used IO devices (NIO Pediatric, BIG Pediatric, EZ-IO, and a manual Jamshidi IO needle) in a pediatric model. Speed of insertion, ease of use, and complications were secondary outcomes. Seventy-five novice physicians from Warsaw, Poland participated in this study; none of whom had prior experience with IO devices. First attempt success rates were 43% (Jamshidi), 90% (BIG), 97% (EZ-IO), and 100% (NIO-P). Median time to achieve IO access was 18 seconds (NIO), 23 seconds (EZ-IO and BIG), and 34 seconds (Jamshidi). 39/68 participants preferred the NIO device, 18/68 preferred the EZ-IO device, 11/68 preferred the BIG device, and none of the participants preferred the Jamshidi needle.

Wagner M, Olischar M, O'Reilly M, et al. Review of routes to administer medication during prolonged neonatal resuscitation. Pediatr Crit Care Med 2018;19(4):332-8. doi: 10.1097/PCC0000000000001493

1029

This article presents a review of current evidence regarding different routes for the administration of medications during neonatal resuscitation, of which the intraosseous route is included. A table comparing four different intraosseous devices, including EZ-IO, is presented in the document.

YEAR: 2017

Bewick VJ. Intraosseous cannulation in children. Anaesth Intens Care Med 2017;18(11):551-4. UK

961

This article describes the anatomy and physiology of IO cannula insertion as well as indications and contraindications of IO use. Devices and techniques as applied to the pediatric population are discussed, including EZ-IO.

Intraosseous Vascular Access Bibliography

Pediatric

Bielski K, Szarpak L, Smereka J, Ladny J, Leung S, Ruetzler K. Comparison of four different intraosseous access devices during simulated pediatric resuscitation. A randomized crossover manikin trial. Eur J Pediatr 2017;176(7):865-71. doi:10.1007/s00431-017-2922-z 899

This study compared success rate, procedure time and user satisfaction of pediatric NIO vs. Pediatric BIG, EZ-IO and Jamshidi intraosseous access devices in pediatric manikins. Study was randomized, crossover trial with 87 paramedics participating. The study evaluated each device on the ease of use in performing their procedures. Results of this study found that paramedics favored the NIO in ease of use in the pediatric manikins.

Faudeux C, Tran A, Dupont A, et al. Development of reliable and validated tools to evaluate technical resuscitation skills in a pediatric simulation setting: resuscitation and emergency simulation checklist for assessment in pediatrics. J Pediatr 2017;188:252-57. doi:10.1016/j.jpeds.2017.03.055 920

This study addresses the need for the development of a reliable and validated tool to evaluate technical resuscitation skills in a pediatric simulation setting. The authors created four resuscitation and emergency simulation checklist and evaluation tools were created, (RESCAPE). Study found that use of the RESCAPE tools are reliable and validated tools for evaluation of resuscitation skills in pediatric simulation-based educational programs.

Helleman K, Kirpalani A, Lim R. A novel method of intraosseous infusion of adenosine for the treatment of supraventricular tachycardia in an infant. Pediatr Emerg Care 2017;33(1):47-8. doi: 10.1097/PEC.0000000000000966 871

This article describes a case in which adenosine was administered to a 2-week old patient with supraventricular tachycardia, which was successfully terminated following intraosseous administration of the drug.

Lee E. The first time. Ann Emerg Med 2017;70(1):99-100. DOI: https://doi.org/10.1016/j.annemergmed.2017.01.021 883

This case study describes a resident's experience treating an infant in respiratory arrest. Among the interventions were tibial intraosseous vascular access using the Arrow® EZ-IO and administration of epinephrine. The baby did not survive.

Walsh BM, Gangadharan S, Whitfill T, et al. Safety threats during the care of infants with hypoglycemic seizures in the emergency department: A multicenter, simulation-based prospective cohort study. J Emerg Med 2017;53(4):467-74. doi:10.1016/j.jemermed.2017.04.028 1030

This article describes a prospective, multicenter, in situ, simulation-based cohort study to describe the frequency of different types of errors between general emergency departments (GEDs) and pediatric emergency department (PEDs) in a simulated pediatric patient case of hypoglycemic seizure. During the debriefing portion of the simulation providers and teams were asked about obtaining vascular access (IV/IO). Questions involved how to obtain vascular access, barriers to obtaining access, assessment of confidence in ability to obtain access, location of access, needle size, time to gain access, who to contact after failed attempts at access, and how to decide which medications or fluids to administer.

YEAR: 2016

Chin YX, Kiat Tan KB, Koh ZX, et al. Comparing intraosseous and intravenous access for out-of-hospital cardiac arrest in Singapore. Resuscitation 2016;106(S1):e25 813

The objective of this study was to determine if there would be a difference in rates of vascular access and ROSC if paramedics were able to use IO access after two initial IV attempts failed. Investigators found higher vascular access success and prehospital epinephrine administration rates with the addition of IO access but no significant difference for ROSC.

Singapore

Drozdz A, Madziara M. Nurses' attitudes and beliefs concerning intraosseous access in pediatric patients. Am J Disaster Med 2016;34(9):1890. doi:10.1016/j.ajem.2016.06.064 916

This study examined the attitudes of nurses working with pediatric patients and intraosseous access in pediatric patients. The study was conducted with the use of a diagnostic survey distributed to 200 nurses, with 135 nurses returning the surveys. The study found that there is a need for more training with nurses to increase their level of knowledge of intraosseous access and improve nurses attitudes for use of intraosseous access in pediatric population in emergency situations.

Hess T, Böhmer R, Arndt F, et al. Bilateral intraossärer zugang am humerus bei reanimation eines 3-Jährigen [Case Report- Bilateral humeral intraosseous access for CPR in a 3-years-old child]. Anästhesiol Intensivmed Notfallmed Schmerzther 2016;51(07-08):468-74. doi:10.1055/s-0042-110237. 819

This article in German describes a case study of a 3 year old child with a serious heart defect (after total cavopulmonary anastomosis) in which bilateral humeral IO access sites were obtained to manage her condition and the patient was discharged after 30 days without neurological deficits. Key messages include that IO access in children should be a primary access route in emergent and urgent situations, unless a suitable venous access is already available; the humeral head insertion site is an accepted method in emergency situations in adults and children; and IO access is intended for regular emergency administration of drugs. The purely preventive use of an IO is not indicated. Article in German.

Intraosseous Vascular Access Bibliography

Pediatric

- Johnson M, Inaba K, Byerly S, et al. Intraosseous infusion as a bridge to definitive access. *Am Surg* 2016;82(10):876-80** 826
This retrospective study examined indications and outcomes associated with IO use at a Level 1 trauma center from 2008-2015. All 68 IO placements were with the EZ-IO device; most patients had trauma diagnoses. Most IO placements were successful on first attempt within 3 minutes of arrival. Non-serious extravasation was the most common complication. Authors concluded IO access "should be considered as a rapid, low risk, high yield aid to long-term IV access in both adults and children, and is an important bridge to definitive access in resuscitation".
- Kjellemo H, Hansen AE, Øines DA, Nilsen TO, Wik L. Pediatric cardiac arrest due to trauma. *Prehosp Emerg Care* 2016;20(3):425-31. doi:10.3109/10903127.2015.1111479** 879
This case study describes a "lifeless child" who had been trapped by an electrically operated garage door. An IO needles was placed in each tibia and adrenalin was administered. Despite being asystolic for up to 19 minutes, the child eventually recovered with neurologic reflexes and motor abilities intact.
- Mittiga MR, FitzGerald MR, Kerrey BT. A survey assessment of perceived importance and methods of maintenance of critical procedural skills in pediatric emergency medicine. *Pediatr Emerg Care* 2016;0(0):1-6.[Epub ahead of print]** 996
This paper describes a survey of pediatric emergency medicine physicians assessing the perceived importance of six critical procedural skills, including intraosseous line placement, in pediatric emergency medicine. IO line placement was perceived as extremely important by 80% of physicians surveyed.
- Schwindt J. Intraosseous access- Of no value in neonatal resuscitation? *Resuscitation* 2016;103:e1. http://dx.doi.org/10.1016/j.resuscitation.2016.01.037** 853
In this letter to the editor, the author calls into question the continued recommended use of the umbilical venous catheter in neonatal resuscitation by the European Resuscitation Council and the lack of intraosseous vascular access recommendation. The author makes the argument that accessing the umbilical vein is difficult for even the most experienced NICU clinicians and that time cannot be spared in these resuscitations; and intraosseous access can provide a viable option for drug delivery.
- Wyllie J. Reply to: "Intraosseous access - Of no value in neonatal resuscitation?" *Resuscitation* 2016;103:e3. doi:10.1016/j.resuscitation.2016.03.007** 835
A letter to the editor regarding use of intraosseous (IO) access in new born babies compared to the use of umbilical catheterization. The author argues that the standard use of umbilical catheterization remains the preferred method of establishing vascular access urgently in newborns; and that though IO access has a role it should not be considered more reliable.
- YEAR: 2015**
- Foley LS, Kulungowski AM. Vascular anomalies in pediatrics. *Adv Pediatr* 2015;62(1):227-55. doi:10.1016/j.yapd.2015.04.009. http://dx.doi.org/10/1016/i.yapd.2015.04.009** 921
This article describes various pediatric vascular anomalies, including intraosseous vascular malformations which can lead to weakness in the bone diaphysis, predisposing to pathological fracture.
- Mogale N, Van Schoor A-N, Bosman MC. A theoretical alternative intraosseous infusion site in severely hypovolemic children. *Afr J Prm Health Care Fam Med* 2015;7(1):835. http://dx.doi.org/10.4102/phcfm.v7i1.835** 951
This article describes a study evaluating the proximal humerus intraosseous insertion site in neonatal cadavers, to determine the viability of the site as an alternative to tibial insertion. The cadavers were placed in the supine position with the arm adducted and the hand secured near the umbilicus. A 22 gauge IV spinal needle was used to establish IO access in 60 neonatal humeri at the greater tubercle of the humerus. The tissue around each insertion site was then dissected and measured to evaluate the needle position in relation to the soft tissue, as well as bony landmarks. The results showed that the point of needle insertion is on average 11 mm from the axillary nerve and posterior circumflex humeral vessels and 8 mm from the long head of the biceps brachii tendon running through the intertubercular groove. The authors concluded that the proximal humerus IO insertion site is likely to be a safe alternative to the tibial IO site in neonates.
- Overbey JK, Kon AA. Dermal abrasion experienced as an adverse effect of the EZ-IO. *J Emerg Med* 2016;50(1):e7-10. doi: 10.1016/j.jemermed.2015.09.003.** 753
This article presents a case report of a 7 month old female who received intraosseous vascular access via the EZ-IO in the distal femur that resulted in a dermal abrasion where the needle hub contacted the skin. The wound healed without significant complication however the scar at the IO site persisted at 11 months post the event. The authors recommend that providers use the minimal force necessary when operating the EZ-IO to avoid similar adverse events.

Intraosseous Vascular Access Bibliography

Pediatric

- Paterson ML, Callahan CW. The use of intraosseous fluid resuscitation in a pediatric patient with ebola virus disease. J Emerg Med 2015;49(6):962-4. <http://dx.doi.org/10.1016/j.jemermed.2015.06.010>** 796
- Case study of 9-month-old patient (approximate weight 7 kg) presented with Ebola Virus Disease (EVD) and severe dehydration. IO access was obtained using a 15 g Jamshidi device to the right proximal tibia. A total bolus of 280 mL of lactated ringers solution was infused; then the IO infusion continued for 12 hours until an IV could be established. Authors stated it is important for emergency disaster responders, as well as their responding organizations, to know and understand that IO access is an important and safe modality to use in patients with EVD, and in the austere settings often found in disaster settings.
- Pifko EL, Busch C, Price A, et al. An observational review of pediatric intraosseous needle placement in the pediatric emergency department. Ann Emerg Med 2015;66(4s):S87** 754
- A retrospective study evaluating attempts to establish intraosseous vascular access in pediatric patients using a manual device and the EZ-IO, in a tertiary care pediatric emergency department. Results showed 35 patients had IO access attempted using manual and EZ-IO devices. In patients greater than and less than 8kg the EZ-IO had a higher success rate but time to placement was longer. Overall success rate including both devices was 64%. There were 2 complications of transient leg swelling after EZ-IO placement in 2 patients.
- Reuter-Rice K, Patrick D, Kantor E, Nolin C, Foley J. Characteristics of children who undergo intraosseous needle placement. Adv Emerg Nurs J 2015;37(4):301-7. doi:10.1097/TME.0000000000000077** 854
- A retrospective study evaluating the use of pre-hospital and emergency department placed IO access in children before transport to a children's hospital. Data were extracted from a Level 1 trauma, tertiary care children's hospital transport database from 1993-2009. There were 143 eligible patients with an average transport distance of 33 miles; all but 8 catheters were placed by the ED. The most common reasons for IO placement were no IV access (53%) and no perfusion (33.6%); the most commonly reported complication was infiltration (27.3%); 46.9% of patients experienced no complication. The authors concluded IO access plays a significant role in promoting life-saving efforts when IV access is unachievable or no perfusion is determined.
- Rottenstreich M, Malka I, Glassberg E, Schwartz O, Tarif B. Pre-hospital intra-osseous freeze dried plasma transfusion: a case report. Disaster and Military Medicine 2015;1(8):1-3** 935
- Case report of a 13 year old girl suffering from severe hemorrhagic shock due to blast injuries and gun shot wounds that received freeze-dried plasma via IO access as part of prehospital resuscitative efforts. Her vital signs improved upon arrival to the hospital; and she was released after 3 weeks of hospitalization.
- Suominen P, Nurmi E, Lauerma K. Intraosseous access in neonates and infants: Increased risk of compartment syndrome and leg amputation. Resuscitation 2015;96(Suppl 1):S131-2. <http://dx.doi.org/10.1016/j.resuscitation.2015.09.313>** 1024
- This is an abstract of a study that analyzed possible technical and anatomical factors leading to the complication of amputation as a result of IO placement. The study was prompted by a case report of amputation in a neonate after IO access using the EZ-IO device. The study measured medullary diameter of the proximal tibia at the recommended IO access site in three groups: 1-28 day old full term neonates, 1-12 month old infants, and 3-4 year old children. The mean diameter in each group was 7.7 mm, 9.9 mm, and 12.4 mm, respectively. The small size of the IO space, especially in neonates and infants, makes correct placement difficult. As such, complications should be taken into consideration in this patient population.
- Suominen PK, Nurmi E, Lauerma K. Intraosseous access in neonates and infants: risk of severe complications- a case report. Acta Anaesthesiologica Scandinavica 2015;59(10):1389-93. doi: 10.1111/aas.12602** 769
- This case study describes a neonate who suffered a cardiac arrest, had return of spontaneous circulation (ROSC) and was treated with multiple medications and therapeutic hypothermia. The patient had received three IO needle insertions, one in the left tibia that was removed following swelling with bolus injection; one in the left distal femur that dislodged with movement of the patient's legs; and one in the right proximal tibia. Twenty-four hours after initial IO needle placement the child developed pallor and discoloration and was diagnosed with compartment syndrome to the right lower extremity. Five days post-IO insertion a below the knee amputation was performed. Medications infused via the IO access included epinephrine and norepinephrine infusions.
- Ventura AMC, Shieh HH, Bousso A, et al. Double-blind prospective randomized controlled trial of dopamine versus epinephrine as first-line vasoactive drugs in pediatric septic shock. Crit Care Med 2015;43(11):2292-302. doi:10.1097/CCM.0000000000001260** 840
- This article describes a prospective double-blind randomized controlled study evaluating the difference between use of dopamine and epinephrine as first-line vasoactive drug in pediatric septic shock patients. This study conducted in the pediatric intensive care unit (PICU) of Hospital Universitario da Universidade de Sao Paulo, Brazil. One hundred twenty-one patients aged 1 month to 15 years who met criteria were randomized to receive either epinephrine (n=57) or dopamine (n=63) via IV or intraosseous (IO) vascular access (via EZ-IO). The authors concluded dopamine was associated with an increased risk of death and healthcare-associated infection; whereas administration of epinephrine via IV or IO routes was associated with increased survival.

Intraosseous Vascular Access Bibliography

Pediatric

YEAR: 2014

- Chansa E, Kansen K, Gustafsson B. [An intraosseous blood transfusion in a critically ill child] Une transfusion sanguine par voie intraosseuse chez un enfant gravement malade. Afr J Emerg Med 2014;4(2):83-5. <https://doi.org/10.1016/j.afjem.2013.05.003>** 658
- This article describes a case study of a 31-month old infant that suffered hypovolemic shock due to severe epistaxis. After several failed peripheral and central line attempts an 18g needle was inserted intraosseously through the proximal tibia. The child received 300 mL of Ringer's Lactate in one hour then 200 mL of blood via the IO route by syringe boluses resulting in improvement. Cloxacillin was also administered IO as prophylaxis for infection. Authors conclude an IO blood transfusion should be the immediate intervention in similar life-threatening situations.
- Zambia
- Craiu M, Stan V, Cochino AV. Intraosseous access-A classical method for vascular access that regains an important role as resuscitation tool. Ro J Pediatr 2014;68(3):233-7. Romanian** 968
- This article reviews the initial development of IO access and provides an overview of IO use in pediatric populations including insertion technique, side effects, and contraindications.
- English and Romanian article
- Cullen PM. Intraosseous cannulation in children. Anaesth Intensive Care Med 2014;15(12):567-9** 734
- This article presented a general overview of IO use in pediatrics. The history, techniques, anatomy and physiology, complications and a short discussion of most devices on the market, including the EZ-IO, were discussed.
- UK
- Dawes J, Ramnarayan P, Lutman D. Stabilisation and transport of the critically ill child J Intensive Care Med 2014;15(1):34-42. doi:10.1177/175114371401500108.** 912
- The focus for the article is the need for early recognition and stabilization of a critically ill child presenting to local hospital and how hospitals admitting critically ill children must be able to resuscitate and stabilize the child prior to transferring to another hospital. The article discusses the initial assessment and resuscitation when a critically ill child presents to a local hospital and the pediatric transport process and the importance of communication between all teams. The article also discusses the need for clinicians working with critically ill children need to be properly trained and be able to maintain those skills.
- Egyptian Pediatric Association Gazette. Hot topics in neonatology: Lecture given at the EPA's national conference-1.1.10. Vascular access. Egypt Pediatr Assoc Gazette 2013;61:92-5. <http://dx.doi.org/10.1016/j.epag.2013.11.007>** 707
- This article identifies new concepts and changes in neonatal resuscitation discussed at the Egyptian Pediatric Association national conference. Intraosseous vascular access is included stating, "temporary intraosseous access to provide fluids and medication to resuscitate critically ill neonates may be indicated following unsuccessful attempts to establish intravenous vascular access or when caregivers are more skilled at securing intraosseous access."
- Egypt
- Khilani A, Mazwi M, Paquette ET. Pediatric sepsis in the global setting. Clin Pediatr Emerg Med 2014;15(2):193-203** 725
- This discussion of pediatric sepsis focuses on the "global setting" making note of inherent differences in policies, diagnostics, causes and management approach between regions. A review of basic assessment, treatment, follow-up and prevention strategies applicable regardless of resources is offered. Goal directed therapy within the first 5 minutes includes establishment of IV/IO access.
- Martin Reyes B, Abolafia del Balazo R, Estepa Sanchez A, Garcia Cazalilla M, camara Anguita S, Rojas Jimenez AM. Emergencies medical services: intraosseous drill in CPR. Resuscitation 2014;85(S):S24** 715
- This abstract describes an observational study evaluating use of the intraosseous drill (EZ-IO) in 20 patients assisted by EMS and receiving CPR within a 3 year period. The study includes 4 pediatric and 16 adult patients. The authors concluded that IO access is a reliable alternative to peripheral venous access and can be implemented fast and with high success rate of CPR in which drugs and fluids are given.
- Spain
- Neuhaus D. Intraosseous Infusion in elective and emergency pediatric anesthesia: when should we use it? Curr Opin Anaesthesiol 2014;27(3):282-7. DOI: 10.1097/ACO.0000000000000069** 723
- General review of IO access, with particular attention to perioperative setting and includes published guidelines of the German Scientific Working Group for Pediatric Anesthesia for use of intraosseous access. The author recommends that for children with known difficult venous access physicians discuss the possibility of IO access preoperatively with the family.
- Switzerland

Intraosseous Vascular Access Bibliography

Pediatric

Oesterlie GE, Petersen KK, Knudsen L, Henriksen TB. Crural amputation of a newborn as a consequence of intraosseous needle insertion and calcium infusion. *Ped Emerg Care* 2014;30(6):413-4 699

Case study of newborn girl resuscitated with 15 mm EZ-IO catheter placed to her right proximal tibia. Medications given included antibiotics, "fluids" and calcium. Demarcation of the infants skin was noted immediately post-calcium administration; with progression to necrosis. Trans-tibial amputation was performed 1.5 months after initial IO access. Authors concluded calcium extravasation most likely caused the injury but were unable to identify extravasation cause; citing possible needle displacement. Cautionary steps to reduce risk emphasized by authors.

Denmark

Swaney PM, Nayman BD, Cabanas JG, Myers JB. Fatal myocardial ischemia in a 12-year-old secondary to fibromuscular dysplasia. *Am J Emerg Med* 2014;32(7):812.e5-7. doi:10.1016/j.ajem.2013.12.027 693

A case study report describing a 12-year-old male who expired following a fatal myocardial ischemia. The patient complained of severe chest pains within the week prior to the event and was misdiagnosed as having GERD. ECG by first responders showed STEMI; IO access was established in the PT for vascular access.

YEAR: 2013

American Academy of Pediatrics. Joint policy statement - guidelines for care of children in the emergency department. *J Emerg Nurs* 2013;39(2):116-27 648

Reprint article of policy statement originally published 2009, endorsed by multiple professional societies providing guidelines for care of children in the emergency department. A recommendation for IO equipment in adult and pediatric sizes is included.

Byars DV, Tsuchitani SN, Yates J, Knapp B. A multijurisdictional experience with the EZ-IO intraosseous device in the prehospital setting. *Am J Emerg Med* 2013;31(12):1712-3. doi: 10.1016/j.ajem.2013.08.056 656

This letter to the editor describes a prospective, observational, trial that evaluated use of the EZ-IO in critically ill and injured patients (adult and pediatric) in a multijurisdictional prehospital setting; 9 EMS agencies were included. The 25mm needle set was the only needle size allowed for the study. One-hundred-eleven EZ-IO placements were performed by EMT-Intermediates and EMT-Paramedics with 96 successful placements (86.5%); the most common cause for failure reported by the author was thought to be patient obesity and inadequate needle length. Cardiac arrest patients made up 74.7% of the study population and the most common site accessed was the proximal tibia. Device operators rated the ease of use 7.87 using a 0 to 10 scale where 10=extremely easy.

Cleugh FM, Maconochie IK. Management of the multiply injured child. *Paediatrics and Child Health* 2013;23(5):194-9 659

General overview of care of a child with multiple trauma. IO vascular access is mentioned as a treatment option after 90 seconds or 3 failed PIV attempts. The B.I.G. is cited as an option along with the manual needles.

Hamed RK, Hartmans S, Gausche-Hill M. Anesthesia through an intraosseous line using an 18-gauge intravenous needle for emergency pediatric surgery. *J Clin Anesth* 2013;25(6):447-51;pii: S0952-8180(13)00202-X. doi: 10.1016/j.jclinane.2013.03.013.http://dx.doi.org/10.1016/j.jclinane.2013.03.013. Accessed September 3, 2013 670

This 30 pediatric patient case series describes use of IO access in the perioperative setting when peripheral and central venous access failed during anesthesia administration for emergency surgery. Due to unavailability of modern IO devices, a standard 18-gauge IV needle with a handmade IV extension set were used to establish IO access. The authors reported administering ketamine, succinylcholine, pancuronium, atracurium, halothane, neostigmine, atropine, blood products, fluids and hydrocortisone through the IO line without complication. The authors concluded that although it is not the first-line method for anesthesia, IO access should be considered by pediatric anesthesiologist when peripheral and central venous access has failed or is difficult.

Iraq

Hunsaker S, Hillis D. Intraosseous vascular access for alert patients. *Am J Nurs* 2013;113(11):34-9 672

This article presents an overview of IO access focused on nurses' use of the technique. A list of available devices, history and support for use and possible complications are included.

Lewis GC, Crapo SA, William JG. Critical skills and procedures in emergency medicine- vascular access skills and procedures. *Emerg Med Clin N Am* 2013;31(1):59-86. doi: 10.1016/j.emc.2012.09.006 631

This article provides an overview of various vascular access modalities in emergency medicine including peripheral IV, venous cut-down, central venous catheter, intraosseous access, umbilical vessel access, and arterial access. The anatomy and physiology, indications and contraindications, procedure steps and special considerations are outlined for each access methods discussed.

Intraosseous Vascular Access Bibliography

Pediatric

Mittiga MR, Geis GL, Kerrey BT, Rinderknecht AS. The spectrum and frequency of critical procedures performed in a pediatric emergency department: Implications of a provider-level view. *Ann Emerg Med* 2013;61(30):263-70. doi.org/10.1016/j.annemergmed.2012.06.021 588

This retrospective study evaluated the number and type of critical procedures, including IO line placement, performed in the ED of a tertiary care pediatric institution over a 12 month period. The authors concluded that critical procedures were rarely performed in a large academic pediatric ED; pediatric emergency medicine faculty are at significant risk for skill deterioration; and fellows are unlikely to achieve competence in performing critical procedures.

Myers LA, Arteaga GM, Kolb LJ, et al. Prehospital peripheral intravenous vascular access success rates in children. *Prehosp Emerg Care* 2013;17(4):425-8. doi: 10.3109/10903127.2013.818180 1000

This retrospective review of medical records submitted by paramedics identified patients 18 years or younger who had prehospital peripheral IV (PIV) attempts. Over 101 months at least 1 PIV attempt was made on 4188 patients ≤18 years old. The study demonstrated that success rates are significantly associated with patient age and each 1 year increase in age increased the odds of successful PIV placement by 11%. The authors suggest that IO access with the use of a semiautomatic IO device (EZ-IO) may be a more efficient first-line method for immediate treatment after 1 PIV access failure, especially in younger patients given their higher rate of PIV insertion failure.

Oksan D, Ayfer K. Powered intraosseous device (EZ-IO) for critically ill patients. *Indian Pediatr* 2013;50(7):689-91 685

A retrospective chart review evaluating use of the EZ-IO in 25 pediatric patients between July 2008 and August 2010 at a Turkish university affiliated hospital. All attempts were made in the proximal tibia and IO access was attempted following failed PIV access within 60 seconds. First attempt success was 80%; the most reported complication was simple extravasation (3 cases) and needle dislodgement (1 case). Turkey

Reinhardt L, Brenner T, Bernhard M, et al. Four years of EZ-IO system in the pre- and in-hospital emergency setting. *Central European Journal of Medicine* 2013;8(2):166-71. Doi:10.2478/s11536-012-0125-6 618

An observational study evaluating use of the EZ-IO by two ground and one air based physician staffed EMS and at a German surgical university hospital between January 1, 2008 and December 31, 2011. The EZ-IO was used to establish IO access 88 times in 87 patients; 83 insertions were performed in the EMS and 5 were performed in the hospital. The proximal tibia was the primary site used (97.7%) and the first attempt success rate was 94%. IO access was the first approach for vascular access in children compared to adults (38.9% vs. 86.2%). There were 5 failures attributed to missed insertions or extravasation and 2 for wrong needle length. There were no serious complications.

Santos D, Carron PN, Yersin B, Pasquier M. EZ-IO intraosseous device implementation in a pre-hospital emergency service: a prospective study and review of the literature. *Resuscitation* 2013;84(4):440-5. http://dx.doi.org/10.1016/j.resuscitation.2012.11.006 604

An observational study evaluating use of the EZ-IO in a Swiss pre-hospital EMS system between January 1, 2009 and December 31, 2011 and comparing those results to the literature. Sixty IO insertions were performed on 58 patients; the proximal tibia was used in all attempts except 1 attempt made in the proximal humerus. Overall success rate was 90%; the 6 failures were attributed to impossibility to infuse, difficult needle insertion, and incorrect insertion site (tibial plateau). Some of the indications for IO access included cardiorespiratory arrest, major trauma, and shock; general anesthesia was successfully induced in 7 patients. Drugs infused are listed. There were no serious complications.

Soto F, Murphy A, Heaton H. Critical procedures in pediatric emergency medicine. *Emerg Med Clin N Am* 2013;31:335-76. http://dx.doi.org/10.1016/j.emc.2012.09.003 623

An overview of pediatric emergency medicine and critical procedures. One of the key points noted: intraosseous vascular access can be used in all ages.

Torres A, Banister N, Fernandez M, Cox K, Fletcher J. Appropriateness and complications of intraosseous needle placements during pediatric transports. *Crit Care Med* 2013;41(12):abstract 215 792

A quality initiative study conducted evaluating use of the EZ-IO needles in pediatric patients and their associated complications rates when placed by EMS/ED staff compared Air Evac Lifeteam placement in 2012. The authors concluded that the powered IO device was appropriately utilized by ED/EMS staff as well as Air Evac staff and that there was no difference in the complication rate when the device was used by the two groups.

Veldhoen ES, de Vooght KMK, Sliker MG, Versluys AB, Turner NMB. Analysis of bloodgas, electrolytes and glucose from intraosseous samples using an i-STAT point-of-care analyser. *Resuscitation* 2013;http://dx.doi.org/10.1016/j.resuscitation.2013.12.002 692

A prospective study comparing IO and venous laboratory values obtained from a point-of-care analyzer (i-STAT) in 20 children. IO blood specimens were collected from the iliac crest; 2 ml were discarded before the sample was collected analysis. Results showed differences between venous and IO sample were clinically acceptable for pH, base excess, sodium, ionized calcium and glucose in hemodynamically stable patients. Authors concluded that analysis of IO samples with a bedside point-of-care analyzer is feasible and in emergency situations may be useful to guide treatment.

Intraosseous Vascular Access Bibliography

Pediatric

Weiser G, Poppa E, Katz Y, Bahouth H, Shavit I. Intraosseous blood transfusion in infants with traumatic hemorrhagic shock - a case report and review of the literature. Am J Emerg Med 2013;31(3):640.e3-4. doi: 10.1016/j.ajem.2012.10.036

646

This article describes a case study of a 5-month old infant that suffered a head injury resulting in shock. She received 100 mL of red blood cells via the EZ-IO in the proximal tibia, resulting in rapid hemodynamic improvement. A literature search was completed for cases of IO blood transfusion in pediatric trauma. Authors note IO availability and knowledge play an important role in hemorrhagic shock; and RBC infusions via the IO route are feasible in this age group.

YEAR: 2012

Barker LT. In the child with gastroenteritis who is unable to tolerate oral fluids, are there effective alternatives to intravenous hydration? Ann Emerg Med 2012;60(5):607-8. doi: 10.1016/j.annemergmed.2012.04.003

534

This article, part of a Review Snapshot series in Annals summarizes a literature review (Rouhani et al in Pediatrics 2011) for evidence of alternatives to traditional IV hydration in a dehydrated child. Thirty-eight articles were included for the analysis with five of them randomized controlled trials; and one of those comparing IO to IV rehydration. (Banerjee et al, which found IO placement faster with no therapeutic outcome differences). The focus of this review was on nasogastric tube rehydration as effective when IV fails and as less invasive than IO or CVC placement.

Cote C, Dumont M, Gagnon JA. Abnormal bone scanning following intraosseous access. Medecine Nucleaire 2012; doi:10.1016/j.mednuc.2012.02.175

537

This case study describes a 12 month boy who received IO access for administration of anticonvulsant therapy. Three days post IO infusion sensitivity to the leg was noted and the child returned to the ED. Blood work showed elevated white blood counts and C-reactive protein. A bone scan showed a small round lucency at the site of IO access. Two weeks later, x-rays were normal. The authors suggest that IO access may cause an increased uptake on bone scan in absence of osteomyelitis.

Dandele LM, Ohler KH. Pharmacotherapy of pediatric advanced life support and toxicological emergencies. AACN Adv Crit Care 2012;23(4):398-412. doi:10.1097/NCI.0b013e31826b4c70

635

PALS 2012 guidelines on pharmacotherapy and toxicological emergencies.

Goodman IS, Lu CJ. Intraosseous infusion is unreliable for adenosine delivery in the treatment of supraventricular tachycardia. Pediatr Emerg Care 2012;28(1):47-8

524

Physicians from two different emergency department settings reported 2 cases of supraventricular tachycardia (SVT) in infants (2 and 4 month old) in which IO administration of adenosine failed to convert SVT to a normal rhythm.

Greene N, Bhananker S, Ramaiah R. Vascular access, fluid resuscitation, and blood transfusion in pediatric trauma. Int J Crit Illn Inj Sci 2012;2(3):135-42 doi: 10.4103/2229-5151.100890

980

This article is a review of techniques and available evidence for establishing intravenous access, rational approaches to fluid resuscitation, and blood product transfusion in the pediatric trauma patient. IO needle systems are available for integration into pre-existing trauma care systems for pediatric patients.

Kalechstein S, Permul A, Cameron BM, et al. Evaluation of a new pediatric intraosseous needle insertion device for low-resource setting. J Pediatr Surg 2012;47(5):974-9. doi: 10.1016/j.pedsurg.2012.01.055

546

This article describes a study evaluating a new manual needle insertion device, the Near Needle Holder, which uses hollow-bore needles to establish IO access. In a comparative study, healthcare professionals attempted IO insertion in the proximal tibia insertion site of a mannequin using the NNH and a standard Cook manual IO needle. Participants then completed a questionnaire regarding their experience. The most reported complication was the plunging of the needle into the medullary space from the decrease in resistance once the cortex was penetrated. Other IO devices on the market are mentioned, including the EZ-IO.

Lammers R, Byrwa M, Fales W. Root causes of errors in a simulated prehospital pediatric emergency. Acad Emerg Med 2012;19(1):37-47. doi: 10.1111/j.1553-2712.2011.01252.x

590

This simulation study evaluated the ability of 2 person EMS crews to manage a pediatric emergency and sought to determine root causes of errors made. Participating EMS crews used the BIG for IO access. The authors concluded that cognitive, procedural, affective, teamwork errors and error-producing conditions were identified as root causes for the errors made in the simulation. Authors also concluded that simulation followed by facilitated debriefing is an effective tool for identifying underlying causes of active and latent errors.

Oriot D, Darrieux E, Boureau-Voultoury A, Ragot S, Scepti M. Validation of a performance assessment scale for simulated intraosseous access. Simul Healthc 2012;7(3):171-5. doi:10.1097/SIH.0b013e31824a5c20

581

This article describes the validation testing of a newly developed performance assessment scale for evaluating the intraosseous manual insertion process in the proximal tibia during simulated procedures. The authors concluded that the scale was a reliable tool to assess the overall IO insertion procedure and that with modifications this scale may be used with other IO devices and in the clinical setting.

Intraosseous Vascular Access Bibliography

Pediatric

Ribiero de Sa RA, Melo CL, Dantas RB, Delfim LVV. Vascular access through the intraosseous route in pediatric emergencies. Rev Bras Ter Intensiva 2012;24(4):407-14 716

The authors evaluated use of IO access in pediatric emergencies through a literature review. The objective was to describe the techniques, professional responsibilities, and care related to obtaining IO access.

Brazil

Rose EC. The evidence-based use of intraosseous lines in pediatric patients. Pediatr Emerg Med Pract 2012;9(6):1-12. www.edmedicine.net 585

This article presents a general overview of intraosseous (IO) vascular access in the pediatric population through an IO literature review. Available IO devices were discussed.

Smith J, Rollin AM. The placement of an intravenous cannula is always necessary during general anesthesia in children: a pro-con debate. Pediatr Anaesth 2012;22(5):455-61. doi:10.1111/j.1460-9592.2012.03834.x 573

This article argues the pros and cons to routinely establishing IV access in anesthetized children. IO access is discussed in the con debate as an alternative to routine peripheral IV access in this population.

Truemper EJ, Beamer CL, Miller LJ, et al. Distal femur site is a viable option for IO vascular access in pediatric patients. Ann Emerg Med 2012;60(4S):S90 761

This abstract presented at the 2012 ACEP Research Forum explored the viability of the distal femur as an IO insertion site with a literature review of IO vascular access and brief overview of a post-mortem study of pediatric distal femur insertion success. Authors concluded that clinical literature, clinical studies, and a post-mortem study confirm that the distal femur is a viable option for IO infusion in pediatric patients. This study was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.

Voigt J, Waltzman M, Lottenberg L. Intraosseous vascular access for in-hospital emergency use: A systematic clinical review of the literature and analysis. Pediatr Emerg Care 2012;28(2):185-99 562

In this article the authors review the evidence supporting the use of IO access; determine the utilization IO access as described in the literature; and assess the level of specialty society support. Various IO devices are mentioned including the EZ-IO

Weiss M, Englehardt T. Cannot cannulate: bonulate! Eur J of Anaesthesiology 2012;29(6):257-8 569

This article is making a case for pediatric anesthesiologists to have IO access equipment readily available wherever children are anesthetized; and for anesthesiologists to consider IO access not only as a last resort but as the route of choice in children requiring urgent vascular access.

YEAR: 2011

Aliman AC, Piccioni Mde A, Piccioni JL, Oliva JL, Auler Junior JO. Intraosseous anesthesia in hemodynamic studies in children with cardiopathy. Rev Bras Anesthesiol 2011;61(1):41-9 654

A comparative study evaluating the effectiveness of IO access in relation to IV access for infusion of anesthetics (ketamine, midazolam, and fentanyl) and fluids during hemodynamic studies in 21 infants with congenital heart disease. IO access was established in the proximal tibia (n=11). Results showed, time to access was significantly shorter with IO access (3.6 vs 9.6 minutes); anesthetic onset was shorter with IV access (56.3 vs 71.3 seconds); and no significant difference between groups for hydration volume and anesthesia recovery time. The authors concluded that due to its easy manipulation and efficiency, hydration and anesthesia by IO access was satisfactory without necessity of other infusion access.

Brazil

Carreras-Gonzalez E, Brio-Sanagustin S, Guimera I, Crespo C. [Complicacion de la via intraosea en un neonate]. Med Intensiva 2011;doi:10.1016/j.medin.2011.05.004. Spanish 487

This article in Spanish describes an IO complication case in which a newborn infant developed tissue necrosis as a result of extravasation during IO infusion.

Cullen PM. Intraosseous cannulation in children. Paediatric Critical Care 2011;13(1):28-30 523

This article presented a general overview of IO use in pediatrics. The history, techniques, anatomy and physiology, complications and a short discussion of most devices on the market, including the EZ-IO, were discussed.

UK

Intraosseous Vascular Access Bibliography

Pediatric

- Dolister M, Miller ST, Borron S, Truemper E, Shah MR. Intraosseous vascular access can be used safely and effectively, and at a lower cost than central venous catheters, for pediatric and adult patients in the hospital setting. *Ann Emerg Med* 2011;58(4S):S311** 453
- This abstract describes the interim results of an observational clinical trial evaluating use of the EZ-IO to establish venous access in patients that would typically receive a central line due to lack of other options. At interim analysis, 50 patients had been enrolled in the study. First attempt IO access success rate was 96%; mean time to IO access was 95.1 seconds. The authors concluded that IO access in place of or as a bridge to central venous catheters is safe, fast, and effective for adult and pediatric patients in the hospital setting with substantial cost savings potential. This research was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.
- Eich C, Weiss M, Neuhaus D, et al. Handlungsempfehlung zur intraossären Infusion in der Kinderanästhesie [Recommended action for intraosseous infusion in children's anesthesia]. *Anästhesiologie Intensivmedizin* 2011;52:S46-52. German** 770
- German Society of Anaesthesiology and Intensivmedizin eV" (DGAI), includes a general discussion of intraosseous (IO) as vascular access, overview of devices and recommendations for pediatric anesthesia with indications for intraosseous infusion in pediatric anesthesia and perioperative care in children. Early or primary IO indications are respiratory and circulatory arrest; critical hemodynamic instability before or during anesthesia introduction; severe laryngospasm; anesthesia induction in respiratory bleeding. Urgent indications (decision based on each case is necessary) include urgent induction of anesthesia in non-fasted children (ileus, RSI); induction of anesthesia in children with unstable circulation or severe cardiac insufficiency. Semi-elective indications (decision based on each case is necessary) after mask induction of anaesthesia (if vascular access required); mandatory induction of "intravenous" anaesthesia (as in malignant hyperthermia). This article is in German.
- Friedman JN. Emergency management of the paediatric patient with generalized convulsive status epilepticus. *Paediatr Child Health* 2011;16(2):91-97** 1073
- This Canadian Paediatric Society paper provides guidelines for the "emergency management of generalized convulsive status epilepticus (CSE) in children and infants older than one month of age". Use of IO access is included for medication administration when IV access is not possible.
- Hansen M, Meckler G, Spiro D, Newgard C. Intraosseous line use, complications, and outcomes among a population-based cohort of children presenting to California hospitals. *Pediatr Emerg Care* 2011;27(10):928-32** 710
- This retrospective cohort study evaluated data from 450 California hospitals and emergency departments to determine the rate of IO access use and related complications in the pediatric population from 2005-2007. Results showed 291 children had IO access placed in 90 hospitals out of 6.6 million pediatric ED visits and 2.2 million pediatric admissions; no complications were identified. The most frequent diagnosis related to IO use was cardiac arrest (34%).
- Heyder-Musolf J, Giest J, Straub J. Kasuistik-Intraossärer Zugang bei einem 1300 g schweren septischen Neugeborenen[Case history-Intraosseous access on a 1300 g septical premature infant]. *Anesthesiologie Intensivmedizin Notfallmedizin Schmerztherapie* 2011;46(10):654-7. doi: 10.1055/s-0031-1291943. [German]** 864
- Case description of a critically ill 15 day old premature infant weighing 1300 g. Tibial IO access was placed perioperatively for an urgent surgery.
- Khan LAK, Anakwe RE, Murray A, Godwin Y. A severe complication following intraosseous infusion used during resuscitation of a child. *Inj Extra* 2011;doi:10.1016/j.injury.2011.05.015** 485
- This article describes the case of an 11-year-old boy who suffered compartment syndrome of the lower leg following use of the EZ-IO for resuscitation and 24 hours of intraosseous infusion of adrenaline, calcium and potassium. The author concluded that further work is needed to develop recommendations for maximum duration, dose, volume and rates for intraosseous infusion.
- Luu JL, Wendtland CL, Gross MF, et al. Three-percent saline administration during pediatric critical care transport. *Pediatr Emerg Care* 2011;27(12):1113-7. doi: 10.1097/PEC.0b013e31823aff59** 866
- Retrospective study describing 3% saline administration during pediatric critical care transports. Primary indications for use included cerebral edema, intracranial bleed with edema and symptomatic hyponatremia. The primary infusion route was peripheral venous with 4 infusions via central line and 2 via the IO route. Most patients received one bolus enroute. No adverse reactions were noted for any route.
- Myers L, Russi CS, Arteaga GM. Semiautomatic intraosseous devices in pediatric prehospital care. *Prehosp Emerg Care* 2011;15(4):473-6. doi:10.3109/10903127.2011.598611** 431
- This article describes the changes in practice experienced when a 12-site statewide ambulance service changed from the manual to the semi-automatic IO device (EZ-IO). There was no statistically significant change in first-attempt success or the number of successes per attempt. However, the use of IO access more than tripled when changing from the manual to the semi-automatic device and PIV access attempts before IO access went from occurring in 35.5% of patients to 1.7% of patients.

Intraosseous Vascular Access Bibliography

Pediatric

Myers LA, Russi CS, Arteaga GM. The introduction of a semiautomated (EZ-IO) device in pediatric prehospital care replacing a manual intraosseous (IO) device improves the success rate for attempts at vascular access. *Prehosp Emerg Care* 2011;15(1):110 508

This abstract describes a 93 patient study presented at the 2011 National Association of EMS Physicians Annual Conference that examined the characteristics of pediatric patients receiving IO infusions and the primary EMS clinical impressions, success rates, and subsequent treatments delivered via manual IO vs. the powered EZ-IO device. Investigators concluded that for the pediatric cohort use of the powered device offered a marginally higher first-attempt success rate compared to the manual device; and that the rate of IO access utilization by EMS more than tripled after adoption of the powered device.

Nagler J, Krauss B. Intraosseous catheter placement in children. *NEJM* 2011;364(8):e14-8 491

This article provides an overview of intraosseous vascular access for pediatrics and discusses general indications, contraindications, complications, and intraosseous devices.

Rajani AK, Chitkara R, Oehlert J, Halamek LP. Comparison of umbilical venous and intraosseous access during simulated neonatal resuscitation. *Pediatrics* 2011;128(4):e954-8.doi:10.1542/peds.2011-0657 478

This study compared time to placement, errors in placement and perceived ease of use for healthcare providers placing umbilical venous catheters (UVC) and intraosseous needles in a simulated delivery room, responding to persistent bradycardia. Results showed mean IO placement time was 46 seconds faster than UVC placement; there was no significant difference in the number of errors and the perceived ease of use between UVC and IO.

Reece A, Cohn A. Safety of power driven devices for intraosseous access in infants. *BMJ* 2011;343:d4362.doi:10.1136/bmj.d4362 435

This letter to the editor is regarding the relative safety of using power driven IO devices in infants. Three cases of amputation secondary to compartment syndrome in children under 2 years of age are referenced. The author expressed concern with the weight designations for IO needles stating some of the needles intended for pediatric patients may actually be too long for smaller children and that manually inserted devices may be safer in younger children.

Rouhani S, Meloney L, Ahn R, Nelson BD, Burke TF. Alternative rehydration methods: a systemic review and lessons for resource-limited care. *Pediatrics* 2011;127:e748-57. doi: 10.1542/peds.2010-0952 551

This article discusses alternative rehydration methods for pediatric patients, including the intraosseous route.

Schexnayder SM, Storm EA, Stroud MD, et al. Chapter 15-Pediatric vascular access and centeses. *Pediatric Critical Care* 2011;4th ed:139-63. ISBN: 978-0-323-07307-3 680

This document addresses pediatric vascular access and includes an overview of intraosseous vascular access. Indications, contraindications, supplies and equipment, technique, complications and maintenance are discussed.

Schmitt ER, Stroh G, Shalit M, Campagne D. Intraosseous access for neonatal and newborn resuscitation in the national park service (NPS). *Prehosp Disaster Med* 2011;26(3):238-9. doi: 10.1017/S1049023X11006285 552

This article discusses the use of IO access for neonatal and newborn resuscitation by the national park service and provides information as to how the decision was made to make IO access a standard of care for those patients.

Taylor CC. Amputation and intraosseous access in infants. *BMJ* 2011;342:d2778. doi:10.1136/bmj.d2778 484

This article describes two cases of leg amputation after intraosseous infusion in a 5-month-old girl and a 17-month-old boy. The author concluded that fluid extravasation, exacerbated by tibial fracture and needle dislodgement during transportation, caused limb ischemia in these two patients, and that adherence to the principles of careful needle placement, splinting/securing the catheter and limb, limited length of infusion and repeated monitoring of the limb will help avoid this devastating complication.

Wechselberger G, Radauer W, Schimpl G, et al. Lower limb salvage in a 7-month-old infant using free tissue transfer. *J Ped Surg*. 2011;46:1852-4. Doi:10.1016/j.jpedsurg.2011.06.037 625

A 7-month-old male infant in septic shock from *Neisseria meningitidis* experienced a complication of bilateral extravasation of noradrenalin at the proximal tibia intraosseous infusion site resulting in severe soft tissue necrosis. Necrosectomy was performed bilaterally and surgical interventions were successfully performed to salvage both limbs. At 19 months the patient was able to crawl without extension deficit.

YEAR: 2010

Craiu M, Iordachescu M, Stan I, et al. Alternative intraosseous infusion technique via spinal needle, valuable tool for pediatric resuscitation. *Resuscitation* 2010;81S:S76. doi:10.1016/j.resuscitation.2010.09.312 609

This abstract describes a retrospective case-series analysis of pediatric IO recipients from 1998-2009. Seventy-two (72) patients were included in the study; IO access was established in the proximal tibia (n=61), medial tibia (n=8), distal tibia (n=1), sternum (n=1), and iliac crest (n=1). IO access devices used in the proximal tibia included the Cook Critical Care needle (n=4), the Jamshidi needle (n=2), the BIG (n=1), and an 18 gauge spinal needle (n=54). The authors concluded that a spinal needle can be used to provide IO vascular access in children.

Intraosseous Vascular Access Bibliography

Pediatric

- Dasgupta S, Playfor S. Intraosseous fluid resuscitation in meningococcal disease and lower limb injury. *Pediatr Rep* 2010;2(1):e5:18-9** 426
- Authors reviewed two complications (extravasation and compartment syndrome) associated with IO access in children with meningococcal disease. Authors concluded that IO systems need formal evaluation to assess safety and complication profiles.
- Detaille T, Pirotte T, Veyckemans F.. Vascular access in the neonate *Best Pract Res CL Anesth* 2010;24(3):403-18.** 913
doi:10.1016/j.bpa.2010.02.017
- This article discusses the challenges of gaining vascular access in small infants and neonates and how new equipment such as ultrasound machines with pediatric probes can provide better guidance and improve safety and efficacy. The article also addresses the importance of education and training in ultrasound use. This article was based on literary research as well as authors' experience.
- Hiller K, Jarrod MM, Franke HA, Degan J, Boyer LV, Fox FM. Scorpion antivenom administered by alternative infusions. *Ann Emerg Med* 2010;56(3):309. doi:10.1016/j.annemergmed.2010.04.007** 471
- This letter to the editor describes 2 cases in which IV administration of antivenom was not possible and was thereby administered via IO route, and in one case via the intramuscular route as well. In both cases the patients recovered.
- Kleinman ME, Chameides L, Schexnayder SM, et al.. Part 14: Pediatric advanced life support: 2010 American Heart Association guidelines for cardiopulmonary resuscitation and emergency cardiovascular care. *Circulation* 2010;122(Suppl 3):S876-S908. doi: 10.1161/CIRCULATIONAHA.110.971101** 947
- Part 14 of the 2010 PALS update supports IO vascular access as easy and quick to establish, useful for first line access in cardiac arrest and equivalent for many medications.
- Larson SD, Hebra A, Raju R, Lee S. Vascular access, surgical treatment. <http://emedicine.medscape.com/article/1018395>. Updated January 25, 2010** 446
- This article describes the vascular access options available to physicians caring for children, including details about each method, placement technique, indication, and complications.
- Mosier JM, Hiller K, Franke H, Degan J, Boyer LV. Scorpion antivenom administered via alternative infusions. *J Med Toxicol* 2010;6:249** 799
- A case study describing administration of scorpion antivenom via intraosseous (IO) vascular access in a 16-month old female. Following failure to obtain IV access in pre-hospital and upon arrival at the ED, IO vascular access was established in the proximal tibia and 3 vials of antivenom in 50 mL saline were administered over 10 minutes. Within 5 minutes, the patients respiratory status improved, intubation was averted, and vital signs stabilized immediately; nystagmus and writhing resolved. The patient was discharged home after a short observation period. The authors concluded that when IV access is difficult, IO access may be a rapid and reasonable rescue maneuver for patients requiring scorpion antivenom.
- Navarro K. Intraosseous infusion. *Texas EMS Magazine* 2010;Nov/Dec:34-9** 447
- This article provides a brief history of IO infusion and further discusses this vascular access technique in terms of anatomy and physiology, indications and contraindications, performing the manual procedure, and possible complications. A case study is discussed in which a 7-month-old male was treated under emergency circumstances with IO infusion in the lower limb and developed compartment syndrome, resulting in a below the knee amputation.
- Neuhaus D, Weiss M, Engelhardt T, et al. Semi-elective intraosseous infusion after failed intravenous access in pediatric anesthesia. *Pediatr Anesth* 2010;20(2):168-71. doi: 10.1111/j.1460-9592.2009.03244.x** 425
- Authors report an observational study of 14 children in whom semi-elective IO infusion was performed under anesthesia after peripheral IV had failed. IO infusion was successful for all 14 patients, using the EZ-IO system for 8 patients and the Cook system for 6 patients.
- Shah MI. Prehospital management of pediatric trauma. *Clin Pediatr Emerg Med* 2010;11(1):10-7** 626
- This article provides an overview of pediatric trauma care in the pre-hospital setting by using a literature review to evaluate the risks and benefits of various aspects of care. Topics discussed include: pre-hospital care time, pre-hospital triage and transport, airway management, intravenous (IV) and intraosseous (IO) vascular access and infusions, cervical spine immobilization, traumatic brain injury, and pain assessment and management.
- Vegunta RK. Chapter 8-Vascular access. *Ashcraft's Pediatric Surgery* 2010;5th ed:110-6** 681
- This document discusses various vascular access methods available for pediatric and neonate patients, including intraosseous access.

Intraosseous Vascular Access Bibliography

Pediatric

YEAR: 2009

- Aguilar T. Intraosseous infusion: an age-old therapy on a new frontier. Nurs Manage 2009;40(12):34-5** 441
Article for nursing audience.
- Baker TW, King W, Soto W, Asher C, Stolfi A, Rowin ME. The efficacy of pediatric advanced life support training in emergency medical service providers. Pediatr Emerg Care 2009;25:508-12** 428
Assessment of PALS training on EMS personnel. PALS-trained personnel had 100% success rate in IO placement (55% non-trained).
- Fortin JL, Capellier G, Manzon C, Giocanti J, Gall O. Intraosseous administration of hydroxocobalamin in the acute treatment of cyanide poisoning. Burns 2009;35(S1):S15-6. doi: 10.1016/j.burns.2009.06.061. France** 801
Case study of a 9- month old treated with IO hydroxocobalamin for suspected smoke inhalation cyanide poisoning. The patient was discharged from the ICU without neurological sequelae. Authors stated the IO route for hydroxocobalamin warrants further exploration to improve ease and speed of treatment.
- Frascone RJ, Jensen J, Wewerka SS, Salzman JG. Use of the pediatric EZ-IO needle by emergency medical services providers. Pediatr Emerg Care 2009;25:329-32** 424
Prospective study of 246 EMS providers at 14 EMS agencies. Reports successful IO placement in 95% of cases (18 of 19).
- Johr M. Das kind mit schwierigen venen [The child with difficult venous access]. Anaesthesist 2009;58:861-2. https://doi.org/10.1007/s00101-009-1609-x. German** 433
This is a letter to the editor, written in German, that states that intraosseous access supplies should be available in every pediatric care setting. It also stresses the need for proper training and experience in order to use the IO devices safely and effectively.
- Sunde GA, Thoresen A, Heltne J-K. [Intraossøs tilgang på kritisk syke pasienter - gammel teknikk får ny heder, eller kun for spesielt interessert]? NAForum 2009;22(1):33-7. German** 407
This article, in German, describes the technique of IO access, the introduction of two different IO devices (Cook and EZ-IO) and describes IO use in pediatric emergency care.
- Tsung HW, Blaivas M, Stone MB. Feasibility of point-of-care colour Doppler ultrasound confirmation of intraosseous needle placement during resuscitation. Resuscitation 2009;80:665-8** 425
Color Doppler ultrasound revealed extraosseous flow in incorrectly placed IO insertions. Recommends point-of-care Doppler machine to verify placement.
- Weiss M, Henze G, Eich C, Neuhaus D. Intraossare infusion: Eine wichtige technik auch für die kideranästhesie [Intraosseous infusion: an important technique also for paediatric anaesthesia]. Anaesthesist 2009;58(9):863-75.doi. 10.1007/s00101-009-1605-1 German** 434
Discusses use of IO for pediatric anesthesia. Specifies importance of equipment, education, guidelines.
- YEAR: 2008**
- Alawi KA, Morrison GC, Fraser DD, Al-Farsi S, Collier C, Kornecki A. Insulin infusion via an intraosseous needle in diabetic ketoacidosis. Anaesth Intensive Care 2008;36:110-2** 408
Case report of resuscitation and insulin infusion in a 5-year old child with severe diabetic ketoacidosis.
- Bosomworth NJ. The occasional intraosseous infusion. Can J of Rural Med 2008; 13: 80-3** 369
Overview of intraosseous vascular access in infants; includes indications, contraindications, complications, equipment (Sur-Fast and Jamshidi), and procedure. Also, small section on IO for adults; describes the FAST-1, Bone Injection Gun, and EZ-IO.
- de Caen AR, Reis A, Bhutta A. Vascular access and drug therapy in pediatric resuscitation. Pediatr Clin N Am 2008;55:909-27** 363
Describes common drugs used in pediatric resuscitation and evidence supporting their use. Also describes routes of administration including intravenous, intraosseous, and intratracheal. Describes IO systems including Bone Injection Gun, FAST-1, and EZ-IO.
- Gayatri J, Tobias JD T. The use of intraosseous infusions in the operating room. J Clin Anesth 2008;20:469-73** 979
This article presents a case study of an IO infusion during the anesthetic care of an infant with cyanotic congenital heart disease (CHD). The article also discusses the role of the IO route in perioperative care and reviews the adverse effect profile.

Intraosseous Vascular Access Bibliography

Pediatric

- Giasi W Jr. Do not waste time trying to get an intravenous (IV) line on an infant in shock when an intraosseous (IO) line will do just as well. In: Slonim AD. Avoiding Common Pediatric Errors. Philadelphia, PA: Lippincott Williams & Wilkins; 2008. ISBN: 0-7817-7489-6, 978-0-7817-7489-5** 1053
- Horton MA, Beamer C. Powered intraosseous insertion provides safe and effective vascular access for pediatric emergency patients. *Pediatr Emerg Care* 2008;24(6):347-50** 381
- A retrospective clinical study was conducted to demonstrate the safety and effectiveness of the EZ-IO intraosseous access device for pediatric patients. For the 95 eligible patients in the study, successful insertion and infusion was achieved in 94% of the patients. Insertion time was 10 seconds or less in 77% of the one-attempt successful cases reporting time to insertion. There were 4 minor complications (4%), but none significant. The results of this study support the use of the EZ-IO for children in emergency situations. The complication rate suggests that the powered IO device is safe and effective for the resuscitation and stabilization of pediatric patients. This study was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.
- Moen TC, Sarwark JF. Compartment syndrome following intraosseous infusion. *Orthopedics* 2008; 31: 815** 411
- Case report of compartment syndrome in a 6-year old girl after IO infusion during cardiac arrest.
- Pfister CA, Egger L, Wirthmoller B, Grief R. Structured training in intraosseous infusion to improve potentially life saving skills in pediatric emergencies: results of an open prospective national quality development project over 3 years. *Paediatr Anaesth* 2008;26:31-8** 409
- Three-year study of IO training and use in 28 hospital and ambulance services in Switzerland. Standardized training improved IO success rate to 100%.
- Abstract only*
- Sixou JL, Barbosa-Rogier ME. Efficacy of intraosseous injections of anesthetic in children and adolescents. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2008; 106:173-8** 447
- Case series of IO anesthesia in 181 children and adolescents. Success rates ranged from 88% to 95%, depending on tooth type.
- van Rijn RR, Knoester H, Maes A, van der Wal AC, Kubat B. Cerebral arterial air embolism in a child after intraosseous infusion. *Emerg Radiol* 2008;15:259-62. doi:10.1007/s10140-007-0681-2** 410
- In this case study a 7-month-old female with comorbidities was taken to the ED in cardiopulmonary arrest. IO access was the only vascular access method available for resuscitation. Post mortem CT of the head showed a considerable amount of air within the arterial circulation; the cause of death was listed as undetermined. The authors conclude that considering the details of the patient, the only logical explanation for the cerebral arterial air embolism is that air was introduced into the bloodstream via the IO route.
- Woosley CR, Mayes TC. The pediatric patient and thoracic trauma. *Thor Cardiovasc Surg* 2008;20:58-63** 399
- This article describes thoracic trauma in the pediatric population. Includes a review of the assessment of pediatric patients. Circulation section of the article strongly recommends rapid intravascular volume expansion by the intraosseous route, and recommends the EZ-IO for "...quick and reliable vascular access during resuscitation ...".
- YEAR: 2007**
- Beamer CL, Horton M. Powered needle insertion provides safe and effective vascular access for pediatric emergency patients. *Ann Emerg Med* 2007;50(3):S40** 395
- This abstract for a presentation at the 2007 American College of Emergency Physicians Research Forum describes an observational study in which the EZ-IO was used to provide emergency vascular access for 95 pediatric patients. Successful insertion and infusion was achieved in 94% of the patients, and insertion time was within 10 seconds for 81% of the placements. There were four minor and no serious complications.
- Buck ML, Wiggins BS, Sesler JM. Intraosseous drug administration in children and adults during cardiopulmonary resuscitation. *Ann Pharmacother* 2007;41:1679-86** 374
- This article reviews and assesses the literature on the use of IO drug administration during cardiopulmonary resuscitation. It addresses the risks and benefits of using IO in adults and children. The article describes the FDA-cleared devices available for use including the Pyng F.A.S.T.1, Waismed Bone Injection Gun and the Vidacare EZ-IO.
- Cooper BR, Mahoney PF, Hodgetts TJ, Mellor A. Intra-osseous access (EZ-IO®) for resuscitation: UK military combat experience. *J R Army Med Corps* 2007;153(4):314-6** 379
- Describes the experience of the UK Defence Medical Service using the EZ-IO for emergency vascular access in Afghanistan. They used the device for 26 patients, including 10 children. Of the 26 EZ-IO placements, 23 were made in the emergency department. There was a 97% insertion success rate with no infection. Significant infusion pain was felt by three patients.

Intraosseous Vascular Access Bibliography

Pediatric

de Caen A. Venous access in the critically ill child. *Pediatr Emerg Care* 2007;23:422-4 372

This review article states the availability of intraosseous (IO) needles for pediatric patients, outlines the limitations of traditional venous access, and discusses the various IO devices currently available, including the Vidacare EZ-IO®.

DeBoer S, Andrews D. Infant venous access: 'Counting fingers' and 'playing baseball'. *Australasian Emerg Nurs J* 2007; 10: 46-51 356

This article summarized the challenges and methods of providing vascular access for infants. It describes IO techniques and devices, including the Jamshidi, Cook, EZ-IO® and Bone Injection Gun (BIG) devices.

Hillewig E, Aghayev E, Jackowski C, Christe A, Plattner T, Thali MJ. Gas embolism following intraosseous medication application proven by post-mortem multislice computed tomography and autopsy. *Resuscitation* 2007;72:149-53 530

This case study describes a 4-month-old boy that was found unresponsive. Resuscitation was started and continued through arrival to the ED; IO access at the proximal tibia was established using a 15 gauge aspiration needle as the only vascular access. Post mortem multislice CT examination showed gas in the hepatic veins, the right atrium, right ventricle, the upper pole of the right kidney and the cerebral vessels. Though air embolism was ruled out as the cause this death, it could have caused death in another case. The authors conclude that gas may have entered the body during resuscitation due to IO needle disconnections and that resuscitation with an inserted, disconnected IO needle should be avoided.

Myers BJ, Lewis R. Induced cooling by EMS (ICE): year one in Raleigh/Wake County. *JEMS* 2007;32:s13-5 398

This article describes the experience of the Wake County (NC) EMS System in inducing hypothermia for patients with return of spontaneous circulation after cardiac arrest. Authors describe their use of the Vidacare EZ-IO (now Arrow® EZ-IO Intraosseous Vascular Access System) for the administration of chilled saline. In this report 56% of vascular access cooling was done utilizing the IO device and an additional 18 % utilized a combination of IO and IV induced cooling. The overall EZ-IO use in this program for all insertions were 414 with an insertion success rate of 94%.

YEAR: 2006

Buck ML. Intraosseous administration of drugs in infants and children. *Pediatr Pharm* 2006;12(12) 367

Overview article of IO vascular access describes technique, efficacy in medication delivery, utility in pediatric emergencies, use in neonates, complications, and commonly-infused medications.

Cataldi E, McGinni-Hainsworth D, Megargel R, Bollinger M, O'Connor R. A comparison of intraosseous and intravenous access in adults and children in the prehospital setting. *Prehosp Emerg Care* 2006;10(1):124 633

An abstract describing a prehospital study comparing peripheral IV to tibial IO access for placement success, time to access and time to drug delivery. The authors concluded that using IO access on the first attempt results in faster drug administration than if IO access were used as a rescue line after failed IV.

Engle WA. Intraosseous access for administration of medications in neonates. *Clin Perinatol* 2006;33(1):161-8 662

An overview of IO vascular access use in neonates, including focus on available evidence, history, technique, physiology, clinical indications, complications, and contraindications. The author closes acknowledging IO administration of resuscitation medications and fluids in neonates is an alternative when IV access is not possible.

La May G, Friese G. Pediatric fluid resuscitation and airway management - a primer on volume replacement in pediatric patients. *EMS* 2006;May:65-72 636

An overview of managing pediatric fluid resuscitation and airway management in the pre-hospital setting.

Tomar S, Gupta BA. Resuscitation by intraosseous infusion in newborn. *MJAFI* 2006;62(2):202-3 393

Two case studies of neonates that successfully received IO infusion.

YEAR: 2005

Fiorito BA, Mirza F, Doran TM, et al. Intraosseous access in the setting of pediatric critical care transport. *Ann Emerg Med* 2005;46(5):475-6. doi:10.1016/j.annemergmed.2005.09.011 858

This abstract describes a retrospective study evaluating use of IO access during pediatric critical care transport. From January 1, 2000 to March 31, 2002, 1,792 transports were performed and 47 patients received 58 IO catheter insertions. Insertion took a mean 1.2 attempts for placement and first attempt success was 78%. Most frequently accessed site as the proximal humerus (95%) and access was maintained for a mean 5.2 hours. The authors concluded EMT/paramedics, emergency physicians, and pediatric critical care transport teams should be familiar with IO placement.

Intraosseous Vascular Access Bibliography

Pediatric

- Fiorito BA, Mirza F, Doran TM, Oberle AN, Cruz EC, Wendtland CL, Abd-Allah SA. Intraosseous access in the setting of pediatric critical care transport. *Pediatr Crit Care Med* 2005;6(1):50-3** 344
Retrospective chart review demonstrating safe and effective IO placement on pediatric patients by EMT-Ps, ED physicians, and members of the transport team in the pediatric critical care transport environment.
- Helm M, Gries A, Fischer S, Hauke J, Lampl L. Invasive techniques in emergency medicine. III. Intraosseous puncture--an alternative vascular access in paediatric emergencies. *Anaesthesist* 2005;54(1):49-56** 330
Review article on IO vascular access in the pediatric patient. Advises that it is not necessary to adjust doses from IV doses, except for hypertonic solutions. Recommends that IO needle be replaced by an IV within 2 hours to avoid complications.
Abstract only. Article in German
- Ritz J. [Vascular access in emergency paediatric anaesthesia]. *Anaesthesist* 2005;54(1):8-16. German** 336
Case studies in 2 children reviewed by 89 members of the Swiss Pediatric Anesthesia and heads of Anesthesia Departments of Swiss Teaching hospitals, IO was determined to be the safest method of vascular access on 1 of the cases.
Abstract only
- Rodriguez Nunez A, Garcia C, Lopez-Herce Cid J; Grupo de Estudio de la Parada Cardiorrespiratoria en Pediatria. [Is high-dose epinephrine justified in cardiorespiratory arrest in children?]. *An Pediatr (Barc)* 2005;62(2):113-6. Spanish** 343
Multicenter, prospective study of cardiopulmonary resuscitation data over 18 months. The study was design to evaluate the impact of survival of IV or IO high-dose epinephrine compared to standard doses in children with cardiorespiratory arrest. Limited conclusions showed that there is no significant difference between the two treatments.
- Smith R, Davis N, Bouamra O, Lecky F. The utilisation of intraosseous infusion in the resuscitation of paediatric major trauma patients. *Injury* 2005;36(9):1034-8** 341
Retrospective study over a 14-year period examining 129 IO insertions among 23,489 pediatric trauma patients. Patients receiving IO fluids and medications tended to be younger and sicker. Concludes that IO is an essential skill for anyone involved in pediatric trauma resuscitation.
- YEAR: 2004**
- Dogan A, Irmak H, Harman M, Ceylan A, Akpinar F, Tosun N. Tibial osteomyelitis following intraosseous infusion: a case report. *Acta Orthop Traumatol Turc* 2004; 38:357-60** 324
Case report of acute osteomyelitis developing 10 days alter IO infusion in a 5-month-old infant admitted for sepsis.
- Eslami. Intraosseous access. <http://www.emedicine.com/ped/topic3053.htm> Last updated October 22, 2004** 320
Web publication discussing the indications, contraindications, insertion sites and complications of IO access.
- Haas NA. Clinical review: vascular access for fluid infusion in children. *Crit Care* 2004;8(6):478-84.doi:10.1186/cc2880** 323
Review article describing how IO has replaced saphenous venous cutdowns in pediatric emergencies and decreased need for immediate central venous access.
- Korszun T, Raio CC, Theodoro D, et al. Can emergency physicians utilize ultrasonography to accurately confirm intraosseous needle placement? *Ann Emerg Med* 2004;44(4):S84** 432
This abstract evaluated the use of ultrasonography to confirm proper IO placement versus improper placement using chicken bone. Results showed 6 participants were able to confirm placement with 100% sensitivity and 94% specificity, suggesting use of ultrasonography in pediatric patients may be beneficial to confirm IO placement.
- Saglam M, Ugurel S, Kilciler M, et al. [Intraosseous urography compared with intravenous urography: An experimental study in the rabbit model]. *Turk J Vet Anim Sci* 2004; 28: 933-42. Turkish** 384
Evaluation of the Bone Injection Gun (BIG) for the administration of contrast media for urography. Concludes that BIG-assisted intraosseous urography may be an effective and reliable alternative to intravenous urography in pediatric and adult human patients.

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Pediatric

YEAR: 2003

Boon JM, Gorry DL, Meiring JH. Finding an ideal site for intraosseous infusion of the tibia: an anatomical study. Clin Anat 2003;16(1):15-8 300

Investigation of the relationship between insertion site for the IO needle, epiphyseal growth plate and ease of needle insertion into the various locations of the tibia in newborn infants. Recommends that needle be placed 10 mm distal to the tibial tuberosity to avoid the epiphyseal growth plate and ensure ease of insertion.

Bowley DM, Loveland J, Pitcher GJ. Tibial fracture as a complication of intraosseous infusion during pediatric resuscitation. J Trauma 2003; 55: 786-7 298

Case report of IO infusion complicated by iatrogenic fracture at the IO insertion site. Concludes that multiple attempts to achieve IO access weakened the bone cortex and that "considerable force" applied by an anxious 100-kg emergency room doctor led to the fracture.

Claudet I, Baunin C, Laporte-Turpin E, Marcoux MO, Grouteau E, Cahuzac JP. Long-term effects on tibial growth after intraosseous infusion: a prospective, radiographic analysis. Pediatr Emerg Care 2003;19(6):397-401 313

Prospective radiographic study of 23 children who had received intraosseous infusion via trocar. Found no long-term effect on tibial growth with properly placed trocar.

Gluckman, W, Forti RJ. Intraosseous cannulation. www.emedicine.com/ped/topic2557.htm Last Updated: Jan 14, 2003 301

Web article discusses IO cannulation procedure insertion sites, pathophysiology, risks, contraindications and complications.

Lake W, Emmerson AJB. Use of a butterfly as an intraosseous needle in an oedematous preterm infant. Arch Dis Child Fetal Neonatal Ed 2003;88(5):F409 307

An 18 gauge butterfly needle was inserted into the proximal tibia of a premature infant born at 25-weeks gestation, following inability to establish other modes of vascular access due to gross oedema. The intraosseous line was left in place for 6 days until it was lost; there were no adverse events reported however the author noted that no safety data on long term use of the device was collected.

LaRocco BG, Wang HE. Intraosseous infusion. Prehosp Emerg Care 2003;7:280-5 309

A comprehensive and accessible review of the history, anatomy, technique, and clinical application of intraosseous infusion.

Launay F, Paut O, Katchburian M, Bourelle S, Jouve JL, Bollini G. Leg amputation after intraosseous infusion in a 7-month-old infant: a case report. J Trauma 2003; 55(4):788-90 306

Case report of a 7-month-old infant who developed severe compartment syndrome associated with popliteal arterial thrombosis following IO fluid infusion resulting in limb amputation.

Ota FS, Yee LL, Garcia FJ, Grisham JE, Yamamoto LG. Which IO model best simulates the real thing? Pediatr Emerg Care 2003;19(6):393-6 311

Evaluation of IO models by 40 emergency and critical care physicians. Chicken, turkey bones and plastic IO models received similar scores, pork rib was rated poorly. Emphasizes that bone models should be age appropriate to the expected patient population when using for IO research and training purposes.

YEAR: 2002

Harty MP, Kao SC. Intraosseous vascular access defect: fracture mimic in the skeletal survey for child abuse. Pediatr Radiol 2002;32(3):188-90 294

Case report emphasizing that a cortical lesion in the proximal tibia corresponding to the site of IO insertion should not be mistaken for a radiographic sign of child abuse.

Stoll E, Golej J, Burda G, Hermon M, Boigner H, Trittenwein G. Osteomyelitis at the injection site of adrenalin through an intraosseous needle in a 3-month-old infant. Resuscitation 2002;53(3):315-8 287

Case report of a 3-month-old infant developing osteomyelitis after IO administration of high-dose epinephrine. Speculates that administration of adrenalin in high concentrations may promote the development of osteomyelitis.

YEAR: 2001

Byrick RJ. Pulmonary fat embolism and intraosseous infusion. Pediatr Crit Care Med 2001;2(2):184-5 282

Review advocating that pathological evidence of a few pulmonary fat emboli should not deter clinicians from using IO because of the many advantages of the technique.

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- Caldwell J, Ziglar M. Hemorrhagic shock in children: Understanding the underlying mechanisms of shock syndrome. *Am J Nurs* 2001;101(Supplement):25-7** 964
This article gives an overview for nurses of the treatment of shock in children. Intraosseous administration of fluids is a means of resuscitation.
- Carley S, Boyd R. Towards evidence based emergency medicine: best BETS from the Manchester Royal Infirmary. *Standard bone marrow needles or special needles for intraosseous access. Emerg Med J* 2001;18(3):211. doi:10.1136/emj.18.3.211** 610
Results of a literature search to determine if a standard bone marrow needle can be used to establish IO access in a pediatric patient. Results showed only one article addressing the issue that indicated standard bone marrow aspiration needles can be used for IO infusion.
- Hancock SW, Knight G. Intraosseous needles: an essential emergency adjunct in paediatric anaesthesia. *Paediatr Anaesth* 2001;11(4):505-6** 284
Review of the use of IO in anesthesiology. Advocates that IO needles be available in all clinical areas where IV access is required.
- Hasan MY, Kissoon N, Khan TM, Saldajeno V, Goldstein J, Murphy SP. Intraosseous infusion and pulmonary fat embolism. *Pediatr Crit Care Med* 2001;2(2):133-8** 278
Article implying that the risk of fat emboli is common with IO, but its clinical relevance is unclear.
- Orgiler Uranga PE, Navarro Arnedo JM, De Haro Marin S. [The intraosseal route. When the veins have disappeared]. *Enferm Intensiva* 2001;12(1):31-40. Spanish** 275
Literature review on intraosseous administration of drugs during pediatric emergencies. Concludes that IO is a valid alternative route for infusion of drugs and other substances into the blood stream with a low complication rate.
- YEAR: 2000**
- Abe KK, Blum GT, Yamamoto LG. Intraosseous is faster and easier than umbilical venous catheterization in newborn emergency vascular access models. *Am J Emerg Med* 2000;18(2):126-9** 256
Study comparing practitioner experience with IO and umbilical vein catheterization with 42 medical students inexperienced in both techniques. IO was twice as fast as umbilical vein catheterization. Concludes that IO provides easy and rapid vascular access for clinicians who do not regularly perform newborn resuscitation.
- Day MW. Using intraosseous access in children. *Nursing* 2000;30(1):68** 253
Nursing article discussing the role of IO infusion when peripheral veins are collapsed. Describes advantages of IO, including ready availability, ability to establish vascular access without interrupting CPR.
- Fisher R, Prosser D. Intraosseous access in infant resuscitation. *Arch Dis Child* 2000;83:87** 252
Laboratory study comparing flow rates through different IV cannulas with an 18 G IO cannula. Found that fluids could be infused more quickly with the IO cannula. Speculates that the bone marrow cavity of an infant has more capacitance than a peripheral vein.
- Khan TM, Kissoon N, Hasan MY, Saldajeno V, Murphy SP, Lima JJ. Comparison of plasma levels and pharmacodynamics after intraosseous and intravenous administration of fosphenytoin and phenytoin in piglets. *Pediatr Crit Care Med* 2000;1(1):60-4** 257
Pharmacokinetic study in piglets comparing IO and IV administration of fosphenytoin and phenytoin. Therapeutic plasma levels were achieved with both administration routes for both drugs. Concludes no need to adjust the standard drug doses of phenytoin for IO administration. Cautions slow infusion rates for fosphenytoin due to concerns over neurotoxicity.
- Mattera CJ. Take aim--hit your IO target. A comprehensive approach to pediatric intraosseous infusion, including site selection, needle insertion & ongoing assessment. Part 2. *JEMS* 2000;25(4):38-48** 264
Overview of pediatric IO infusion targeted for an EMS/paramedic audience. Discusses anatomy of long bones, indications, advantages, contraindications, steps for insertion, fluid administration and ongoing assessment and documentation.
- McCarthy G, Buss P. Does intraosseous have to mean intramedullary? *J Accid Emerg Med* 2000; 17: 432** 267
Case report of a 3-year-old collapsed child successfully resuscitated with the use of an intraosseous needle placed in the calcaneum. Includes detailed description of needle insertion technique.

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Pediatric

- Nijssen-Jordan C. Emergency department utilization and success rates for intraosseous infusion in pediatric resuscitations. Canadian J Emerg Med 2000;2(1):10-4** 679
- A retrospective chart review that evaluated use of IO access in pediatric patient resuscitation in a tertiary emergency department between 1989 and 1995. Results showed IO access was successfully established in 86% of patients. Median time to placement was 8 minutes; two complications of bone fracture were reported in one 10-day-old neonate patient.
- Canada
- Vreede E, Bulatovic A, Rosseel P, Lassalle X. Intraosseous infusion. Update in Anesthesia 2000;12 (Article 10):1. <http://rcpals.com/downloads/2007files/may/pals/IntraosseousInfusion.html>** 263
- Brief overview of IO infusion for an anesthesiology audience. Discusses technique, indications, contraindications, equipment, anatomical target sites and potential complications.
- YEAR: 1999**
- Bohn D. Intraosseous vascular access: from the archives to the ABC. Crit Care Med 1999; 27: 1053-4** 243
- Brief review of IO history, flow rates, fluids and medications.
- Claudet I, Alberge C, Bloom MC, Fries F, Lelong-Tissier MC. [Intraosseous infusion in children]. Ann Fr Anesth Reanim 1999;18:313-8. French** 239
- A retrospective non-comparative study of IO infusion in 41 children. Concludes that IO insertion is an easy technique. Recommends IO for emergency cases when other vascular access techniques have failed in the first 5 minutes of treatment.
- Abstract
- Claudet I, Fries F, Bloom MC, Lelong-Tissier MC. [Retrospective study of 32 cases of intraosseous perfusion]. Arch Pediatr 1999; 6: 516-9. French** 238
- Retrospective study of 32 cases of IO infusion over a 3 year period. Concludes that IO is rapid, safe and effective and provides an essential alternative vascular route in pediatric resuscitation.
- Abstract
- Daga SR, Gosavi DV, Verma B. Intraosseous access using butterfly needle. Trop Doct 1999;29(3):142-4** 236
- Evaluation of the utility of 18-gauge butterfly needles for IO administration of fluids and drugs in 23 children presenting in shock. 22 of 23 children were successfully stabilized after IO infusion.
- Abstract
- DeBoer S, Zeglin D. Pediatric rapid sequence intubation: Intraosseous style. Air Medical Journal 1999;5(5):11-2** 565
- This article discusses the basic steps of performing rapid sequence intubation in children with a referenced case study and literature review. The authors stated that based upon the evidence, when emergency intubation is needed, IO access can be an acceptable route for RSI in the absence of peripheral venous access.
- Ellemunter H, Simma B, Trawoger R, Maurer H. Intraosseous lines in preterm and full term neonates. Arch Dis Child Fetal Neonatal Ed 1999; 80: F74-5** 241
- Observational study in 27 newborns, describing 30 intraosseous lines placed after failed IV access. Reports that all patients survived the resuscitation procedures with no long-term side effects.
- Feillet F, Borsa A, Monin P. [Intraosseous approach, yes but...]. Arch Pediatr. 1999; 6: 1349-50. French** 232
- No abstract available.
- Geller E, Crisci KL. Intraosseous infusion of iodinated contrast in an abused child. Pediatr Emerg Care 1999;15(5):328-9** 247
- This case study described administration of iodinated contrast via IO infusion in the tibia, for an abdominal CT scan in a 7 week old infant. CT imaging demonstrated adequate enhancement of the solid organs and vasculature.
- Herman MI, Chyka PA, Butler AY, Rieger SE. Methylene blue by intraosseous infusion for methemoglobinemia. Ann Emerg Med 1999;33(1):111-3** 244
- Case report of a 6-week-old female infant with methemoglobinemia successfully treated with IO Methylene blue when other venous access was not feasible.

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Pediatric

YEAR: 1998

Halm B, Yamamoto LG. Comparing ease of intraosseous needle placement: Jamshidi versus Cook. Am J Emerg Med 1998; 16: 420-1 228

Study comparing placement of Cook and Jamshidi IO needles in turkey bones.

McCarthy G, Buss P. The calcaneum as a site for intraosseous infusion. J Accid Emerg Med 1998;15:421.doi:10.1136/emj.15.6.421 445

A 3-year old male presented at the emergency department with rapidly progressing circulatory collapse clinically aligned with meningococcal septicemia. Attempts at peripheral and central venous access were unsuccessful. Attempts at tibial IO insertion were unsuccessful with a number of needles bending when cortical penetration was attempted. IO insertion was successfully achieved at the medial aspect of the calcaneum. IO infusion was continued for 6 hours and removed when no longer needed. The patient fully recovered and the calcaneal site healed without complication.

Nasimi A, Gorin P, Berthier M, Boussebart T, Follet-Bouhamed C, Oriot D. [Use of the intraosseous route in a premature infant]. Arch Pediatr 1998; 5: 414-7. French 231

Case report of a 34-week-old pre-term neonate with septic shock requiring emergency treatment. Umbilical vein was unusable. Resuscitation with IO access was successful. Concludes that IO access be used before attempting access with superior longitudinal sinus.
Abstract

Ramet J, Clybouw C, Benatar A, Hachimi-Idrissi S, Corne L. Successful use of an intraosseous infusion in an 800 grams preterm infant. Eur J Emerg Med 1998; 5: 327-8 229

Case report of successful use of an IO access line in an 800 gm pre-term infant.

Stovroff M, Teague WG. Intravenous access in infants and children. Pediatr Clin North Am 1998;45:1373-93 227

Review article discussing techniques for venous access in the pediatric patient includes anatomical target sites, clinical indications, advantages and disadvantages.

Review

YEAR: 1997

Cambray EJ, Donaldson JS, Shore RM. Intraosseous contrast infusion: efficacy and associated findings. Pediatr Radiol 1997;27:892-3 222

Pediatric article detailing use of an IO line for bolus infusion of nonionic contrast material for CT contrast enhancement; a radiographic band may occur as a result of retained contrast material within the marrow.

Manley L. Pediatric hypovolemia: back to the basics. Int J Trauma Nurs 1997; 3:93-8 220

Review article for trauma nursing audience describing advances in trauma care.

Nafiu OO, Olumese PE, Gbadegesin RA, Osinusi K. Intraosseous infusion in an emergency situation: a case report. Ann Trop Paediatr 1997;17(2):175-7. Abstract 394

Case report of an 18-month-old boy with cardiopulmonary arrest secondary to penicillin anaphylaxis successfully resuscitated by IO administration of emergency medications.

Seigler RS. Intraosseous infusion performed in the prehospital setting: South Carolina's six-year experience. J S C Med Assoc 1997;93:209-15 217

Clinical study finding that prehospital IO did not improve outcome in pediatric patients with cardiac arrest. Cautions that the sample size was too small to reach a statistically significant conclusion.

Abstract only

YEAR: 1996

Friedman FD. Intraosseous adenosine for the termination of supraventricular tachycardia in an infant. Ann Emerg Med 1996;28(3):356-8 211

Case report of successful resolution of supraventricular tachycardia in an infant following IO administration of adenosine.

Garcia CT, Cohen DM. Intraosseous needle: use of the miniature C-arm imaging device to confirm placement. Pediatr Emerg Care 1996;12:94-7 210

Describes a miniature C-arm imaging device to accurately confirm proper needle placement in intraosseous infusions.

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Pediatric

- Gunal I, Kose N, Gurer D. Compartment syndrome after intraosseous infusion: an experimental study in dogs. J Pediatr Surg 1996;31(11):1491-3** 208
Preclinical study finding no compartment syndrome with up to 350 ml of IO fluid infusion; however, radio-opaque dye was detected in the soft tissues with compartment pressures increasing to more than 35 mmHg. Calls for a dose and time independent scale for safe intraosseous infusion.
- Moller JC, Tegtmeier FK, Schaible TF, Sussmane JB. [Intraosseous puncture as vascular access in pediatric emergency and intensive care medicine]. Anaesthesiol Reanim 1996;21(4):103-7. German. Abstract** 209
Article describing IO infusion 18 pediatric resuscitative situations. Authors conclude that 11 patients would not have survived without IO access. Complications included a minor fracture, 1 case of compartment syndrome that did not require surgical intervention and a minor fat embolism that was of no clinical significance.
- YEAR: 1995**
- Carbajal R, Paupe A, Lenclen R, Blanc P, Olivier-Martin M, Simon N. [Intraosseous infusion in children]. Arch Pediatr 1995;2:339-42. French** 191
Case report of successful IO administration colloid, human albumin, and 1.4% sodium bicarbonate via the left hip of a 5-month-old infant with profound hypovolemia. Patient was discharged 4 days after admission.
Abstract only
- Erb T, Hampl KF, Frei FJ. An unusual complication of intra-osseous infusion during paediatric resuscitation. Anaesthesia 1995;50(5):471** 192
Case report describing extravasation of fluids through a previous IO puncture site in the same tibia.
- Evans RJ, Jewkes F, Owen G, McCabe M, Palmer D. Intraosseous infusion--a technique available for intravascular administration of drugs and fluids in the child with burns. Burns 1995; 21: 552-3** 193
Case report finding IO a viable method of venous access in a child with burns.
- Hurren JS, Dunn KW. Intraosseous infusion for burns resuscitation. Burns 1995; 21; 285-7. Review** 194
Describes 2 cases of resuscitation of a scalded child by IO infusion following failed IV attempts. Reviews IO techniques.
- Moller JC, Reiss I, Schaible T. Vascular access in neonates and infants--indications, routes, techniques and devices, complications. Intensive Care World 1995;12(2):48-53** 197
Suggests that intraosseous infusion is reliable alternative to peripheral vein access for rapid infusion of fluids in neonates and infants when venous access is impossible.
Abstract only
- Plewa MC, King RW, Fenn-Buderer N, Gretzinger K, Renuart D, Cruz R. Hematologic safety of intraosseous blood transfusion in a swine model of pediatric hemorrhagic hypovolemia. Acad Emerg Med 1995;2(9):799-809** 205
Preclinical study examining hematologic parameters (hemoglobin, schistocytes, free hemoglobin in plasma, bilirubin, lactate dehydrogenase, platelets, fibrinogen, and alveolar-arteriolar O2 gradient) with IO and IV autologous blood transfusions. Found that all hematologic parameters remained within normal limits in both IO and IV groups. Concludes IO blood transfusions to be hematologically safe, i.e. without risk of appreciable hemolysis, DIC or fat embolism syndrome.
- Rodriguez-Munez A, Martinez-Soto I, Martinon JM. Elective use of intra-osseous infusions in paediatrics. Eur J Pediatr 1995; 154: 755** 202
Case report of IO access in a non-emergency situation. A blood transfusion was performed with no complications in a severely anemic 1-month old infant with an 18 G IO needle (Cook).
- Strausbaugh SD, Manley LK, Hickey RW, Dietrich AM. Circumferential pressure as a rapid method to assess intraosseous needle placement. Pediatr Emerg Care 1995;11:274-6** 196
Preclinical study in dog tibias demonstrating that circumferential pressure about an IO infusion site is a rapid method to detect incorrect placement of the IO needle.

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Pediatric

YEAR: 1994

- Alba RM, Ruiz Lopez MJ, Flores JC. Use of the intraosseous route in resuscitation in a neonate. *Intensive Care Med* 1994; 20: 529-33** 170
Case report of resuscitation of a 10-day-old female infant with 2 IO infusion sites. Patient received 240 ml fluids, epinephrine, dopamine, sodium bicarbonate, human albumin, packed red cells, fresh frozen plasma, glucose, ampicillin, gentamicin, vitamin K, and pancuronium.
- Anderson TE, Arthur K, Kleinman M, Drawbaugh R, Eitel DR, Ogden CS, Baker D. Intraosseous infusion: success of a standardized regional training program for prehospital advanced life support providers. *Ann Emerg Med* 1994;23(1):52-5** 165
Study of IO training for advanced life support providers. Providers were able to establish IO access in 13 of 15 (87%) of pediatric patients (age range 1-24 months) following completion of an 1-hour training course and supervised hands-on simulation. All procedures were performed in less than 10 minutes.
- Bachmann DC. [Heart arrest: septic and hypovolemic shock--intraosseous infusion technique]. *Ther Umsch* 1994;51(9):593-7. German** 189
Describes causes and treatment of hypovolemic and septic shock. Discusses techniques for intraosseous puncture and infusion.
Article in German - abstract only
- Banerjee S, Singhi SC, Singh S, Singh M. The intraosseous route is a suitable alternative to intravenous route for fluid resuscitation in severely dehydrated children. *Indian Pediatr* 1994;31:1511-20** 188
Study of IO vs. IV for administering fluids for resuscitation in 60 children (age range 3-24 months) with severe dehydration. The IO route was successful in all cases within the first 5 minutes of attempt. The IV line could not be secured in 33% of patients within 5 minutes. Time for successful IV access was 129 seconds, significantly longer than time t for IO cannulation. Fluid infusion through either route was equally effective in stabilizing vital signs and normalizing laboratory values. No significant complications of IO route were noted on short-term follow-up.
- Barron BJ, Tran HD, Lamki LM. Scintigraphic findings of osteomyelitis after intraosseous infusion in a child. *Clin Nucl Med* 1994; 19: 307-8** 186
Case report of unilateral tibial osteomyelitis in a 20-month-old child following bilateral IO infusion. Reviews clinical indications, potential complications, and scan findings.
- Evans RJ, McCabe M, Thomas R. Intraosseous infusion. *Br J Hosp Med* 1994;51(4):161-4** 175
Review of IO infusion in children 6 years old and younger. Recommends IO for patients with life-threatening conditions requiring immediate vascular access. Reports less than 1% complication rate.
- Gayle M, Kissoon N. A case of compartment syndrome following intraosseous infusions. *Pediatr Emerg Care* 1994;10:378** 185
Case report of compartment systems following improper intraosseous infusion technique.
- Getschman SJ, Dietrich AM, Franklin WH, Allen HD. Intraosseous adenosine. As effective as peripheral or central venous administration? *Arch Pediatr Adolesc Med* 1994;148(6):616-9** 183
Preclinical study comparing IO administration of adenosine with peripheral and central venous routes to induce atrioventricular block during pacing. Found that IO administration was effective. Required dose of adenosine was highest for the peripheral venous route, lowest for central venous route.
- Katz DS, Wojtowycz AR. Tibial fracture: a complication of intraosseous infusion. *Am J Emerg Med* 1994; 12: 258-9** 160
Long bone fractures should be considered a potential, although rare, complication of intraosseous infusion in children.
- Losek JD, Szewczuga D, Glaeser PW. Improved prehospital pediatric ALS care after an EMT-paramedic clinical training course. *Am J Emerg Med* 1994;12:429-32** 176
Study demonstrating improved performance of pre-hospital endotracheal intubation and vascular access of younger children after introduction of an EMT-P PALS clinical course.
- Neal CJ, McKinley DF. Intraosseous infusion in pediatric patients. *J Am Osteopath Assoc* 1994;94(1):63-6. Review** 187
Describes frustration associated with difficult venous access. Recommends intraosseous infusion technique as a non-collapsible vein for parenteral infusions.

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Pediatric

- Oriot D, Cardona J, Berthier M, Nasimi A, Boussemart T. [Intraosseous vascular access, a technic previously underestimated in France]. Arch Pediatr 1994;1(7):684-8. French** 190
Review article suggesting that IO infusion should be the primary technique of intravascular access in infants for pediatric resuscitation and the first alternative technique for vascular access after failed intravenous access in young children.
Abstract only
- Orlowski JP. Emergency alternatives to intravenous access. Intraosseous, intratracheal, sublingual, and other-site drug administration. Pediatr Clin North Am 1994;41(6):1183-99** 164
Seminal article describing alternatives to intravenous cannulation including intraosseous access, intratracheal drug administration, sublingual and intralingual injection, intra-penile administration, and intracardiac injection. Concludes that the intraosseous method is an effective alternative to intravenous access in emergency situations.
Review
- Rosovsky M, FitzPatrick M, Goldfarb CR, Finestone H. Bilateral osteomyelitis due to intraosseous infusion: case report and review of the English-language literature. Pediatr Radiol 1994;24:72-3** 171
Case report of bilateral osteomyelitis secondary to intraosseous infusion.
Review
- Simmons CM, Johnson NE, Perkin RM, van Stralen D. Intraosseous extravasation complication reports. Ann Emerg Med 1994;23(2):363-6** 178
Case reports of 2 children with severe complications of IO infusions. One child developed severe tissue necrosis after IO placement. A second child developed compartment syndrome requiring fasciotomy.
- Ummenhofer W, Frei FJ, Urwyler A, Drewe J. Are laboratory values in bone marrow aspirate predictable for venous blood in paediatric patients. Resuscitation 1994;27(2):123-8** 560
In this study bone marrow aspirate from the iliac crest and peripheral venous blood samples from 30 pediatric patients were compared to investigate the predictive value of bone marrow aspirate in performing laboratory studies. Laboratory tests with high predictability, moderate but clinically useful predictability are summarized. Tests that were systematically different from venous blood are also summarized.
- Weaver BL. Intraosseous infusions. Neonatal Netw 1994;13(8):68-9** 162
A brief overview on establishing intraosseous vascular access in the neonatal patient population. Discusses insertion techniques, anatomy and physiology, absorption rates, indications and contraindications.
- Wright R, Reynolds SL, Nachtsheim B. Compartment syndrome secondary to prolonged intraosseous infusion. Pediatr Emerg Care 1994;10:157-9** 172
Case report of compartment syndrome after prolonged intraosseous infusion (53 hours). Recommends that IO lines be used only temporarily until more permanent vascular access is established.
Review
- YEAR: 1993**
- Bielski RJ, Bassett GS, Fideler B, Tolo VT. Intraosseous infusions: effects on the immature physis--an experimental model in rabbits. J Pediatr Orthop 1993;13:511-5** 143
Preclinical study in 20 immature rabbits receiving IO infusion of saline, bicarbonate, or dopamine solutions into the tibia. Found no changes in bone growth or epiphyseal injury related to IO infusion.
- Burke T, Kehl DK. Intraosseous infusion in infants. Case report of a complication. J Bone Joint Surg Am 1993; 75: 428-9** 153
Case report of a 4-month-old infant developing compartment syndrome after IO infusion. The patient underwent a fasciotomy and had full and normal use of the leg at the 6 month follow up visit.
- Glaeser PW, Hellmich TR, Szewczuga D, Losek JD, Smith DS. Five-year experience in prehospital intraosseous infusions in children and adults. Ann Emerg Med 1993;22(7):1119-24** 158
Retrospective analysis of prehospital IO infusion covering 165 attempts on 152 patients over a 5-year period, found a success rate of 73%, with success rates significantly higher in younger children (<2 years old). EMT-PPs maintained proficiency in the technique over time despite infrequent use.

Intraosseous Vascular Access Bibliography

Pediatric

- Guy J, Haley K, Zuspan SJ . Use of intraosseous infusion in the pediatric trauma patient. *J Pediatr Surg* 1993;28:158-6.1** 144
Observational study finding 7 of 27 critically injured patients (ages 3mo-10y) successfully resuscitated using IO. Concluded that IO is a rapid, safe and simple method of obtaining short term vascular access in critically ill and injured children.
- Kelsall AW. Resuscitation with intraosseous lines in neonatal units. *Arch Dis Child* 1993;68:324-5** 146
Case reports of 2 infants in the neonatal unit in which IO access was used for successful resuscitation from collapse.
- Platt SL, Notterman DA, Winchester P. Fungal osteomyelitis and sepsis from intraosseous infusion. *Pediatr Emerg Care* 1993;9:149-50** 141
Case report of fungal osteomyelitis following IO infusion in a child. Cautions that physicians consider both bacterial and fungal sources for infection.
- Ribeiro JA, Price CT, Knapp DR Jr. Compartment syndrome of the lower extremity after intraosseous infusion of fluid. A report of two cases. *J Bone Joint Surg Am* 1993;75A(3):430-3** 155
This article presented two case studies in which pediatric patients received emergency IO infusions that ultimately resulted in compartment syndrome. In both cases the patients underwent a four-compartment fasciotomy and recovered without deficit. The authors conclude that though compartment syndrome is a risk of IO infusion, insertion of an IO line in emergency situations is a valuable technique.
- Salino D, Cottin X, Bordenet M. [Intraosseous infusions in pediatric life-threatening emergencies]. *Ann Fr Anesth Reanim* 1993; 12: 469-73. Review. French** 154
Case reports of 2 9-month-old infants with severe dehydration treated with IO infusions after failed IV attempts. IO lines were replaced shortly after venous access was obtained.
Abstract only
- Schwartz RE, Pasquariello CA, Stayer SA. Elective use in pediatric anesthesia of intraosseous infusion: proceed only with extreme caution. *Anesth Analg* 1993; 76: 918-9** 159
Letter to the editor recommending intraosseous infusion only for truly urgent situations.
- Selby IR, James MR. The intraosseous route for induction of anaesthesia. *Anaesthesia* 1993;48:982-4** 157
Case report of a 6-week-old infant with a head injury resulting in a fractured skull and scalp haematoma who was successfully resuscitated and anesthetized with IO infusions of colloid, blood, midazolam, suxamethonium and atracurium.
- Tighe SQ, Rudland SV, Kemp PM, Kershaw CR. Paediatric resuscitation in adverse circumstances: a comparison of three routes of systemic access. *J R Nav Med Ser* 1993;79:75-9** 156
Study comparing 3 vascular access routes for fluid administration: intravenous (6 patients), intraosseous (6 patients) and/or intraperitoneal routes (4 patients). Concluded that IO and intraperitoneal routes allowed for severely dehydrated children to be resuscitated without significant complications when IV access is difficult to establish.
abstract only
- Vidal R, Kissoon N, Gayle M. Compartment syndrome following intraosseous infusion. *Pediatrics* 1993;91:1201-2** 152
Case report outlining precautions to prevent compartment syndrome following IO infusion. Advocates early recognition and aggressive treatment to preserve function in the affected limb.
- YEAR: 1992**
- American Heart Association. Guidelines for cardiopulmonary resuscitation and emergency cardiac care: chain of survival. *JAMA* 1992; 268: 2171-2302** 130
Evaluation of the chain of survival from cardiac arrest using standard measurements of performance.
- Cilley RE. Intraosseous infusion in infants and children. *Semin Pediatr Surg* 1992;1(3):202-7** 139
Article promoting increased awareness of intraosseous infusion, familiarity with IO insertion techniques, and careful use of anatomical landmarks.
Abstract only

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- Ghirga G, Ghirga P, Palazzi C, Befani P, Presti A. [Intraosseous route in pediatric emergencies. Description of 2 clinical cases and review of the literature]. *Minerva Pediatr* 1992; 44: 377-84. Italian** 123
Case reports of resuscitation of 2 pre-term infants with medications administered via the intraosseous route. Also includes a short review of the history, physiology, technique, complications and contraindications of IO procedure.
Abstract only
- Gut J, Karbula D. [Intraosseous infusions in children]. *Cesk Pediatr* 1992;47:726-7. Czech** 133
A review of intraosseous infusion and the possible applications in pediatric emergency medicine.
Abstract only
- Hapnes SA, Robertson C. CPR--drug delivery routes and systems. A statement for the Advanced Life Support Working Party of the European Resuscitation Council. *Resuscitation* 1992;24(2):137-42** 127
Descriptive comparison of the 4 available routes to provide drugs to adult patients during cardiopulmonary resuscitation.
- Hoekstra JH, van Kempen AA. [Intraosseous infusions in children]. *Tijdschr Kindergeneeskde* 1992;60(4):123-6. Dutch** 128
Recommendation of the tibial site for intraosseous infusion in children and discussion of risk for complications.
Abstract only
- Medina FA. Rapid sequence induction/intubation using intraosseous infusion of vecuronium bromide in children. *Am J Emerg Med* 1992;10(4):359-60** 121
Case reports in 2 children finding IO infusion of vecuronium allowed for successful rapid sequence induction/intubation.
- Molyneux E. Intraosseous infusion. *Arch Dis Child* 1992;67:665** 722
Letter to the editor written in response to previous article on IO access that includes sternal access as a site for children. This author states IO route for fluids and drugs is underutilized but believes sternal site to be hazardous and upper tibia, lower femur and humerus are favored.
- Stewart FC, Kain ZN. Intraosseous infusion: elective use in pediatric anesthesia. *Anesth Analg* 1992;75(4):626-9** 140
Case report of IO infusion for induction and maintenance of anesthesia in an infant with other IV access.
- Tibballs J. Endotracheal and intraosseous drug administration for paediatric CPR. *Aust Fam Physician* 1992;21(10):1477-80** 126
Article advocating IO administration of drugs and resuscitative fluids for CPR in children. Also asserts that adrenalin, lidocaine, and atropine can be readily absorbed through the respiratory tract via endotracheal administration.
Abstract only
- Woodall BN, Pender ES, Pollack CV Jr, Miller H, Tubbs RC, Andrew ME. Intraosseous infusion of resuscitative fluids and drugs: long-term effect on linear bone growth in pigs. *South Med J* 1992;85:820-4** 131
Preclinical study in pigs demonstrating that IO infusion of fluids and resuscitative drugs does not adversely affect subsequent bone growth and development.
- Zabala Arguelles JI, Maranon Pardillo R, Gonzalez Serrano P, Serina Ramirez C. [Main vascular access in situations of extreme urgency: intra-osseous infusion]. *An Esp Pediatr* 1992;37(6):489-92. Spanish** 132
Review article on IO access for a pediatric medicine audience. Concludes that IO administration can be used for all forms of medications. Osteomyelitis appeared in 0.6% of the cases.
Abstract only
- YEAR: 1991**
- Bilello JF, O'Hair KC, Kirby WC, Moore JW. Intraosseous infusion of dobutamine and isoproterenol. *Am J Dis Child* 1991;145(11):165-7** 111
Preclinical study comparing IV and IO administration of dobutamine and isoproterenol demonstrating significant physiologic responses to IO administered drugs comparable to response with IV administration.
- Christensen DW, Vernon DD, Banner W Jr, Dean JM. Skin necrosis complicating intraosseous infusion. *Pediatr Emerg Care* 1991;7:289-90** 114
Case reports of 2 patients with local skin necrosis complicating IO infusion.

Intraosseous Vascular Access Bibliography

Pediatric

- Clarke P. Making sense of intraosseous infusion. Nurs Times 1991;87(1):40-1** 115
Article for nurses on intraosseous infusion as an alternative to intravenous vascular access presented in a question and answer format.
- Driggers DA, Johnson R, Steiner JF, Jewell GS, Swedberg JA, Goller V. Emergency resuscitation in children. The role of intraosseous infusion. Postgrad Med 1991;89(4):129-32** 105
Review article discussing aspects of intraosseous infusion, including indications, technique, and pharmacokinetic factors. Concludes that multiple drugs and fluids can be safely administered through the intraosseous route.
- Galpin RD, Kronick JB, Willis RB, Frewen TC. Bilateral lower extremity compartment syndromes secondary to intraosseous fluid resuscitation. J Pediatr Orthop 1991;11:773-6** 109
Case report of a child with severe compartment syndrome of both lower extremities following IO fluid resuscitation.
- Grisham J, Hastings C. Bone marrow aspirate as an accessible and reliable source for critical laboratory studies. Ann Emerg Med 1991;20(10):1121-4** 108
Clinical study demonstrating blood from the IO space to be a viable alternative source of blood for laboratory studies.
- Jaimovich DG, Kecskes S. Intraosseous infusion: a re-discovered procedure as an alternative for pediatric vascular access. Indian J Pediatr 1991;58(3):329-34** 110
Review of indications and benefits of intraosseous infusion. Concludes IO access may be especially valuable for medical personnel who rarely care for critically ill children because the IO technique is easily mastered even with limited practice.
- Ryder IG, Munro HM, Doull IJ. Intraosseous infusion for resuscitation. Arch Dis Child 1991;66:1442-3** 113
Case report of an 11-week old infant in cardiac arrest due to haemorrhage successfully treated using IO infusion. The child was discharged with no apparent neurological deficit.
- Velasco AL, Delgado-Paredes C, Templeton J, Steigman CK, Templeton JM Jr. Intraosseous infusion of fluids in the initial management of hypovolemic shock in young subjects. J Pediatr Surg 1991;26:4-8** 117
Preclinical study in 39 puppies comparing IO treatment with Ringer's lactate with antishock trousers and control group receiving no treatment. Concludes that emergency administration of IO fluids is safe and effective for the initial resuscitation of hypovolemic shock.
- YEAR: 1990**
- Chameides L, Hazinski MF, eds. Intraosseous cannulation. In: Textbook of Pediatric Advanced Life Support. Chameides L, Hazinski MF, Eds.. Dallas: American Heart Association; 1990** 102
Textbook chapter on IO.
- Crane RG. Where are the fractures and needles? Ann Emerg Med 1990;19(6):731** 87
Letter to the editor regarding a previous article, "Iatrogenic Bilateral Tibial Fracture After Intraosseous Infusion Attempts in a 3-Month-Old Infant." Inquires if fractures were caused by questionable technique or an unexplainable complication of a proximally placed needle.
- Dollberg S, Gale R. [Intraosseous emergency infusion]. Harefuah 1990;119(11):357-8. Abstract-Hebrew** 96
Case report of a critically ill preterm neonate who received needed emergency fluids via IO infusion.
- Fiser DH. Intraosseous infusion. N Engl J Med 1990;322(22):1579-81** 98
Review of the use of intraosseous infusion in children in the prehospital setting and in the emergency department. Outlines anatomy, indications and contraindications, technique, complications and role of intraosseous infusion in pediatrics.
- Fries F, Rousset A, Bloom MC, Lelong-Tissier MC, Regnier C. [Intra-osseous route. Administration route of drugs in cardiac arrest]. Arch Fr Pediatr 1990;47(9):663-4. French** 103
Case report of a 6-month-old infant in cardiac arrest successfully resuscitated with IO epinephrine.
Abstract
- Goldstein B, Doody D, Briggs S. Emergency intraosseous infusion in severely burned children. Pediatr Emerg Care 1990;6:195-7** 88
Case report of 2 severely burned children saved after IO was used to establish IV access.

Intraosseous Vascular Access Bibliography

Pediatric

- Hopkins RL. Pediatric intraosseous infusion. J LA State Med Soc 1990;142(3):31-2** 104
Concludes that infusion of fluids and drugs can be readily performed with the intraosseous technique.
- Joffe M. Blasts in peripheral blood with intraosseous infusions. Pediatr Emerg Care 1990;6:106-7** 89
Case reports of 2 children who died from Sudden Infant Death Syndrome (SIDS) with immature white cells in the peripheral blood. Blood was sampled near IO infusion site. Urges physician awareness of that patients receiving IO infusion may be at risk for immature white blood cells in the peripheral circulation in the absence of malignant, infectious, or infiltrative disease of the marrow.
- King ML, Moses EC. Intraosseous infusion: a lifesaving technique. Nursing 1990;20:32K,32N-32P** 93
Nursing article describing intraosseous infusion techniques and benefits.
- Miccolo MA. Intraosseous infusion. Crit Care Nurse 1990;10(10):35-47** 100
Nursing article that describes benefits of intraosseous infusion. Recommends IO for cardiopulmonary arrest and other medical
- Moscato R, Moore GP. Compartment syndrome with resultant amputation following intraosseous infusion. Am J Emerg Med 1990; 8: 470-1** 91
Case report of compartment syndrome following IO infusion. Emphasizes IO to be useful for temporary vascular access. Advises that that IV lines be placed as soon as possible after IO infusion. Recommends that radiograph be performed after the procedure in very young children to check for bone abnormalities.
- Salassi-Scotter M, Fiser DH. Adoption of intraosseous infusion technique for prehospital pediatric emergency care. Pediatr Emerg Care 1990;6:263-5** 95
Discusses current limited pre-hospital use of intraosseous infusion. Stresses need for a concerted effort to promote broad adoption.
- Tobias JD, Nichols DG. Intraosseous succinylcholine for orotracheal intubation. Pediatr Emerg Care 1990;6(2):108-9** 468
This article describes two cases of IO administration of succinylcholine for emergency airway management in children that resulted in adequate intubating conditions within 45 seconds for both cases.
- Zenk KE. Use of intraosseous infusions in infants and children. Clin Pharm 1990;9:90-1** 94
Article advocating IO infusion over endotracheal administration of medications. Asserts that IO infusion is equivalent to IV infusion.
- YEAR: 1989**
- Iseron KV. Intraosseous infusions in adults. J Emerg Med 1989;7(6):587-91** 75
Study of 22 cardiac arrest patients arriving at the Emergency Department with no or insufficient intravenous access. Intraosseous needle placed and flow established in less than 1 minute in all patients. Observed flow rates of 5 to 12 mL/min with pressure bag attached. IO needle placed in the medial supramalleolus.
- La Fleche FR, Slepian MJ, Vargas J, Milzman DP. Iatrogenic bilateral tibial fractures after intraosseous infusions attempts in a 3-month-old infant. Ann Emerg Med 1989;18(10):1099-101** 82
Case report of bone fracture following IO access in an infant.
- Lathers CM, Jim KF, Spivey WH. A comparison of intraosseous and intravenous routes of administration for antiseizure agents. Epilepsia 1989;30(4):472-9** 81
Preclinical study in pigs finding equivalence in physiologic response between IO and IV administration of antiepileptic drugs.
- Miner WF, Corneli HM, Bolte RG, Lehnhof D, Clawson JJ. Prehospital use of intraosseous infusion by paramedics. Pediatr Emerg Care 1989;5(1):5-7** 74
Study of IO infusion by paramedics on pediatric patients (>5 years of age) in cardiac arrest. Paramedics completed a training program in IO technique. Observed 85% success rate (10 of 12 IO attempts). Discusses training methods, limitations and implications for future use.

Intraosseous Vascular Access Bibliography

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- Orlowski JP, Julius CJ, Petras RE, Porembka DT, Gallagher JM. The safety of intraosseous infusions: risks of fat and bone marrow emboli to the lungs. *Ann Emerg Med* 1989;18(10):1062-7** 78
Preclinical study in dogs examining lung samples for fat and bone marrow emboli following IO infusion. Found no significance difference in embolism formation or density between dogs receiving IO infusion of emergency drugs and control group.
- Schoffstall JM, Spivey WH, Davidheiser S, Lathers CM. Intraosseous crystalloid and blood infusion in a swine model. *J Trauma* 1989;29(3):384-7** 85
Preclinical study of IO infusion in a swine model. Concludes that IO infusion holds potential as a first line of action for fluid resuscitation in pediatric subjects.
- Seigler RS, Tecklenburg FW, Shealy R. Prehospital intraosseous infusion by emergency medical services personnel: a prospective study. *Pediatrics* 1989;84:173-7** 84
Prospective study finding EMS personnel able to successfully establish IO access in 16 of 17 pediatric patients with cardiopulmonary arrest. Observed 13 successful infusions within 1 minute on first attempts at IO access. No significant complications.
- Wheeler CA. Pediatric intraosseous infusion: an old technique in modern health care technology. *J Intraven Nurs* 1989;12(6):371-6** 76
Review article for a nursing audience presenting a brief historical overview of IO technique and insertion methods, with discussion of clinical applications and nursing management aspects.
- YEAR: 1988**
- Brickman KR, Rega P, Koltz M, Guinness M. Analysis of growth plate abnormalities following intraosseous infusion through the proximal tibial epiphysis in pigs. *Ann Emerg Med* 1988;17(2):121-3** 65
Preclinical study in pigs examining the epiphyseal plate after intentional penetration with IO needle and subsequent fluid infusion. Found no significant growth defects despite injury to the developing growth plate.
- Brillman JC. Intraosseous infusion for emergency intravascular access. *Top Emerg Med* 1988;10(1):75-80** 73
Description of IO infusion technique, site selection, procedure, anatomy, physiology, historical perspectives, contemporary research, indications, contraindications, complications, and future direction.
- Brunette DD, Fischer R. Intravascular access in pediatric cardiac arrest. *Am J Emerg Med* 1988;6(6):577-9** 63
Retrospective chart review of 33 pediatric patients finding 83% success in establishing IO infusion. IO and percutaneous peripheral catheterization were the quickest methods for vascular access. Observed no major and minimal delayed complications.
- Glaeser PW, Losek JD, Nelson DB, Bonadio WA, Smith DS, Walsh-Kelly C, Hennes H. Pediatric intraosseous infusions: impact on vascular access time. *Am J Emerg Med* 1988;6:330-2** 48
Retrospective chart review over a 1-year period finding IO reduced vascular access time in patients with cardiac arrest when standard techniques failed.
- Glaeser PW, Losek JD. Intraosseous needles: new and improved. *Pediatr Emerg Care* 1988;4(2):87-91** 607
This article describes the Kormed/Jamshidi disposable Illinois sternal/iliac needle as well suited to establish intraosseous vascular access in the pre-hospital and hospital setting.
- Katan BS, Olshaker JS, Dickerson SE. Intraosseous infusion of muscle relaxants. *Am J Emerg Med* 1988;6(4):353-4** 62
Case report of anesthetic induction through IO administration of succinylcholine chloride, atracurium besylate, and thiopental sodium in a child with seizure activity.
- Manley L, Haley K, Dick M. Intraosseous infusion: rapid vascular access for critically ill or injured infants and children. *J Emerg Nurs* 1988;14(2):63-9** 66
Article for emergency nursing audience describing IO technique, anatomy, absorption rates, clinical indications and contraindications, technique, complications and training in critically ill or injured infants and children.
- Mofenson HC, Tascone A, Caraccio TR. Guidelines for intraosseous infusions. *J Emerg Med* 1988;6:143-6** 68
Guidelines for IO in pediatric patients.

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Pediatric

- Neish SR, Macon MG, Moore JW, Graeber GM. Intraosseous infusion of hypertonic glucose and dopamine. Am J Dis Child 1988;142(8):878-80** 69
Preclinical study finding IO infusion of hypertonic glucose and dopamine to be as effective as IV administration.
- Peck KR, Altieri M. Intraosseous infusions: an old technique with modern applications. Pediatr Nurs 1988;14(4):296-8** 70
Nursing article recommending IO early in the treatment of critically ill or injured children with difficult venous access. Highlights speed and ease of IO technique.
- Sacchetti A, Linkenhelmer R. On the effectiveness of intraosseous infusion. J Emerg Med 1988;6(5):433** 61
Article discussing IO infusion and associated rapid intravascular absorption of solutions.
- Smith RJ, Keseg DP, Manley LK, Standeford T. Intraosseous infusions by prehospital personnel in critically ill pediatric patients. Ann Emerg Med 1988;17(5):491-5** 67
Concludes intraosseous infusion to be a safe and viable technique in the pre-hospital setting, especially in the aeromedical area.
- Wagner MB, McCabe JB. A comparison of four techniques to establish intraosseous infusion. Pediatr Emerg Care 1988;4(2):87-91** 64
Comparison study of success rate in establishing IO infusion in anesthetized piglets with 4 types of IO needles: standard hypodermic, spinal, bone marrow, Turkel. Practitioners were 24 medical residents with no prior experience in IO technique. Overall success rate was 67.7%. There were no statistical differences in success rate among the 4 different types of needles.
- YEAR: 1987**
- Hodge D, Delgado-Paredes C, Fleisher G. Intraosseous infusion flow rates in hypovolemic "pediatric" dogs. Ann Emerg Med 1987;16(3):305-7** 58
Preclinical study of IO flow rates during hypovolemia. Concludes that IO flow rates may be insufficient for definitive treatment of severe hypovolemic or hemorrhagic shock.
- Spivey WH. Intraosseous infusions. J Pediatr 1987;111(5):639-43** 56
Review article on IO infusion, includes historical background, physiology, method, clinical applications and complications of the IO procedure.
- YEAR: 1986**
- Glaeser PW, Losek JD. Emergency intraosseous infusions in children. Am J Emerg Med 1986;4:34-6** 50
Case report illustrating value of familiarity with insertion technique for IO. Recommends that IO fluids and medications be considered early in patients requiring resuscitation.
- Iseron KV, Criss E. Intraosseous infusions: a usable technique. Am J Emerg Med 1986;4(6):540-2** 54
This article describes case reports and also a study comparing 3 types of needles for IO insertion: spinal needles, standard IV needles, and bone marrow aspiration/biopsy needles on a pediatric cadaver leg. The bone marrow aspiration needle was easiest to insert. The clinical cases described 5 adult and 10 pediatric IO patients with insertion at the "medial malleolus".* Authors conclude that IO infusion is a safe, rapid way to access the venous circulation, providing a stable, usable fluid line in dehydrated pediatric patients. *(Often referred to as distal tibia.)
- Kanter RK, Zimmerman JJ, Strauss RH, Stoeckel KA. Pediatric emergency intravenous access. Evaluation of a protocol. Am J Dis Child 1986;140(2):132-4** 53
Evaluation of a sequential protocol comparing femoral vein catheterization, saphenous vein cutdown, and IO (in order) when conventional IV access was impossible in a pediatric patient population. Found that IV access was attained in 4.5 minutes when the protocol was followed, compared to 10 minutes when protocol was not followed. Suggests that IV access should always be attained in 5 minutes or less.
- Mayer TA. Emergency pediatric vascular access: Old solutions to an old problem. Am J Emerg Med 1986;4(1):98-101** 51
Discusses rediscovery of intraosseous infusion as a straightforward technique for an extremely difficult clinical problem. Suggests that many fluids and medications can be administered via the IO route.
- McNamara RM, Spivey WH, Sussman C. Pediatric resuscitation without an intravenous line. Am J Emerg Med 1986;4:31-3** 49
Case report of an unresponsive 3-month-old infant with no cardiac activity. Patient was resuscitated and achieved stable cardiac rhythm and blood pressure through IO administered medications.

Intraosseous Vascular Access Bibliography

Pediatric

- Melker RJ. Intraosseous infusions. *Am J Emerg Med* 1986;4:490** 46
Letter to the editor discussing guidelines for IO in Standards and Guidelines for Cardiopulmonary Resuscitation and Emergency Cardiac Care, and in the chapter on Intravenous and Intra-arterial Techniques for the Pediatric Advanced Life Support (PALS) textbook being completed by the Working Group on Pediatric Resuscitation of the American Heart Association.
- Parrish GA, Turkewitz D, Skiendzielewski JJ. Intraosseous infusions in the emergency department. *Am J Emerg Med* 1986;4(1):59-63** 47
Discusses IO route as a safe, proven, and technically easy method for administration of replacement fluids, blood products, and resuscitative drugs. Presents value, historical context, technique, and complications of the IO infusion.
- Walsh-Kelly CM, Berens RJ, Glaeser PW, Losek JD. Intraosseous infusion of phenytoin. *Am J Emerg Med* 1986;4(6):523-4** 52
Case report of child with status epilepticus. IO phenytoin resulted in seizure resolution and therapeutic serum levels of drug.
- YEAR: 1985**
- Hodge D. Intraosseous infusions: a review. *Pediatr Emerg Care* 1985;1(4):215-8** 44
Review of IO insertion techniques of insertion, clinical indications, contraindications, and complications.
- Rosetti VA, Thompson BM, Miller J, Mateer JR, Aprahamian C. Intraosseous infusion: an alternative route of pediatric intravascular access. *Ann Emerg Med* 1985;14(9):885-8** 42
Discusses the historic technique of tibial intraosseous infusion as an alternative IV route in young children. Concludes from review of the medical literature that IO access is a rapid, reliable method with acceptably low complication rate. Discusses substances absorbed through the marrow, flow rates, technical difficulties, and complications.
- Spivey WH, Lathers CM, Malone DR, et al.. Comparison of intraosseous, central, and peripheral routes of sodium bicarbonate administration during CPR in pigs. *Ann Emerg Med* 1985;14(12):1135-40** 43
Preclinical study in pigs examining blood pH during CPR with sodium bicarbonate administered via different vascular access routes. Found that pH of blood obtained via central venous access and intraosseous access were significantly different from the peripheral group, and that all three groups were significantly different from the control. Pathology studies showed only minor damage to bone with IO sodium bicarbonate administration.
- Turkel H. Emergency bone marrow infusions. *Am J Dis Child* 1985;139(5):438-9** 45
Letter to the editor asserting that while the Turkel trephine technique may stabilize the IO needle better and minimize fluid leakage into the subcutaneous tissue, few physicians are familiar with the technique and it is more time-consuming than using a standard bone marrow needle or standard hypodermic needle.
- YEAR: 1984**
- Berg RA. Emergency infusion of catecholamines into bone marrow. *Am J Dis Child* 1984;138(9):810-1** 40
Case report of continuous IO infusion of dopamine hydrochloride and dobutamine hydrochloride in a 6 month old infant. Concludes that IO infusion is efficacious and complications rare.
- Orlowski JP. My kingdom for an intravenous line. *Am J Dis Child* 1984;138(9):803** 41
Seminal article on IO infusion by the "Father of IO." Drugs and fluids infused through the IO space enter the central circulation as rapidly as through IV routes. Unlike peripheral veins, the intramedullary blood vessels will not collapse in shock.
- Rosetti V, Thompson BM, Aprahamian C, Darin JC, Mateer JR. Difficulty and delay in intravascular access in pediatric arrests. *Ann Emerg Med* 1984;13(5):406** 39
Outlines problems with conventional vascular access in emergency medicine. Discusses possible resurgence of the "old" technique of intraosseous infusion.
- YEAR: 1983**
- Turkel H. Intraosseous infusion. *Am J Dis Child* 1983;137(7):706** 37
Case report of 3-year-old child permanently blinded and brain damaged because of inability to administer anesthetic intravenously. Patient was on oxygen following an inhalation anesthetic. Concludes that IO administration of anesthesia would have prevented this poor outcome.

Intraosseous Vascular Access Bibliography

Pediatric

YEAR: 1947

Elston JT, Jaynes RV, Kaump DH, Irwin WA. Intraosseous infusions in infants. *Am J of Clinical Path* 1947;17(2):143-50 20
Early article on IO puncture and infusion, emphasizing technique. Concludes their technique is safer and more effective than previously described techniques.

Heinild S, Sondergaard T, Tudvad F. Bone marrow infusion in childhood: Experiences from a thousand infusions. *J of Pediatrics* 1947; 30: 400-11 21
Early study on IO. Makes strong distinction between ordinary blood transfusion or infusion of isotonic solutions (generally safe) and continuous infusion or the infusion of hypertonic solutions. The latter carries considerable risk of osteomyelitis and subsequent disturbance in growth of the bone.

YEAR: 1946

Quilligan JJ, Turkel H. Bone marrow infusion and its complications. *Am J Dis Child* 1946; 71: 457-65 18
Historical article discussing refinements in IO technique and analysis of IO complications. Includes case report of an infant who developed osteomyelitis subsequent to IO infusion.

YEAR: 1945

Gunz FW, Dean RFA. Tibial bone-marrow transfusions in infants. *Br Med J* 1945;1(4389):220-1 800
Abstract describes experience in one institution using tibial IO access to replace fluids, mostly due to dehydration.

YEAR: 1944

Arbeiter H I, Greengard J. Tibial bone marrow infusion in infancy. *J Pediatr* 1944; 25:(1):1-12 12
Early article describes technique for tibial bone marrow infusion. Reports 6 failures and 2 partial failures in 43 attempts on 34 young children. X-ray studies post IO infusion showed small bone defects and periosteal elevation with new bone formation.

Behr G. Bone-marrow infusions for infants. *Lancet* 1944; (Oct 7):472-3 14
Describes the tibia as a useful route for infusions in infants. Main advantages over IV infusions are ease, speed, and firm placement.

Gimson JD. Bone-marrow transfusion in infants and children-Introducing a specially designed needle. *Br Med J* 1944;1(4352):748-9 11
Describes a simple method of bone marrow transfusion using a specially designed needle that is more safe and effective than intravenous needles.

Meola F. Bone marrow infusions as a routine procedure in children. *J Pediatr* 1944;25(1):13-6 13
Early observational study on IO infusion at the Children's Hospital of Akron, OH.

YEAR: 1943

Ravitch MM. Suppurative anterior mediastinitis in an infant following intrasternal blood transfusion. *Arch Surg* 1943;47(3):250-7 1012
This article provides a brief history of intraosseous infusion beginning in 1903 with supportive literature through the writing of this article in 1943. An overview of mediastinitis, a complication of intrasternal blood transfusion, is also provided followed by a case report of anterior mediastinitis in an infant.

YEAR: 1942

Papper EM. The bone marrow route for injecting fluids and drugs into the general circulation. *Anesthesiology* 1942;3(3):307-13 8
Discusses IO infusion, pioneered by Tocantins, as a viable route for parenteral fluids, drug therapy, and anesthesia. Includes case reports.

Intraosseous Vascular Access Bibliography

Pediatric

YEAR: 1941

Tocantins LM, O'Neill JF, Jones H. Infusion of blood and other fluids via the bone marrow: Application in pediatrics. JAMA 1941a; 117(5):1229-34

7

Describes emergency IO infusion of citrated blood and saline into the tibia or femur of 9 infants. IV access was impossible. Found no complications upon clinical or x-ray examination post-infusion.

YEAR: 1922

Drinker C, Drinker K, Lund C. The circulation in the mammalian bone marrow. Am J Physiol 1922;62(1):1-92

1

Seminal article on blood circulation in the IO space. Demonstrates movement of red blood cells from the bone marrow into the circulating blood by perfusion of the tibia of the dog and by injections into the bone marrow in the rabbit and cat.

Intraosseous Vascular Access Bibliography

Pharmacokinetics/Dynamics

YEAR: 2019

Burgert JM, Johnson AD, O'Sullivan JC, et al. Pharmacokinetic effects of endotracheal, intraosseous, and intravenous epinephrine in a swine model of traumatic cardiac arrest. *Am J Emerg Med* 2019;(in press). doi: 10.1016/j.ajem.2019.02.035

1046

This pre-clinical study compared various PK parameters, return of spontaneous circulation (ROSC), time to ROSC, and odds of ROSC after epinephrine was administered via endotracheal (ETT), IO, and IV routes in a swine traumatic cardiac arrest model (TCA). IO groups included sternal IO (SIO), humeral IO (HIO), and tibial IO (TIO). CPR only and CPR plus defibrillation (CPRD) groups were included for analyzing ROSC. The Cmax of the IV epinephrine group was significantly higher than that of the IO group (p=0.049). The tmax of the TIO group was significantly longer than that of all other groups (p=0.008). There were significant differences in mean plasma concentrations over time between the IV and TIO groups at 90, 120, 150, and 180 seconds (p<0.05) with the TIO group having an unexpectedly prolonged absorption phase. There was no difference in the rate of ROSC between ETT, TIO, HIO, SIO, IV and CPRD groups. The PK findings relative to ROSC support the concept that neither epinephrine nor the route of administration influenced the outcome. All IO insertions were performed using the EZ-IO device.

YEAR: 2018

Burgert J, Martinez A, O'Sullivan M, Blouin D, Long A, Johnson A. Sternal route more effective than tibial route for intraosseous amiodarone administration in a swine model of ventricular fibrillation. *Prehosp Emerg Care* 2018;22(2):266-75. doi:10.1080/10903127.2017.1358782

903

This study examined the measured mean plasma concentration, maximum plasma concentration (Cmax), and time to maximum concentration (Tmax) of amiodarone administered by 3 different routes, sternal IO (SIO), tibial IO (TIO), and IV over a time period of 5 minutes in 21 swine who were randomly assigned to one of the 3 routes. The swine were under general anesthesia and ventricular fibrillation was induced and CPR initiated. After 4 minutes in ventricular fibrillation the swine were administered 300 mg of amiodarone and blood samples were taken at 30 second intervals over 300 seconds. Authors concluded that the SIO and IV routes of amiodarone were comparable. The TIO group took almost 3 times longer to reach Tmax than the SIO and IV groups. In the swine model used in this study, the authors concluded that SIO route was more effective than the TIO route for the amiodarone delivery in a swine with VF and ongoing CPR.

Symonds T, Parkinson B, Hazratwala K, McEwen P, Wilkinson M, Grant A. Use of regional administration of prophylactic antibiotics in total knee arthroplasty. *ANZ J Surg* 2018;88:848-53

1025

This paper discusses prosthetic joint infection (PJI) after total knee arthroplasty (TKA) and the use of prophylactic antibiotics to prevent PJI. Current literature recommends IV administration of cephalosporins, however, rising resistance rates limit the effectiveness of IV cephalosporins. Alternatives include clindamycin, teicoplanin, and vancomycin. The author reviews alternative routes of administration to increase time dependent or concentration dependent antibiotic killing including intravenous regional administration (IVRA) and intraosseous regional administration (IORA). Supporting literature is reviewed. The author concludes that IVRA and IORA of prophylactic antibiotics in TKA is a novel way to increase tissue concentrations of prophylactic antibiotics and the current literature supports changing guidelines (after further research) to allow IVRA and IORA in TKA. The EZ-IO device was utilized for IORA of prophylactic antibiotics in the reviewed studies.

YEAR: 2017

Boysen SR, Pang JM, Mikler JR, Knight CG, Semple HA, Caulkett NA. Comparison of tranexamic acid plasma concentrations when administered via intraosseous and intravenous routes. *Am J Emerg Med* 2017;35(2):227-33. doi:http://dx.doi.org/10.1016/j.ajem.2016.10.054

867

Swine study comparing pharmacokinetic (pK) parameters of TXA given by the IO vs IV route. For the 4 min and 5 min results Cmax plasma concentrations were higher in the IV group but similar from injection completion onwards. Other pK parameters were not significantly different. Limitations included swine model, normotensive animals and proximity of sampling site (jugular vein) to the IV infusion site (auricular). Investigators concluded this study supports the pharmacokinetic bioequivalence of IO and IV administration of TXA in this animal model.

Burgert JM, Johnson AD, Garcia-Blanco J, Fulton LV, Loughren MJ. The resuscitative and pharmacokinetic effects of humeral intraosseous vasopressin in a swine model of ventricular fibrillation. *Prehosp Disaster Med* 2017;32(3):305-10. doi:10.1017/S1049023X17000140

940

This preclinical study reported data evaluating the pharmacokinetics of HIO and IV vasopressin and the ROSC in a swine model of ventricular fibrillation cardiac arrest. For the parameters of occurrence of ROSC, odds of ROSC, time to ROSC, Cmax, Tmax, and plasma concentrations over time, the IO and IV routes results were comparable.

Intraosseous Vascular Access Bibliography

Pharmacokinetics/Dynamics

Tallman CI, Darracq M, Young M. Analysis of intraosseous blood samples using an EPOC point of care analyzer during resuscitation. Am J Emerg Med 2017;35(3):499-501. doi:10.1016/j.ajem.2016.12.005

805

A prospective study comparing results of intravenous (IV) and intraosseous (IO) blood specimens when analyzed using an EPOC point of care analyzer during resuscitation of non-traumatic cardiac arrest and critically ill patients. Seventeen patients who had IO and IV specimens collected within 5 minutes of each other were included in the study; IO samples were collected before administration through the IO catheter in the proximal tibia or proximal humerus. Results showed that based upon Bland Altman plots, there was reasonable agreement between IV and IO values for PH, bicarbonate, sodium and base excess, and moderate agreement for lactic acid. The intraclass correlation co-efficient was excellent for sodium and reasonable for pH, pO₂, bicarbonate and glucose. The primary limitation noted was the small sample size (n=17) and the substantial impact of single outliers in the data.

YEAR: 2016

Beaumont D, Baragchizadeh A, Johnson C, Johnson D. Effects of tibial and humerus intraosseous administration of epinephrine in a cardiac arrest swine model. Am J Disaster Med 2016;11(4):243-50. doi:10.5055/ajdm.2016.0246

898

This study examined the differences of pharmacokinetics and pharmacodynamics of epinephrine via of tibial intraosseous access and IV access. Interruptions in CPR in order to obtain vascular access reduces the flow of blood to vital organs. Study results showed that TIO access may be a faster alternative to IV access for delivery of vasoactive medications.

Burgert JM, Johnson AD, Garcia-Blanco J, et al. The effects of proximal and distal routes of intraosseous epinephrine administration on short-term resuscitative outcome measures in an adult swine model of ventricular fibrillation: A randomized controlled study. Am J Emerg Med 2016;34:49-53. doi:10.1016/j.ajem.2015.09.007

778

Preclinical RCT evaluating the relationships between the anatomical distance of IO epinephrine and measures of resuscitative outcome in an adult swine model of ventricular fibrillation (VF). There were no significant differences between the HIO, TIO, and IV groups relative to the occurrence of ROSC, 30-minute post-ROSC survival, and time to ROSC. The anatomical distance of IO epinephrine injection from the heart did not affect short-term measures of resuscitative outcome in an adult swine model of VF including the occurrence of ROSC, 30 minute post-ROSC survival, and time to ROSC. Rapidly administered epinephrine, irrespective of route of administration, increased the chance of ROSC and survival to 30 minutes post-ROSC in this study.

Cornell M, Kelbaugh J, Todd B, et al. Pharmacokinetics of sternal intraosseous atropine administration in normovolemic and hypovolemic swine. Am J Disaster Med 2016;11(4):233-6. doi:10.5055/ajdm.2016.0244

911

This prospective, experimental study was to characterize and compare the pharmacokinetics of atropine that is administered via sternal intraosseous (IO) route in hypovolemic and non-hypovolemic swine. Main outcomes PK parameters, maximum concentration (C_{max}) and time to reach maximum concentration (T_{max}). Authors concluded sternal IO route is effective for administration of atropine and data gained from this study was found to be similar to previous information reported on tibial IO and IV administration even in situations of significant hemorrhage.

Davis J, Bates L. Rapid sequence induction via an intraosseous needle. J Intensive Care Society 2016;17(2):178-9

788

This article presents a case study of rapid sequence intubation via intraosseous (IO) access with a review of relevant literature. The authors describe a case of an adult male patient, peri-arrest with cardiogenic shock, cyanosed with un-recordable oxygen saturations and blood pressure. IO access was established in the proximal tibia and rapid sequence induction was performed using fentanyl, ketamine and suxamethonium. After 30 seconds direct laryngoscopy was attempted and intubation was secured on first attempt. The authors concluded that use of IO access for RSI can be useful in cases of difficult vascular access and rapid intubating conditions can be achieved which are comparable to using IV drug delivery.

Eriksson M, Strandberg G, Lipcsey M, Larsson A. Evaluation of intraosseous sampling for measurements of alanine aminotransferase, alkaline phosphatase, aspartate aminotransferase, creatinine kinase, gamma-glutamyl transferase and lactate dehydrogenase. Scand J Clin Lab Invest 2016;76(8):597-600. doi:10.1080/00365513.2016.1230774

809

This preclinical study compared arterial and intraosseous derived biomarkers to determine if the results would correlate well enough over a period of 6 hours to consider use of IO derived blood when traditional samples are difficult to obtain. Authors noted there were no clinically relevant average differences between alanine aminotransferase, alkaline phosphatase, aspartate aminotransferase, creatinine kinase and gamma-glutamyl transferase values which may be good enough for initial estimates of these markers analyzed in intraosseous and arterial samples. However the lactate dehydrogenase levels showed less correlation; and the precision of IO samples may be limited.

Fulkerson J, Lowe R, Anderson T, Moore H, Craig W, Johnson D. Effects of intraosseous tibial vs. intravenous vasopressin in a hypovolemic cardiac arrest model. West J Emerg Med 2016;17(2):222-8. doi:10.5811/westjem.2015.12.28825

777

Randomized, prospective preclinical study that examined the differences in pharmacokinetics and pharmacodynamics of tibial IO (TIO) and IV-delivered vasopressin during cardiac arrest and CPR until ROSC was achieved. No difference was noted for ROSC between TIO and IV delivered vasopressin. Authors concluded the use of IO access could avoid the time delay associated with IV access, and that it is effective for treatment of hypovolemic cardiac arrest and should be first line for rapid vascular access.

Intraosseous Vascular Access Bibliography

Pharmacokinetics/Dynamics

- Hampton K, Wang E, Argame JI, Bateman T, Craig W, Johnson D.** *The effects of tibial intraosseous versus intravenous amiodarone administration in a hypovolemic cardiac arrest porcine model.* *Am J Disaster Med* 2016;11(4):253-60 829
- This study compared IV to tibial IO administration of amiodarone. Investigators found no significant differences for the endpoints of Cmax, Tmax and time to/return of ROSC between IO and IV.
- Holloway MM, Jurina SL, Orszag JD, et al.** *Effects of humerus intraosseous versus intravenous amiodarone administration in a hypovolemic porcine model.* *Am J Disaster Med* 2016;11(4):261-9 828
- In a swine study comparison of the humeral IO and IV amiodarone administration routes investigators found no difference in time to ROSC or rate, time to maximum concentration (Tmax) p = 0.501) or in maximum plasma drug concentration (Cmax) (p = 0.232).
- Montez DF, Puga TA, Davlantes C, Higgins R, Miller LJ, Philbeck TE.** *Blood transfusion via intraosseous access: A pre-clinical study.* *J Vasc Access* 2016;17(4):e5-6 783
- A preclinical study evaluating blood transfusion via IO vascular access in anesthetized swine. Results showed pressurized blood transfusion through IO vascular access resulted in acceptable flow rates and did not result in appreciable hemolysis as indicated by free hemoglobin values. This study was sponsored by Teleflex Incorporated.
- Nemeth M, Williams GN, Prichard D, et al.** *Onset and duration of intravenous and intraosseous rocuronium in hypovolemic swine.* *Am J Disaster Med* 2016;11(4):279-82. doi: 10.5055/ajdm.2016.0250 1002
- This study characterizes and compares the onset and duration of neuromuscular blockade after IV and IO administration of rocuronium in a hypovolemic swine model. Eight pigs were randomized to receive rocuronium IV or IO in a hypovolemic state. Onset and peak times were not statistically different between groups. The IO group took statistically longer than the IV group to return to 25, 50, 75, and 95 percent baseline.
- Puga T, Montez D, Philbeck T, Davlantes C.** *Adequacy of intraosseous vascular access insertion sites for high-volume fluid infusion.* *Crit Care Med* 2016;44(12 Suppl):143 821
- This study was completed on 30 healthy subjects to evaluate infusion rates via the sternum (SIO) and proximal humerus (PH) sites under 300 mmHg via pressure bag. The mean SIO infusion rate was 9,587±2,706mL/hr (n=27); mean PH infusion rate was 6,292 ±3,277mL/hr (n=52). There were no serious complications; minor complications were 5 cases of excess pain, 2 cases vagal response, and mammary tissue engorgement. The mean PH flow rate was significantly lower than that of SIO, but placing IO catheters in each humeri with simultaneous infusion could result in fluid delivery of 13,000mL/hr, surpassing that of the sternum. This study was sponsored by Teleflex Incorporated.
- Puga TA, Montez DF, Davlantes C, Miller LJ, Philbeck TE.** *Swine study shows no intramedullary effects of power-injected contrast media using intraosseous access.* *J Vasc Access* 2016;17(4):e16 785
- A preclinical study evaluating the immediate effects of power injected contrast media on the medullary space of anesthetized swine. Contrast media (150 mL) was administered at a rate of 5 mL/second. For each limb receiving power injection a control limb was submitted for evaluation. The pathologist was blinded to which limb received power injection. Results showed no histological difference in limbs receiving and not receiving power injection. This study was sponsored by Teleflex Incorporated.
- Smith S, Borgkvist B, Kist T, Annelin J, Johnson D, Long R.** *The effects of sternal intraosseous and intravenous administration of amiodarone in a hypovolemic swine cardiac arrest model.* *Am J Disaster Med* 2016;11(4):271-7. doi:10.5055/ajdm.2016.0249 830
- A pre-clinical study comparing the effects of IV and sternal IO administered amiodarone in a swine cardiac arrest model. Following 2 minutes of cardiac arrest, CPR was initiated and after an additional 2 minutes, amiodarone was administered via sternal IO or IV access. Blood samples were collected over 5 minutes. Results showed no statistical difference between routes for return of spontaneous circulation (ROSC), time to ROSC, T-max, or C-max. The authors concluded sternal IO route provides rapid and reliable access to administer life-saving medications during cardiac arrest.
- Strandberg G, Lipcsey M, Eriksson M, Lubenow N, Larsson A.** *Analysis of thromboelastography, PT, APTT and fibrinogen in intraosseous and venous samples-an experimental study.* *Scand J Trauma Resusc Emerg Med* 2016;24:131. doi:10.1186/s13049-016-0318-0 814
- In this porcine study IO and venous samples were analyzed for thromboelastography (TEG), prothrombin time (PT), activated partial thromboplastin time (APTT) and fibrinogen concentration. The IO samples were clinically hypercoagulable, rendering some samples unevaluable; clinically relevant differences were observed for APTT but not for PT and fibrinogen and the TEG demonstrated a shortened reaction time. The ability to use IO drawn blood for coagulation studies may be limited.

Intraosseous Vascular Access Bibliography

Pharmacokinetics/Dynamics

Uwaydah NI, Hoskins SL, Bruttig SP, et al. Intramuscular versus intraosseous delivery of nerve agent antidote pralidoxime chloride in swine. Prehosp Emerg Care 2016;20(4):485-92. doi:10.3109/10903127.2014.942479 842

A preclinical study comparing delivery of nerve agent antidote when administered via intramuscular (IM) and proximal tibia intraosseous (IO) routes, in normovolemic and hypovolemic swine. IO and IV administration of the antidote achieved and surpassed therapeutic levels in normovolemic groups; time to therapeutic level with IM was 2 minutes versus 15 seconds with IO access. Combined administration via IO route initially, followed by IM injection 60 minutes post IO injection resulted in therapeutic levels for a prolonged time, most closely mimicking standard hospital care of poisoned patients. The authors concluded the rapid increase in plasma concentrations, coupled with the sustainability of the drug in plasma supported advantages of IO over IM delivery.

Vallier DJ, Torrence AD, Stevens, III R, Arcinue PN, Johnson D. The effects of sternal and intravenous vasopressin administration on pharmacokinetics. Am J Disaster Med 2016;11(3):203-9. doi:10.5055/ajdm.2016.0240 841

A preclinical study comparing the maximum concentration (Cmax), time to maximum concentration (Tmax) when administering vasopressin via intravenous (IV) and sternal intraosseous (SIO) access in a cardiac arrest swine model. Anesthetized swine were put into cardiac arrest, after 2 minutes CPR was initiated for 2 minutes, then 40 units of vasopressin was administered via IV or SIO route. Results showed no significant difference in SIO and IV groups for Cmax or Tmax.

Wimmer MH, Heffner K, Smithers M, et al. The comparison of humeral intraosseous and intravenous administration of vasopressin on return of spontaneous circulation and pharmacokinetics in a hypovolemic cardiac arrest swine model. Am J Disaster Med 2016;11(4):237-42. doi:10.5055/ajdm.2016.0245 827

A preclinical study comparing IV and humeral intraosseous (IO) access administration of vasopressin in a hypovolemic swine model in cardiac arrest. Following exsanguination, the swine were placed in cardiac arrest for 2 minutes, then resuscitated for 2 minutes in accordance with ACLS guidelines. Vasopressin was administered. Blood samples were collected at various time points following vasopressin injection and analyzed for maximum concentration (Cmax) and time to maximum concentration (Tmax) between groups; return of spontaneous circulation was also captured. ROSC was achieved for all HIO subjects (n=7) and in seven out of eight IV subjects; mean time to ROSC was 9.8 minutes for HIO and 10.7 for the IV group. However, statistically there was no significant difference between HIO and IV administration of vasopressin for achievement of ROSC, time to ROSC, Cmax, Tmax, concentration over time, survivability, or odds ratio.

Wong MR, Reggio MJ, Morocho FR, et al. Effects of intraosseous epinephrine in a cardiac arrest swine model. J Surg Res 2016;201(2):327-33. doi:10.1016/j.jss.2015.11.015 776

Preclinical study that examined the differences in pharmacokinetics and pharmacodynamics of tibial IO (TIO) and IV-delivered epinephrine during cardiac arrest and CPR. There were no significant differences between IV versus TIO epinephrine in achieving ROSC, time to ROSC, and Cmax. In the context of ROSC, epinephrine delivered via TIO route was a clinically relevant alternative to IV administration. The authors concluded that when IV access cannot be immediately obtained in cardiac arrest patients, TIO access should be considered.

YEAR: 2015

Eriksson M, Strandberg G, Lipcsey M, Larsson A. Intraosseös provtagning kan vara värdefull i akuta lagen [Intraosseous sampling can be valuable in emergency situations]. Lakartidningen 2015 Feb 24;112pii:DCR3. Swedish 789

This article in Swedish describes a study evaluating use of aspirate obtained from the IO space for laboratory analysis. The authors note that point-of-care equipment should be used for analysis. Creatinine, morphine and troponin was successfully analyzed; leucocytes and platelets were noted to possibly cause falsely elevated values.

Eriksson M, Strandberg G, Lipcsey M, Larsson A. Troponin I can be determined in intraosseous aspirates in a porcine shock model. Clin Lab 2015;doi:10.7754/Clin.Lab.2015.141212 758

A preclinical study in which 8 anesthetized swine were put into an induced septic shock state to allow troponin I level measurements to be compared from serial venous plasma, arterial plasma and intraosseous aspirate specimens collected hourly. Two milliliters of IO aspirate were wasted before collecting each IO specimen for analysis. The levels of IO troponin I increased during the first 3 hours of shock but then plateaued at a high level while the venous and arterial levels continued to increase. Authors concluded that troponin I can be analyzed in bone marrow aspirates in a shock model and that this information may be useful in medical emergencies where cardiac damage is suspected to be involved.

Hill SL, Thomas SHL, Flecknell PA, et al. Rapid and equivalent systemic bioavailability of the antidotes HI-6 and dicobalt edetate via the intraosseous and intravenous routes. Emerg Med J 2015;32(8):626-31. doi: 10.1136/emmermed-2014-204171 751

A preclinical study evaluating the bioavailability of antidotes HI-6 oxime and dicobalt edetate when given via proximal tibia intraosseous (IO) access, established via the EZ-IO, compared to intravenous administration via central access in minipigs. Results showed rapid and similar systemic bioavailability of the antidotes when given by both routes and that IO access is an appropriate access route when IV access is impractical.

Intraosseous Vascular Access Bibliography

Pharmacokinetics/Dynamics

Johnson D, Garcia-Blanco J, Burgert J, et al. Effects of humeral intraosseous versus intravenous epinephrine on pharmacokinetics and return of spontaneous circulation in a porcine cardiac arrest model: A randomized control trial. *Ann Med Surg* 2015;4(3):306-10. doi:10.1016/j.amsu.2015.08.005

802

Prospective preclinical study by to determine the effects of humeral IO (HIO) and IV epinephrine administration during cardiac arrest on pharmacokinetics, ROSC, and odds of survival. There were no significant differences in ROSC, maximum concentration; except at 30 s, and time-to-concentration-maximum between the HIO and IV groups. Significant differences existed between the experimental groups and the control. The HIO delivered a higher concentration of epinephrine than the IV route at 30 s, which they noted may be a survival advantage. Authors suggested clinicians consider using the IO route to administer epinephrine when IV access is unobtainable.

Montez DF, Puga T, Miller L, et al. Intraosseous infusions from the proximal humerus reach the heart in less than 3 seconds in human volunteers. *Ann Emerg Med* 2015;66(4s):S47. http://dx.doi.org/10.1016/j.annemergmed.2015.07.165

771

In a healthy adult volunteer study contrast media was injected through the proximal humerus site and captured under fluoroscopy as it entered the heart. The mean time it took from injection at the insertion site to visualize contrast entry into the superior vena cava and the right atrium was 2.42 seconds. Abstract presented at ACEP 2015. This study was sponsored by Teleflex Incorporated.

Overbaugh R, Davlantes C, Miller L, Montez D, Puga T, Philbeck TE. Intraosseous vascular access catheter appears safe during extended dwell: a preliminary report. *Ann Emerg Med* 2015;66(4):S5

772

Abstract describing preliminary results for the first 24 subjects of an EZ-IO study evaluating catheter dwell times for 48 hours. Initial data indicate that IO vascular access can be safely maintained for a period up to 48 hours without risk of osteomyelitis or other serious adverse events. Authors also noted that additional analgesics for IO infusion pain management may be more effective than the current solely administering lidocaine into the IO space. This study was sponsored by Teleflex Incorporated.

Pasley J, Miller CHT, DuBose J, et al. Intraosseous infusion rates under high pressure: a cadaveric comparison of anatomic sites. *J Trauma Acute Care Surg* 2015;78(2):295-9. DOI: 10.1097/TA.0000000000000516

750

A cadaveric study evaluating intraosseous (IO) vascular access insertion sites for attainable flow rates under 300 mmHg. The EZ-IO was used to establish IO access at the proximal humerus and proximal tibia sites; the FAST1 was used to establish sternal IO access. The total volume of fluid infused at the three IO access sites was 469 ± 190 mL for the sternum; 286 ± 218 mL for the humerus; and 154 ± 94 mL for the tibia. The mean flow rate infused at each site was as follows: 93.7 ± 37.9 mL/min for the sternum; 57.1 ± 43.5 mL/min for the humerus; and 30.7 ± 18.7 mL/min for the tibia. First attempt placement success was 100% for the sternum and proximal humerus and 81% for the tibia.

Rubal BJ, Meyers BL, Kramer SA, Hanson MA, Andrews JM, DeLorenzo RA. Fat intravasation from intraosseous flush and infusion procedures. *Prehosp Emerg Care* 2015;19(3):376-90. doi: 10.3109/10903127.2014.980475

748

This preclinical study evaluated the occurrence of fat intravasation resulting from intraosseous (IO) flush and infusion in anesthetized swine. Intravasated fat was assessed using a lipophilic fluoroprobe (Nile red) and by vascular ultrasound imaging. Fat intravasation was observed during all IO infusion regimens, with subclinical pulmonary fat emboli persisting 24 hours post infusion. It was noted that initial flush was a significant factor in fat intravasation, low levels of intravasation occurred with infusions ≤ 300 mmHg, fat intravasation and bone marrow shear-strain increased with IO infusion rates, and intravasation was influenced by cannula insertion site.

Salzman JG, Frasccone RJ, Zagar AE et al. Intraosseous pressure monitoring in critical care patients. *Ann Emerg Med* 2015;66(4s):S148

755

The authors described a proof of concept pilot study conducted to determine intraosseous (IO) pressure measures and their relationship to blood pressure obtained using an external blood pressure cuff in ICU patients. The average IO systolic blood pressure, IO diastolic blood pressure, and IO mean were 39.5 ± 12.7 mm Hg, 31.5 ± 7.6 mmHg, and 35.0 ± 8.8 mm Hg respectively. The ratio of IO systolic blood pressure to cuff systolic blood pressure, IO diastolic blood pressure to cuff diastolic blood pressure, and IO mean to cuff mean are $34.5 \pm 13.4\%$, $40.5 \pm 22.3\%$, and $40.1 \pm 17.1\%$ respectively. There were no adverse events reported. Investigators concluded that in their convenience sample of severely ill and injured patients, IO pressure was reliably obtained and appeared to be 35% to 40% of blood pressure readings obtained via external blood pressure cuff; and that this method of pressure monitoring may be an appropriate alternative to invasive monitoring option in the future. This study was sponsored by Teleflex Incorporated.

Strandberg G, Larsson A, Lipcsey M, Michalek J, Eriksson M. Intraosseous and intravenous administration of antibiotics yields comparable plasma concentrations during experimental septic shock. *Acta Anaesthesiol Scand* 2015;doi: 10.1111/aas.12454

738

Preclinical study using a porcine model to determine whether there were differences in intraosseous (IO) and intravenous (IV) antibiotic (cefotaxime and gentamicin) concentrations during septic shock. Both methods of administration yielded comparable concentrations. Authors concluded in an emergency, IO administration of these antibiotics may be considered in severe infections when venous access is difficult
Sweden

Intraosseous Vascular Access Bibliography

Pharmacokinetics/Dynamics

YEAR: 2014

- Barnard EBG, Moy RJ, Kehoe AD, Bebarta VS, Smith JE. Rapid sequence induction of anesthesia via the intraosseous route: a prospective observational study. Emerg Med J 2014;32(6):449-52. doi:10.1136/emered-2014-203740** 702
- A prospective observational study that evaluated use of intraosseous vascular access for delivery of rapid sequence intubation (RSI) drugs. Data was collected between January and May 2012 at a combat hospital in Afghanistan. Thirty-four (34) patients underwent RSI with drug delivery via the IO route. Access was established in the proximal humerus and tibia using the EZ-IO and in the sternum using the FAST-1. All placements were successful on first attempt; first pass intubation success rate was 97%; a Cormack-Lehane (C-L) laryngoscopic grade view of 1 was reported 91%. Authors concluded that IO access is a safe and feasible route for delivery of anesthetic drugs for RSI.
- Bebarta VS, Pitotti RL, Bondreau S, Tanen DA. Intraosseous versus intravenous infusion of hydroxocobalamin for the treatment of acute severe cyanide toxicity in a swine model. Aca Emerg Med 2014;21(11):1203-11** 865
- Randomized swine study with the objective to compare the efficacy of IO delivery of hydroxocobalamin to intravenous (IV) injection for the management of acute cyanide toxicity. The survival rate, physiologic parameters such as reversal of hypotension, and pharmacokinetic results were similar between the IV and IO group. The primary limitation was use of a swine model. Investigators concluded intraosseous hydroxocobalamin may be as effective as the intravenous route in treatment of cyanide toxicity.
- Bebarta VS, Vargas TE, Castaneda M, Boudreau S. Evaluation of extremity tissue and bone injury after intraosseous hypertonic saline infusion in proximal tibia and proximal humerus in adult swine. Prehosp Emerg Care 2014;doi:10.3109/10903127.2014.912704** 697
- Randomized comparative study of adult pigs infused intraosseously with either: 7.5% hypertonic solution (HTS), 3% HTS or normal 0.9% isotonic saline. The animals were observed daily for infection, necrosis and gait up to 5 days, then necropsy and histological analysis was performed for tissue necrosis. Observations included regular tissue morphology and normal gait scores over the 5 day observation period; and absence of gross tissue necrosis and microscopic ischemia post IO HTS infusion in this swine model. Authors concluded this study confirms the clinical safety of IO HTS infusion and its use as an alternative lifesaving treatment.
- Burgert J, Mozer J, Williams T, et al. Effects of intraosseous transfusion of whole blood on hemolysis and transfusion time in a swine model of hemorrhagic shock: a pilot study. AANA Journal 2014;82(3):198-202** 733
- Preclinical study using a porcine model to determine whether there were differences in intraosseous (IO) and intravenous (IV) whole blood transfusion relative to hemolysis and transfusion time. IO transfusion does not significantly increase hemolysis (using free hemoglobin as outcome measure) or transfusion time compared with IV transfusion. Authors concluded transfusion of whole blood through an IO device is an effective transfusion method that may be used until other vascular access is obtained.
- Cervinski MA. Laboratory analysis of intraosseous blood: bad to the bone? Clin Chem Lab Med 2014;doi:10.1515/cclm-2014-0104** 704
- A letter to the editor questioning the practice of using IO blood for laboratory analysis. The author identifies there is a lack of clinical evidence supporting IO blood laboratory analysis and concludes that IO access should be limited to infusion of fluid and medications until the relationship of IO blood to peripheral blood is defined.
- Johnson D, Dial J, Ard J, et al. Effects of intraosseous and intravenous administration of Hextend on time of administration and hemodynamics in a swine model. J Spec Oper Med 2014;14(1):79-85** 713
- A preclinical study comparing intraosseous (IO) and intravenous (IV) administration of Hextend in 27 swine for time of administration and hemodynamics. IO access was established in the proximal humerus using the EZ-IO. Results showed time for administration was not significant; there were no significant differences between IV and IO relative to hemodynamics. The author concluded that the IO route is an effective method of administering Hextend
- Lewis P, Wright C. Saving the critically injured trauma patient: a retrospective analysis of 1000 uses of intraosseous access. Emerg Med J 2014;31(9):784. doi:10.1136/emered-2014-203588** 714
- This retrospective study reported IO use over a 7-year period during combat operations in Afghanistan by the UK Defence Medical Services. The EZ-IO and FAST1 IO devices were available for use; IO use data was collected from the front line, during helicopter evacuation and at the combat hospital. A total of 1014 IO devices were inserted into 830 adult patients; various medications infused via IO access are listed. Across all cases there were no serious IO complications and 14 minor complications. The author concluded that in the pre-hospital setting in particular and in severely injured trauma patients, IO access should be considered a primary method of obtaining vascular access.
- Loughren M, Banks S, Naluan C, Portenlanger P, Wendorf A, Johnson D. Onset and duration of intravenous and intraosseous Rocuronium in swine. West J Emerg Med 2014;XV(2):241-5** 721
- A preclinical study comparing the time to onset, time to onset peak, and time to recovery of peripheral intravenous and tibial intraosseous administration of Rocuronium. Study results demonstrated there was no statistical difference from the time of administration to complete neuromuscular blockade between the IO and IV administration of Rocuronium; and the recovery of neuromuscular function was significantly longer after IO administration, however was not deemed clinically significant. The authors concluded that Rocuronium can effectively be used via the IO route without the need for dose adjustments.

Intraosseous Vascular Access Bibliography

Pharmacokinetics/Dynamics

- Puga T, Montez D, Davlantes C, et al. Whole blood transfusion via IO access does not result in gross hemolysis in a pre-clinical study. Crit Care Med 2014;42(12):A1421. abstract 251** 760
- In this pre-clinical study, 18 units of blood were transfused into 10 anesthetized swine via intraosseous (IO) access. Venous specimens were collected to evaluate free hemoglobin levels as an indicator of hemolysis. Seventeen transfusions were given via the proximal humerus site and 1 via the proximal tibia, using a pressure bag set to 300 mmHg. Mean transfusion flow rate was 61.6 ± 37.3 mL/min and the mean blood volume transfused was 266 ± 74 mL (n=18). The authors concluded that blood transfusion via IO access resulted in high flow rates and did not result in appreciable hemolysis as indicated by free hemoglobin values. This study was sponsored by Teleflex Incorporated.
- Schlimp CJ, Solomon C, Keibl C, et al. Recovery of fibrinogen concentrate after intraosseous application is equivalent to the intravenous route in a porcine model of hemodilution. J Trauma Acute Care Surg 2014;76(5):1235-42** 717
- A preclinical study comparing the recovery of fibrinogen in a porcine model when fibrinogen concentrate is administered via IV and IO access. The study results suggested intraosseous administration of fibrinogen concentrate results in a recovery of fibrinogen similar to that of intravenous administration.
- Sontgerath JS, Rubal BJ, DeLorenzo RA, Morgan TL, Ward JA. Variability in intraosseous flush practices of emergency physicians. Am J Emerg Med 2014;http://dx.doi.org/10.1016/j.ajem.2014.03.001** 719
- This prospective study sought to evaluate intraosseous flush practices of emergency physicians. Using cadavers, 15 emergency physicians were asked to flush an IO catheter placed in the proximal tibia and proximal humerus IO insertion sites with 10 mL normal saline as they would in clinical practice; IO pressure measurements were recorded using an IO catheter inserted in the diaphysis of the target bones. Results showed the median IO pressure generated was 903 mmHg and the median flush duration was 5.2 seconds. Result showed significant interoperator variability with greater than 35-fold difference in flush forces. The authors concluded that it may be prudent practice for providers to extend the flush over several seconds to limit the maximal pressures.
- Winkler M, Talley C, Landwehr K, et al. Use of intraosseous needles for power injection of iodinated contrast media for emergency computed tomography angiography. J Cardiovasc Comput Tomogr 2014;9th annual scientific meeting abstracts:S76-7** 701
- Abstract presented at the Society of Cardiovascular Computed Tomography on preliminary findings of an observational study done after training ER physicians and techs on intraosseous (IO) catheter use and implementation of a policy for IO access use. Authors report high injection rates and excellent computed tomography angiography (CTA) scans safety with use of an IO for power injection of iodinated contrast media (ICM). Authors concluded cardiovascular imaging physicians, surgeons, ER physicians, and CT technologists should be familiar with the techniques of IO needle placement and use for power injection of ICM for CTA. The diagnosis and treatment of critically ill and unstable patients may be hastened by this technique.
- Young SW, Zhang M, Freeman JT, Mutu-Grigg J, Pavlou P, Morre GA. The Mark Coventry Award: Higher tissue concentrations of vancomycin with low-dose intraosseous regional versus systemic prophylaxis in TKA. Clin Orthop Relat Res 2014;472(1):57-65. doi:10.1007/s11999-013-3038-z** 620
- This randomized, controlled study compared tissue concentrations at the surgical site of regionally and systemically administered prophylactic vancomycin, in 30 patients undergoing total knee arthroscopy. The antibiotic was administered using three methods: 250mg through IO regional administration in the proximal tibia (IORA); 500mg through IORA; and 1g administered systemically through IV. Results showed the tissue concentration of vancomycin was greater in the 250mg IORA group than the systemic IV group, and the 500mg IORA group had higher concentrations than both groups.
- YEAR: 2013**
- Ahrens KL, Reeder SB, Keevil JG, Tupesis JP. Successful computed tomography angiogram through tibial intraosseous access: a case report. J Emerg Med 2013;45(2):182-5. doi: 10.1016/j.jemermed.2012.11.091** 632
- Case report of 54-year-old male obtunded patient requiring a CT angiogram to diagnosis a suspected massive pulmonary embolism. After several failed attempts to reestablish PIV access, 150mL of contrast were injected through the proximal tibia IO catheter placed by EMS. Excellent opacification of the pulmonary arteries was achieved and there were no immediate complications from the injection noted.
- Frascone RJ, Salzman JG, Ernest EV, Burnett AM. Use of an intraosseous device for invasive pressure monitoring in the ED. Am J of Emerg Med 2014;32(6):692.e3-692.e4.doi:10.1016/j.ajem.2013.12.029** 667
- A case study describing intraosseous pressure monitoring, through tibial IO access, using a standard arterial pressure monitoring transducer during resuscitation of a 31-year-old male in cardiac arrest. Pressure readings were recorded for approximately 53 minutes and were compared to non-invasive blood pressure cuff monitoring at the same time points. IO systolic, diastolic and mean IO pressures were approximately 40% of arterial pressures. This is the first case report demonstrating IO space has a measureable blood pressure and it correlates with pressure obtained through conventional techniques.
- Grossman V. Hot Topics: CT contrast and intraosseous lines: friends or enemies? J Radiol Nurs 2013; 32(1):41-4. http://dx.doi.org/10.1016/j.jradnu.2012.12.004** 643
- General discussion on use of the intraosseous vascular access route for infusion of CT contrast, with attention to clinical considerations pertinent to nurses working in the imaging suite. Author also reviews general IO principles and IO devices.

Intraosseous Vascular Access Bibliography

Pharmacokinetics/Dynamics

Hamed RK, Hartmans S, Gausche-Hill M. Anesthesia through an intraosseous line using an 18-gauge intravenous needle for emergency pediatric surgery. J Clin Anesth 2013;25(6):447-51;pii: S0952-8180(13)00202-X. doi: 10.1016/j.jclinane.2013.03.013.http://dx.doi.org/10.1016/j.jclinane.2013.03.013. Accessed September 3, 2013

670

This 30 pediatric patient case series describes use of IO access in the perioperative setting when peripheral and central venous access failed during anesthesia administration for emergency surgery. Due to unavailability of modern IO devices, a standard 18-gauge IV needle with a handmade IV extension set were used to establish IO access. The authors reported administering ketamine, succinylcholine, pancuronium, atracurium, halothane, neostigmine, atropine, blood products, fluids and hydrocortisone through the IO line without complication. The authors concluded that although it is not the first-line method for anesthesia, IO access should be considered by pediatric anesthesiologist when peripheral and central venous access has failed or is difficult.

Iraq

Harris M, Balog R, Devries G. What is the evidence of utility for intraosseous blood transfusion in damage-control resuscitation? J Trauma Acute Care Surg 2013;75(5):904-6. doi:10.1097/TA.0b013e3182a85f71

671

This article explores the use of IO access for blood product administration and whether or not it is clinically effective. Based upon lack of clinical evidence and physics principles, the author argues that maximum flow rates attainable for IO blood infusion are not adequate for resuscitation.

Larsson T, Strandberg G, Eriksson M, Bondesson U, Lipcsey M, Larsson A. Intraosseous samples can be used for opioid measurements- and experimental study in the anesthetized pig. Scand J Clin Lab Invest 2013;73(2):102-6. doi:10.3109/00365513.2012.744088

605

In this preclinical swine study, investigators sought to evaluate whether intraosseous blood samples can be used to measure opioids, and if so, to determine the level of accuracy of those measurements. Blood samples were drawn from bilateral tibial IO catheters and from a central venous catheter for six hours. Authors concluded that IO blood samples can be used for the analysis of opioids if an IV route is not available.

Santos D, Carron PN, Yersin B, Pasquier M. EZ-IO intraosseous device implementation in a pre-hospital emergency service: a prospective study and review of the literature. Resuscitation 2013;84(4):440-5. http://dx.doi.org/10.1016/j.resuscitation.2012.11.006

604

An observational study evaluating use of the EZ-IO in a Swiss pre-hospital EMS system between January 1, 2009 and December 31, 2011 and comparing those results to the literature. Sixty IO insertions were performed on 58 patients; the proximal tibia was used in all attempts except 1 attempt made in the proximal humerus. Overall success rate was 90%; the 6 failures were attributed to impossibility to infuse, difficult needle insertion, and incorrect insertion site (tibial plateau). Some of the indications for IO access included cardiorespiratory arrest, major trauma, and shock; general anesthesia was successfully induced in 7 patients. Drugs infused are listed. There were no serious complications.

Spencer TR. Intraosseous administration of thrombolytics for pulmonary embolism. J Emerg Med 2013;45(6):e197-e200. http://dx.doi.org/10.1016/j.jemermed.2013.05.057

682

A case report describing administration of thrombolytics via tibial IO vascular access for pulmonary embolism in a 36-year-old woman. Due to the emergent nature of the situation, IO access was determined to be the best option for immediate vascular access. Alteplase was administered through the IO line at 100 mg over 2 hours without complication. The patient successfully recovered and was discharged from the hospital on day 7 without long-term disability. The author concluded that this case study raised the potential use of IO lines to deliver thrombolytics in patients with massive pulmonary embolism and that further evaluation is needed to compare the risk and benefits of the alternative method of administration.

Veldhoen ES, de Vooght KMK, Sliker MG, Versluys AB, Turner NMB. Analysis of bloodgas, electrolytes and glucose from intraosseous samples using an i-STAT point-of-care analyser. Resuscitation 2013;http://dx.doi.org/10.1016/j.resuscitation.2013.12.002

692

A prospective study comparing IO and venous laboratory values obtained from a point-of-care analyzer (i-STAT) in 20 children. IO blood specimens were collected from the iliac crest; 2 ml were discarded before the sample was collected analysis. Results showed differences between venous and IO sample were clinically acceptable for pH, base excess, sodium, ionized calcium and glucose in hemodynamically stable patients. Authors concluded that analysis of IO samples with a bedside point-of-care analyzer is feasible and in emergency situations may be useful to guide treatment.

Weiser G, Poppa E, Katz Y, Bahouth H, Shavit I. Intraosseous blood transfusion in infants with traumatic hemorrhagic shock - a case report and review of the literature. Am J Emerg Med 2013;31(3):640.e3-4. doi: 10.1016/j.ajem.2012.10.036

646

This article describes a case study of a 5-month old infant that suffered a head injury resulting in shock. She received 100 mL of red blood cells via the EZ-IO in the proximal tibia, resulting in rapid hemodynamic improvement. A literature search was completed for cases of IO blood transfusion in pediatric trauma. Authors note IO availability and knowledge play an important role in hemorrhagic shock; and RBC infusions via the IO route are feasible in this age group.

Intraosseous Vascular Access Bibliography

Pharmacokinetics/Dynamics

- Young SW, Zhang M, Freeman JT, Vince KG, Coleman B. Higher cefazolin concentrations with intraosseous regional prophylaxis in TKA. Clin Orthop Relat Res 2013;471(1):244-9. doi:10.1007/s11999-012-2469-2** 576

A clinical study comparing Cefazolin concentrations found at the operation site following total knee arthroscopy when prophylactic antibiotics are administered systemically, through IV administration, and regionally, through IO injection directly at the site using the EZ-IO. Subcutaneous fat and bone samples were collected for evaluation from 22 subjects. Authors concluded that regional IO administration of prophylactic antibiotics can achieve tissues levels higher than with systemic administration.

YEAR: 2012

- Burgert J, Gegel B, Loughren M. Comparison of tibial intraosseous, sternal intraosseous, and intravenous routes of administration on pharmacokinetics of epinephrine during cardiac arrest: A pilot study. AANA Journal 2012;80(4):S6-S10** 660

Preclinical study using a porcine model comparing the maximum concentration and time to maximum concentration of epinephrine administered via the tibial IO, sternal IO and IV routes during CPR. The IV route of administration of 1mg of epinephrine resulted in a serum concentration 5.87 and 2.86 times greater than the tibial route and sternal route respectively. The times to peak concentration was similar for IV and sternal IO groups but delayed for the tibial route. Authors conclude that due to limitations of their study the guidelines of administering 1mg of epinephrine via the IO route should not be changed; further studies using larger sample size, larger volume flush, arterial blood samples and the use of a more precise method of measuring serum epinephrine should be done.

- Carness JM, Russell JL, Lima RM, Navarro LHC, Kramer GC. Fluid resuscitation using the intraosseous route: Infusion with lactated ringers and hetastarch. Mil Med 2012;177(2):222-8.** 529

This pre-clinical study evaluated IO flow rates obtainable with infusion of lactated Ringer's and hetastarch 6% through the proximal tibia and sternum IO insertion sites, using a swine model. The EZ-IO 25mm was used to facilitate tibial IO access; sternal access was established using a Jamshidi needle. Results showed that hetastarch flow rates were lower than lactated Ringer's flow rates at both insertion sites; sternal infusion of hetastarch is likely to provide greater estimated intravascular volume expansion than lactated Ringer's, despite the lower infusion rates; resuscitation using the IO rate is likely to benefit from pressure bag or high-pressure pump delivery. This study was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.

- Dandele LM, Ohler KH. Pharmacotherapy of pediatric advanced life support and toxicological emergencies. AACN Adv Crit Care 2012;23(4):398-412. doi:10.1097/NCI.0b013e31826b4c70** 635

PALS 2012 guidelines on pharmacotherapy and toxicological emergencies.

- Duncan L, Cohen J, Triner W, Rea J, King C. Intraosseous administration of CT Contrast in a porcine model: a feasibility study. Ann Emerg Med 2012;60(4S):S92** 598

This abstract presented at the 2012 ACEP Research Forum discusses a swine pre-clinical study evaluating CT image opacification when contrast is delivered via IV and proximal humerus IO access. The EZ-IO was used to facilitate IO access. Results showed that under blinded radiology review the IV and IO images were judged adequately opacified to meet diagnostic criteria. Authors concluded that IO administration of contrast material may be a viable alternative if other vascular access is unavailable or if establishing other access will lead to a delay in diagnostic evaluation. This study was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.

- Goodman IS, Lu CJ. Intraosseous infusion is unreliable for adenosine delivery in the treatment of supraventricular tachycardia. Pediatr Emerg Care 2012;28(1):47-8** 524

Physicians from two different emergency department settings reported 2 cases of supraventricular tachycardia (SVT) in infants (2 and 4 month old) in which IO administration of adenosine failed to convert SVT to a normal rhythm.

- Hoskins SL, Nascimento P Jr., Lima RM, Espana-Tenorio, JM, Kramer GC. Pharmacokinetics of intraosseous and central venous drug delivery during cardiopulmonary resuscitation. Resuscitation 2012;83(1):40-5. doi:10.1016/j.resuscitation.2011.07.041** 442

Pharmacokinetics of IO drug delivery was compared using the tibia or sternum, versus central venous delivery during CPR. Anesthetized swine with KCl arrest were used for this study. CPR was initiated 8 minutes post arrest. Using 2 study groups, dye was injected as a bolus with adrenaline through either the IO sternal and tibial needles or through the IO sternal and IV central venous needles. Results showed peak arterial blood concentrations were faster for sternal IO vs tibial IO administration. Tibial IO delivered 65% of the total dose delivered with sternal administration. Peak blood concentrations were similar for sternal IO and central venous administration. Sternal IO delivered 86% of the total dose delivered by central venous administration. The EZ-IO and Jamshidi were used to facilitate IO access. This research was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.

- Mazaheri-Khameneh R, Sarrafzadeh-Rezaei F, Asri-Resaei S, Dalir-Naghadeh B. Evaluation of clinical and paraclinical effects of intraosseous vs intravenous administration of propofol on general anesthesia in rabbits. Vet Res Forum 2012;3(2):103-9** 614

A preclinical study evaluating the effects of propofol on selected blood parameters and physiological variables during general anesthesia in rabbits when administered via intraosseous and intravenous routes. Results showed the IO route was as effective as the IV route for propofol administration at doses inducing general anesthesia. The authors concluded that use of IO propofol could be recommended as a safe method of anesthesia in small animals with limited vascular access.

Intraosseous Vascular Access Bibliography

Pharmacokinetics/Dynamics

Mazaheri-Khameneh R, Sarrafzadeh-Rezaei F, Asri-Rezaei S, Dalir-Naghadeh B. Comparison of time to loss of consciousness and maintenance of anesthesia following intraosseous and intravenous administration of propofol in rabbits. J Am Vet Med Assoc 2012;241(1):73-80 589

A pre-clinical study evaluating the time to loss of consciousness and effective maintenance of anesthesia following IO and IV administration of propofol in 24 rabbits. The authors concluded that in all evaluated aspects of anesthesia, IO administered propofol was as effective as IV administration in rabbits

Miller LJ, Puga TA, Montez DF, Morgan J. New in therapeutic hypothermia: preclinical evidence validates the IO Route; chilled tubing works best. Ann Emerg Med 2012;60(4S):S90 601

This abstract presented at the 2012 ACEP Research Forum describes a preclinical swine study evaluating the ability to induce therapeutic hypothermia by infusing chilled saline via IV and IO access. The EZ-IO was used to facilitate IO access. Results showed statistical equivalence between IV and IO routes when used to deliver chilled saline to induce therapeutic hypothermia. Results also showed that use of chilled saline and infusion tubing submerged in an ice water bath provides the most effective means of cooling. This study was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.

Murray DB, Eddleston M, Thomas S, et al. Rapid and complete bioavailability of antidotes for organophosphorus nerve agent and cyanide poisoning in minipigs after intraosseous administration. Ann Emerg Med 2012;60(4):425-30. <http://dx.doi.org/10.1016/j.annemergmed.2012.05.013> 587

A pre-clinical study evaluating the systemic bioavailability of antidotes when administered via the intraosseous (IO), intravenous (IV), and intramuscular (IM) routes is described. Results showed rapid and substantial antidote bioavailability after IO administration similar to that of the IV route. Authors concluded that the IO route of antidote administration should be considered when IV access is difficult.

Paxton JH. Intraosseous vascular access: A review. Trauma 2012;14(3):195-232. DOI:10.1177/1460408611430175 690

An overview of IO vascular access including a review of currently available literature. The author discusses various IO devices available and their performance metrics, IO access sites, flow rates, advantages and disadvantages of IO access compared to conventional access methods, complications and recommendations on use of the approach. The author concludes that while IO access may not be appropriate for all patients, it deserves a place in the modern provider's armamentarium.

Strandberg G, Eriksson M, Gustafsson MG, Lipcsey M, Larsson A. Analysis of intraosseous samples using point of care technology: An experimental study in the anesthetized pig. Resuscitation 2012; 83(11):1381-5. doi: 10.1016/j.resuscitation.2012.04.007 558

This preclinical study sought to determine the accuracy of IO blood lab values by comparing lab results obtained using an I-Stat for IO blood and arterial blood. The authors concluded that the agreement between intraosseous and arterial analysis seemed to be good enough to be clinically useful, and that there were no clinically significant differences between samples collected from the right and left tibia.

Tan BKK, Chong S, Koh ZX, Ong MEH. EZ-IO in the ED: an observational, prospective study comparing flow rates with proximal and distal tibia intraosseous access in adults. Am J Emerg Med 2012;30(8):1602-6.doi.10.1016/j.ajem.2011.10.025 519

This prospective observational study compared flow rates between distal and proximal tibia IO access in adults, with each adult serving as their own control. The EZ-IO was used to facilitate IO access. IO infusion was performed with and without pressure. The authors concluded that infusion flow rates were significantly higher in the proximal tibia as compared to the distal tibia, and that flow rates are significantly higher with pressured infusion vs. non-pressured infusion. This study was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.

YEAR: 2011

Aliman AC, Piccioni Mde A, Piccioni JL, Oliva JL, Auler Junior JO. Intraosseous anesthesia in hemodynamic studies in children with cardiopathy. Rev Bras Anesthesiol 2011;61(1):41-9 654

A comparative study evaluating the effectiveness of IO access in relation to IV access for infusion of anesthetics (ketamine, midazolam, and fentanyl) and fluids during hemodynamic studies in 21 infants with congenital heart disease. IO access was established in the proximal tibia (n=11). Results showed, time to access was significantly shorter with IO access (3.6 vs 9.6 minutes); anesthetic onset was shorter with IV access (56.3 vs 71.3 seconds); and no significant difference between groups for hydration volume and anesthesia recovery time. The authors concluded that due to its easy manipulation and efficiency, hydration and anesthesia by IO access was satisfactory without necessity of other infusion access.

Brazil

Baombe J, Foex B. Is intraosseous access a safe option in adult cardiac arrest? A review of literature. Critical Care 2011;15(S1):S105. doi:10.1186/cc9714 594

This abstract reports a literature review using both MEDLINE and Embase databases up to August 2010 to determine feasibility and safety of IO administration during adult cardiac arrest. Authors reported a lack of literature (only two studies met their level of evidence criteria) but concluded IO access in adults appears to be a fast, reliable method to deliver drugs and fluid during CPR allowing adequate drug concentrations and pharmacological response; and should be considered if other medication delivery methods have failed. (Presented at the March 2011 International Symposium on Intensive Care and Emergency Medicine)

Intraosseous Vascular Access Bibliography

Pharmacokinetics/Dynamics

- Bebarta VS, Lairet J, Pitotti R, Dixon P, Valtier S, Tanen DA. Intravenous hydroxocobalamin versus intraosseous hydroxocobalamin in the treatment of acute, severe cyanide toxicity in a validated swine model. *Ann Emerg Med* 2011;58(4S):S324** 444
- This abstract describes a study comparing the return to baseline of mean arterial blood pressure between two groups of swine (total n=24) in acute cyanide toxicity and treated with hydroxocobalamin via IV or IO. They also compared blood cyanide lactate, pH, nitrotyrosine levels, cerebral near infrared spectrometry oxygenation, and inflammatory markers. Results showed that all test values in both groups were similar. The author concluded that IO infusion of hydroxocobalamin was found to be equally efficacious to IV administration in the animal model.
- Borron SW, Arias JC, Bauer CR, et al. Intraosseous line placement for antidote injection by first responders and receivers wearing personal protective equipment. *Am J Emerg Med* 2011;29(4):373-81. doi:10.1016/j.ajem.2009.10.009** 424
- This article describes a preclinical trial with a caprine model that assessed the ability of protected, experienced first responders and limited-experience first receivers to place IO lines for antidote administration using the EZ-IO device. First responders placed IO lines successfully in 100% of cases, and first receivers placed IO lines successfully in 91% of the cases. Investigators concluded that IO lines may facilitate earlier administration of antidotes to hazardous material victims.
- Lairet JR, Bebarta V, Boudreau S, King J. Use of intraosseous hydroxocobalamin for treatment of hemorrhagic shock in an adult swine (*Sus Scrofa*) model: A pilot study. *Ann Emerg Med* 2011;58(4S):S265** 455
- This abstract describes a study evaluating use of hydroxocobalamin as a treatment for hemorrhagic shock. Once the animal had a decrease of mean arterial pressure of 50% from baseline, the drug was infused over 7 minutes in 3 different dose groups; animals were observed for 90 minutes. Results showed the mean arterial pressure in the three groups rebounded to baseline at 105%, 90% and 78%, respectively. The authors concluded that IO administration of the drug significantly increased mean arterial blood pressure and systemic vascular resistance and that hydroxocobalamin may prove to be a pharmacologic adjunct for hemorrhagic shock.
- Rouhani S, Meloney L, Ahn R, Nelson BD, Burke TF. Alternative rehydration methods: a systemic review and lessons for resource-limited care. *Pediatrics* 2011;127:e748-57. doi: 10.1542/peds.2010-0952** 551
- This article discusses alternative rehydration methods for pediatric patients, including the intraosseous route.
- Strandberg G, Larsson A, Lipcsey M, Eriksson M. Intraosseous blood aspirates analysed by a portable cartridge-based device. *Crit Care* 2011;15(S1):P138. doi:10.1186/cc9558** 571
- In this pre-clinical study, IO and arterial blood samples were collected over a 6-hour timeframe from the tibia of anesthetized swine, analyzed using an iStat and compared. Results showed compliant values between IO and arterial blood for electrolytes, hemoglobin, pH, and pCO₂. Lactate, BE, PO₂ and SO₂ were less compliant. There were high correlations between SO₂ and PO₂ although the levels in arterial blood were higher.
- Zuercher M, Kern KB, Indik JH, et al. Epinephrine improves 24-hour survival in a swine model of prolonged ventricular fibrillation demonstrating that early intraosseous is superior to delayed intravenous administration. *Anesth Analg* 2011;112(4):884-90. doi: 10.1213/Ane.0b013e31820dc9ec** 533
- In this preclinical study, 30 swine in ventricular fibrillation received IO epinephrine, IV epinephrine, or placebo. Return of spontaneous circulation, 24-hour survival, and 24-hour survival with good neurological outcome was evaluated. Results showed ROSC to be nearly universal for the IV and IO groups with no differences between rates; 24-hour survival was substantially more likely in the IO group than the IV group; survival with good neurological outcome was more likely in the IO group than the IV group.
- YEAR: 2010**
- Attaran RR, Ewy GA. Epinephrine in resuscitation: Curse or cure? *Future Cardiol* 2010;6(4):473-82. http://www.medscape.com/viewarticle/726448_print** 449
- This article explores the use of epinephrine during cardiac arrest to evaluate the lack of demonstrated efficacy in human trials of out-of-hospital cardiac arrest as compared to the laboratory animal model. The author concluded that the value of epinephrine as an adjunct to resuscitation of cardiac arrest depends on the dosage, timing of administration and the initiating factor the cardiac arrest, and suggests that IO administration of epinephrine may help address the issue of timing of administration.
- Mosier JM, Hiller K, Franke H, Degan J, Boyer LV. Scorpion antivenom administered via alternative infusions. *J Med Toxicol* 2010;6:249** 799
- A case study describing administration of scorpion antivenom via intraosseous (IO) vascular access in a 16-month old female. Following failure to obtain IV access in pre-hospital and upon arrival at the ED, IO vascular access was established in the proximal tibia and 3 vials of antivenom in 50 mL saline were administered over 10 minutes. Within 5 minutes, the patients respiratory status improved, intubation was averted, and vital signs stabilized immediately; nystagmus and writhing resolved. The patient was discharged home after a short observation period. The authors concluded that when IV access is difficult, IO access may be a rapid and reasonable rescue maneuver for patients requiring scorpion antivenom.

Intraosseous Vascular Access Bibliography

Pharmacokinetics/Dynamics

- Valdes M, Araujo P, de Andres C, Sastre E, Martin T. Intraosseous administration of thrombolysis in out-of-hospital massive pulmonary thromboembolism. Emerg Med J 2010;27(8):641-4. doi:10.1136/emj.2009.086223** 434

This case study describes a 25 year-old woman who had a massive pulmonary thromboembolism and was administered thrombolysis via IO route (internal tibial malleolus) in the air-transfer pre-hospital setting. The patient recovered.

- Xie F, Hou KD, Song Q, Jiang CG. The change in bone marrow after intraosseous hypertonic saline-hydroxyethyl starch infusion for resuscitation of hemorrhagic shock in dog. Chin Crit Care Med 2010;22(5):309-12.doi.10.3760/cma.j.issn.1003-0603.2010.05.017** 459

This article in Chinese, describes a study that evaluated the effects to the bone marrow following IO infusion of hypertonic saline-hydroxyethyl (HSH) in the dog model; using a normal saline group (NS) and a non-infusion group. The test subjects were put into shock and resuscitated. Results showed that at 48 hours post infusion and 1 week post infusion changes were seen in the bone marrow and peripheral blood in the HSH and NS groups as compared to the non-infusion group. At 4 weeks post infusion, the NS group and HSH group recovered to normal level. Bone marrow morphology changed slightly but no bone necrosis occurred. The author concluded that HSH in small amounts via IO is safe and effective as a fluid resuscitation measure for shock, and little change in bone marrow has been found after infusion.

YEAR: 2009

- Borron SW, Arias JC, Bauer CR, Sanchez M, Fernandez M, Jung I. Hemodynamics after intraosseous administration of hydroxocobalamin or normal saline in a goat model. Am J Emerg Med 2009;27:1065-71** 439

In a preclinical study using a caprine model, researchers assessed the hemodynamics of hydroxocobalamin (OHCo) compared to normal saline (NS) by the intraosseous (IO) route and concluded that the effects of OHCo given by the IO route in non-CN-poisoned goats are mild and well tolerated. Investigators concluded that IO administration of OHCo may "find a role in the settings of individual patients with cyanide-induced cardiovascular collapse or mass cyanide casualties".

- Menegazzi JJ, LaCovary AC, Negron KI, et al. Potential reduction in time to drug administration if vascular access preceded intubation during out-of-hospital cardiac arrest. Prehosp Emerg Care 2009;13(1):133** 416

This abstract describes a retrospective study to determine the time from EMS dispatch to IV or IO drug delivery, time savings to drug delivery if vascular access preceded intubation, the internal validity of that point estimate using matched cases in which IV/IO was performed first, and the theoretical increase in rate of return to spontaneous circulation. Investigators concluded that time from dispatch to IV/IO delivery could be reduced by 4 minutes if vascular access preceded intubation and could, potentially double ROSC.

- Miller J, Lairet J, DeLorenzo R, Pitotti R. Intraosseous infusion of crystalloid fluid immediately after intraosseous infusion of nitroglycerin in the proximal tibia of a swine (sus scrofa) model. Ann Emerg Med 2009;54(3):S140** 414

This abstract for a presentation at the 2009 ACEP Research Forum describes a swine study that evaluated crystalloid fluid flow through an IO needle following nitroglycerin infusion in a swine model. Investigators concluded there was not a significant increase in flow rate after administration of IO nitroglycerin.

- Von Hoff DD, Kuhn JG, Burris HA, Miller LJ. La perfusion intraosseuse est-elle equivalente a la perfusion intraveineuse? Urgence Pratique 2009;36:36-40** 507

This French version of an article previously published in American Journal of Emergency Medicine describes a 25-patient clinical study that compared the pharmacokinetics of intraosseous using the Vidaport (a predecessor of the Vidacare EZ-IO) vs. intravenous administration of morphine sulfate in adults. Results showed no differences between IO and IV administration of morphine for nearly all pharmacokinetic parameters, including maximum plasma concentration, time to maximum plasma concentration, and area under plasma concentration-time curve. There was a significant difference in the volume of distribution in the central compartment, which investigators attributed to a minor deposition effect near the IO port or in the bone marrow. Investigators concluded that the results support the bioequivalence of IO and IV administration of morphine in adults.

- Wright JK, Christy RJ, Tharp RV, Kalns JE. Evaluation of intraosseous delivery of factor VIIa during hemorrhagic shock in the pig. Mil Med 2009;174:119-23** 419

This swine study was designed to determine if intraosseous infusion is suitable to delivery recombinant human factor VIIa (rFVIIa) during hemorrhagic shock. Investigators concluded that administration of rFVIIa via IO infusion is a safe route for delivery and is likely to produce blood levels required to improve hemostasis during shock.

YEAR: 2008

- Borron S, Arias J, Sanchez M, et al. Intraosseous line placement by hazardous materials responders and receivers for hydroxocobalamin administration. Ann Emerg Med 2008;52(4):S97** 420

Animal (goat) study to determine the capacity and time required for protected hazardous materials responders and receivers to accomplish vascular access and hydroxocobalamin administration for antidotal treatment for exposure to cyanide and other poison agents. Using the EZ-IO device, researchers concluded that the time required for IO administration of the drug was shorter than intravenous administration; and that IO placement is readily accomplished wearing all levels of chemical protective garments and equipment.

Intraosseous Vascular Access Bibliography

Pharmacokinetics/Dynamics

- Jensen J, Nusstein J, Drum M, Reader A, Beck M. Anesthetic efficacy of a repeated intraosseous injection following a primary intraosseous injection. J Endod 2008;34(2):126-30** 745
- The objective of this study was to determine the anesthetic efficacy of repeated intraosseous injections of 2% lidocaine with epinephrine given 30 minutes following a primary injection for pain management for dental procedures. Results found that a repeated injection provided 15 minutes of additional pulpal anesthesia.
- Nicoll SJB, Rochester SJ. Blood sampling through intraosseous needles: Time to stop? Resuscitation 2008;79:168-176.doi: 10.1016/j.resuscitation.2008.04.018** 549
- Two letters to the editor regarding use of IO blood for sampling in the emergency setting. One letter states it should no longer be done and only arterial or femoral venous samples should be used during resuscitation; the second notes the importance of IO blood sampling in emergency situations when time cannot be delayed for central line access, stating it is key that the sample be properly labeled as IO blood.
- Salter R. Reply to letter: Blood sampling through intraosseous needles: time to stop? Resuscitation 2008;79:168-9. doi:10.1016/j.resuscitation.2008.04.017** 727
- Two letters to the editor regarding use of IO blood for sampling in the emergency setting. One letter by S. Nicoll and S. Rochester states it should no longer be done and only arterial or femoral venous samples should be used during resuscitation. The second by R. Salter notes the importance of IO blood sampling in emergency situations when time cannot be delayed for central line access, stating it is key that the sample be properly labeled as IO blood.
- UK
- Von Hoff DD, Kuhn JG, Burris HA, Miller LJ. Does intraosseous equal intravenous? A pharmacokinetic study. Am J Emerg Med 2008; 26: 31-8** 387
- This article describes a 25-patient clinical study that compared the pharmacokinetics of intraosseous vs. intravenous administration of morphine sulfate in adults. Results showed no differences between IO and IV administration of morphine sulfate for nearly all pharmacokinetic parameters. Investigators concluded that the results support the bioequivalence of IO and IV administration of morphine in adults.
- YEAR: 2007**
- Favier JC, Landy C, Pernod G, Walkowiak P, Rottiman M. [Continuous intraosseous epinephrine infusions in adults: its interest when haemodynamics is poor]. Ann Fr Anesth Reanim 2007; 26: 884-5. French** 406
- Article describes the IO route to deliver epinephrine.
- Pugh JA, Tyler J, Churchill TA, Fox RJ, Aronyk KE. Intraosseous infusion into the skull: potential application for the management of hydrocephalus. J Neurosurg 2007;106(2 Suppl):120-5** 859
- A pre-clinical study evaluating use of intraosseous infusion into the skull, in large adult swine, for the purpose of cerebrospinal fluid (CSF) reabsorption. The authors created intraosseous infusion devices designed specifically for use in this study. Results showed IO infusion demonstrated similarities to systemic absorption characteristics; and authors concluded IO skull infusion may eventually provide another alternative in the management of hydrocephalus.
- Canada
- YEAR: 2006**
- Buck ML. Intraosseous administration of drugs in infants and children. Pediatr Pharm 2006;12(12)** 367
- Overview article of IO vascular access describes technique, efficacy in medication delivery, utility in pediatric emergencies, use in neonates, complications, and commonly-infused medications.
- Hoskins SL, Kramer GC, Stephens CT, Zachariah BS. Abstract 79: Efficacy of epinephrine delivery via the intraosseous humeral head route during CPR. Circulation 2006;114:II_1204** 422
- Results from this study which sought to determine the efficacy of intraosseous drug delivery using the proximal humerus during CPR in swine showed that the humeral route generated higher mean arterial pressures than central venous or endotracheal delivery.
- YEAR: 2005**
- Hoskins S, Nascimento P, Espana J, Kramer G. Pharmacokinetics of intraosseous drug delivery during CPR. Shock 2005;23:35** 423
- This animal study compared IO drug delivery in the tibia versus the sternum during CPR. Researchers concluded that during CPR IO infusions delivered via both sites were effective—although sternal delivery was faster; and that IO sternum access is comparable to IV access for drug delivery during CPR.

Intraosseous Vascular Access Bibliography

Pharmacokinetics/Dynamics

Hoskins S, Stephens C, Kramer G. Efficacy of intraosseous drug delivery during cardiopulmonary resuscitation in swine. Paper presented at the annual meeting of the National Association of EMS Physicians, Registry Resort, Naples, FL. 2009-05-25 from http://www.allacademic.com/meta/p64887_index.html 506

This study abstract discusses use of the EZ-IO to determine the pharmacokinetics (PK) and efficacy of tibial IO drug delivery during treatment of cardiac arrest in the swine model, as compared to IV access. Results showed that PK analysis of IO drug delivery via the tibial route showed a delay of 20-50 seconds compared to IV; however, physiologically significant levels of epinephrine were reached as MAP. This research was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.

Mattson SE, Pearce SG, Boure LP, Dobson H, Hurtig MB, Black WD. Comparison of intraosseous and intravenous infusion of technetium Tc 99m pertechnetate in the distal portion of forelimbs in standing horses by use of scintigraphic imaging. Am J Vet Res 2005; 66: 1267-72 346

Animal study comparing distribution of technetium Tc 99m pertechnetate following IO or IV injection. Both routes resulted in effective perfusion of the distal portion of the forelimb and similar distribution in the phalanges of horses.

Rodriguez Nunez A, Garcia C, Lopez-Herce Cid J; Grupo de Estudio de la Parada Cardiorrespiratoria en Pediatria. [Is high-dose epinephrine justified in cardiorespiratory arrest in children?]. An Pediatr (Barc) 2005;62(2):113-6. Spanish 343

Multicenter, prospective study of cardiopulmonary resuscitation data over 18 months. The study was design to evaluate the impact of survival of IV or IO high-dose epinephrine compared to standard doses in children with cardiorespiratory arrest. Limited conclusions showed that there is no significant difference between the two treatments.

Rubio-Martinez L, Lopez-Sanroman J, Cruz AM, Santos M, San Roman F. Medullary plasma pharmacokinetics of vancomycin after intravenous and intraosseous perfusion of the proximal phalanx in horses. Vet Surg 2005; 34: 618-24 338

Veterinary study of IO and IV pharmacokinetics of vancomycin in horses. Found no significant differences in pharmacokinetic variables and plasma drug concentrations between IO and IV administration.

Smith R, Davis N, Bouamra O, Lecky F. The utilisation of intraosseous infusion in the resuscitation of paediatric major trauma patients. Injury 2005;36(9):1034-8 341

Retrospective study over a 14-year period examining 129 IO insertions among 23,489 pediatric trauma patients. Patients receiving IO fluids and medications tended to be younger and sicker. Concludes that IO is an essential skill for anyone involved in pediatric trauma resuscitation.

Wood M, Reader A, Nusstein J, Beck M, Padgett D, Weaver J. Comparison of intraosseous and infiltration injections for venous lidocaine blood concentrations and heart rate changes after injection of 2% lidocaine with 1; 100,000 epinephrine. J Endod 2005;31:435-8 334

Prospective randomized dental study of the pharmacokinetics and pharmacodynamic effect of lidocaine and epinephrine administered via IO and infiltration injections. Found no difference in plasma levels of lidocaine for maxillary anterior IO and infiltration injections. Found a significant increase in heart rate with IO administration compared to infiltration injection.

YEAR: 2004

Carrera RM, Pacheco AM Jr, Caruso J, Mastroti RA. Intraosseous hypertonic saline solution for resuscitation of uncontrolled, exsanguinating liver injury in young swine. Eur Surg Res 2004;36:282-92 316

Preclinical study in young pigs comparing IO and IV administration of hypertonic saline solution in an uncontrolled hemorrhagic shock swine model. Found no significant difference between IO and IV administration.

Abstract only

Clem M, Tierney P. Intraosseous infusions via the calcaneus. Resuscitation 2004;62(1):107-12 322

Cadaver study demonstrating immediate entry of methyl green dye into the venous system after IO infusion via the calcaneus in 14 of 20 cadaver legs (70%).

YEAR: 2003

Nusstein J, Kennedy S, Reader A, Beck M, Weaver J. Anesthetic efficacy of the supplemental x-tip intraosseous injection in patients with irreversible pulpitis. J Endo 2003;29(11):724-8 299

Dental study finding successful injections of 2% lidocaine with epinephrine in 27 of 33 (82%) X-tip IO injections (82%) for anesthesia in mandibular teeth.

Intraosseous Vascular Access Bibliography

Pharmacokinetics/Dynamics

YEAR: 2002

Alam HB, Punzalan CM, Koustova E, Bowyer MW, Rhee P. Hypertonic saline: intraosseous infusion causes myonecrosis in a dehydrated swine model of uncontrolled hemorrhagic shock. J Trauma 2002;52(1):18-25 285

IO infusion of 7.5% hypertonic saline in this model was associated with a high rate of local complications (soft tissue or bone marrow necrosis).

Olsen D, Packer BE, Perrett J, Balentine H, Andrews GA. Evaluation of the bone injection gun as a method for intraosseous cannula placement for fluid therapy in adult dogs. Vet Surg 2002;31(6):533-40 288

Veterinary study comparing the B.I.G. with the manually driven Jamshidi IO needle. Concludes the B.I.G. provides more rapid access to the IO space.

YEAR: 2001

Butt TD, Bailey JV, Dowling PM, Fretz PB. Comparison of 2 techniques for regional antibiotic delivery to the equine forelimb: intraosseous perfusion vs. intravenous perfusion. Can Vet J 2001;42(8):617-22 283

Veterinary study comparing IO and IV pharmacokinetics of Amikacin in horses. Found that maximal concentration of Amikacin concentration was significantly higher with IV perfusion.

Chastagner P, Lozniewski A, Lascombes P, Barberi-Heyob M, Merthes PM, Merlin JL. Pharmacokinetic longitudinal studies of antibiotics administered via a permanent intraosseous device in micropigs. Med Pediatr Oncol 2001;36(6):635-40 273

Preclinical study in micropigs investigating the short and long term efficacy and safety of an implantable IO device. The study compared serum concentrations of Amikacin and Vancomycin administered through the implantable IO device, an intra-tibial needle, and a central IV line. Found similar concentration curves among all 3 routes for both antibiotics, though vancomycin levels did not reach therapeutic levels for both IO routes. Concludes that long term administration of antibiotics through an implantable IO device is feasible and safe in micro-pigs.

Donati F, Guay J. The substitute for the intravenous route. Anesthesiology 2001;95(4):1041 542

This letter is in response to an editorial on management of laryngospasms without previous intravenous access. The authors debate the use of intramuscular succinylcholine vs. intraosseous administration.

Voelckel WG, Lurie KG, McKnite S, Zielinski T, Lindstrom P, Peterson C, Wenzel V, Lindner KH. Comparison of epinephrine with vasopressin on bone marrow blood flow in an animal model of hypovolemic shock and subsequent cardiac arrest. Crit Care Med 2001; 29: 1587-92 279

Preclinical study in pigs. Found that blood flow in the IO space is responsive to both physiologic stress response caused by electroshock and to vasopressors given during resuscitation after hypovolemic cardiac arrest. Blood flow in the IO space was nearly absent following successful resuscitation with high-dose epinephrine, but was maintained after high-dose vasopressin. Concludes there may be a need for a pressurized intraosseous infusion during hemorrhagic shock.

YEAR: 2000

Chamberlain TM, Davis RD, Murchison DF, Hansen SR, Richardson BW. Systemic effects of an intraosseous injection of 2% lidocaine with 1; 100,000 epinephrine. Gen Dent 2000; 48: 299-302 250

Dental study of IO injection of lidocaine in 20 human volunteers. Found a statistically significant increase in heart rate immediately after IO injection (12 beats per minute) but no effect on blood pressure.

Gallatin E, Stabile P, Reader A, Nist R, Beck M. Anesthetic efficacy and heart rate effects of the intraosseous injection of 3% mepivacaine after an inferior alveolar nerve block. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2000; 89: 83-7 268

Dental study demonstrating that intraosseous injection of 1.8 ml of 3% mepivacaine to augment nerve block in the first molar significantly increased the anesthetic success over 30 minutes and had a minimal effect on heart rate.

Khan TM, Kisson N, Hasan MY, Saldajeno V, Murphy SP, Lima JJ. Comparison of plasma levels and pharmacodynamics after intraosseous and intravenous administration of fosphenytoin and phenytoin in piglets. Pediatr Crit Care Med 2000;1(1):60-4 257

Pharmacokinetic study in piglets comparing IO and IV administration of fosphenytoin and phenytoin. Therapeutic plasma levels were achieved with both administration routes for both drugs. Concludes no need to adjust the standard drug doses of phenytoin for IO administration. Cautions slow infusion rates for fosphenytoin due to concerns over neurotoxicity.

Intraosseous Vascular Access Bibliography

Pharmacokinetics/Dynamics

- Pan'ko SV, Antipov IuG, Semenido IuN, Sosnovskaia Olu, Golovanova TA, Sanin AV.** [Suppression of graft versus host reaction by depositing a magnet-controlled adriamycin dosage form in bone marrow allotransplantation in animal experiments]. *Vestnik Rossiiskoi Akademii Meditsinskikh Nauk* 2000;(3): 10-5. Russian. Abstract 251

Intraosseous transplantation of bone marrow in combination with long-acting Adriamycin may inhibit acute and chronic graft versus host reactions.

- Stabile P, Reader A, Gallatin E, Beck M, Weaver J.** Anesthetic efficacy and heart rate effects of the intraosseous injection of 1.5% etidocaine (1; 200,000 epinephrine) after an inferior alveolar nerve block. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2000;89(4):407-11 258

Dental study in 48 volunteers finding IO injection of etidocaine resulted in a significant increase in anesthetic effect. The majority of subjects receiving IO etidocaine solution experienced a transient increase in heart rate.

YEAR: 1999

- Brown R.** Intraosseous anesthesia: a review. *J Calif Dent Assoc* 1999;27(10):785-92 233

This article describes use of intraosseous injection of anesthetic for dental applications.

- Efimov IuV, Zaitsev VG, Sychugov AV.** [The treatment of patients with complicated mandibular fractures using a method for the intraosseous administration of biologically active drug agents]. *Stomatologiya (Mosk)* 1999; 78; 26-7. Russian 248

Article in Russian; no English translation.

- Geller E, Crisci KL.** Intraosseous infusion of iodinated contrast in an abused child. *Pediatr Emerg Care* 1999;15(5):328-9 247

This case study described administration of iodinated contrast via IO infusion in the tibia, for an abdominal CT scan in a 7 week old infant. CT imagining demonstrated adequate enhancement of the solid organs and vasculature.

- Kentner R, Haas T, Gervais H, Hiller B, Dick W.** Pharmacokinetics and pharmacodynamics of hydroxyethyl starch in hypovolemic pigs; a comparison of peripheral and intraosseous infusion. *Resuscitation* 1999;40(1):37-44 240

Preclinical study in hypovolemic pigs finding no significant difference in pharmacokinetic and pharmacodynamic parameters between IO and IV infusion of hydroxyethyl starch.

- Replogle K, Reader A, Nist R, Beck M, Weaver J, Meyers WJ.** Cardiovascular effects of intraosseous injections of 2 percent lidocaine with 1; 100,000 epinephrine and 3 percent mepivacaine. *J Am Dent Assoc* 1999;130(9):649-57 234

Dental study in 42 volunteers finding most subjects receiving IO Lidocaine-epinephrine solution experienced a transient increase in heart rate. No significant increase in heart rate was observed with the intraosseous injection of 3% Mepivacaine.

- Wenzel V, Lindner KH, Augenstein S, Voelckel W, Strohmenger HU, Prengel AW, Steinbach G.** Intraosseous vasopressin improves coronary perfusion pressure rapidly during cardiopulmonary resuscitation in pigs. *Crit Care Med* 1999;27(8):1565-9 246

Preclinical study in pigs finding that plasma levels of vasopressin, hemodynamic variables, and return of spontaneous circulation were comparable for IO and IV administration. Concludes IO vasopressin may be a viable alternative during CPR when IV access is delayed or not available.

YEAR: 1998

- Bennett RA, Schumacher J, Hedjazi-Haring K, Newell SM.** Cardiopulmonary and anesthetic effects of propofol administered intraosseously to green iguanas. *J Am Vet Med Assoc* 1998;212(1):93-8 230

Veterinary study in 14 iguanas were finding that IO propofol resulted in a significant decrease in heart rate that appeared 35 minutes after induction of anesthesia and persisted for 120 minutes. Serum pO2 values decreased after induction of anesthesia.

Abstract only

YEAR: 1997

- Dubick MA, Kramer GC.** Hypertonic saline dextran (HSD) and intraosseous vascular access for the treatment of haemorrhagic hypotension in the far-forward combat arena. *Ann Acad Med Singapore* 1997;26(1):64-9 218

Review article highlighting preclinical data and 1 clinical study. Demonstrates that IO administration can be used for safe and rapid infusion of hypertonic saline dextran with the hemodynamic effect as IV administration.

Intraosseous Vascular Access Bibliography

Pharmacokinetics/Dynamics

YEAR: 1996

Friedman FD. Intraosseous adenosine for the termination of supraventricular tachycardia in an infant. *Ann Emerg Med* 1996;28(3):356-8 211

Case report of successful resolution of supraventricular tachycardia in an infant following IO administration of adenosine.

Sheikh AA, Eaker JA, Chin CC, Gunther RA, Kramer GC. Intraosseous resuscitation of hemorrhagic shock in a pediatric animal model using a low sodium hypertonic fluid. *Crit Care Med* 1996;24(6):1054-61 213

Preclinical study in piglets demonstrating successful resuscitation from hemorrhagic shock with IO administration of hypotonic saline.

YEAR: 1995

Kayser SR. Pharmacologic management of cardiac arrest: an update perspective. *Prog Cardiovasc Nurs* 1995;10(3):35-41 204

Nursing article on pharmacologic management of cardiac arrest discussing administration routes for cardiac medications.

Kristensen BB, Mikkelsen SS. [Pharmacological routes of administration in circulatory collapse]. *Ugeskr Laeger* 1995;157(490):6864-8. Dutch. Abstract 201

Review article discussing medication administration routes during CPR when patient is in shock. Recommends IO access for medications, crystalloids and colloids as a viable alternative. Cautions against IO for hypovolemic shock due to lower infusion rates.

Ronning G, Busund R, Revhaug A, Sager G. Effect of haemorrhagic shock and intraosseous resuscitation on plasma and urine catecholamine concentrations and urinary clearance in pigs. *Eur J Surg* 1995;161(6):387-94 203

Preclinical study of IO versus resuscitation in hemorrhagic shock with an infusion of small volume hyperosmotic saline. Found that plasma catecholamine levels returned to normal 90 minutes after IO infusion. Found no significant differences in catecholamine levels between IV and IO infusion.

Ronning G, Sager G, Revhaug A. Intraosseous infusion of a small volume of hyperosmotic fluid increases mean arterial pressure and lessens the catecholamine response in pigs with haemorrhagic shock. *Eur J Surg* 1995;161(10):715-20 195

Preclinical study in pigs demonstrating that IO hyperosmotic resuscitation increases circulatory performance and reduces the plasma and catecholamines concentrations during hemorrhagic shock .

Waisman M, Roffman M, Bursztejn S, Heifetz M. Intraosseous regional anesthesia as an alternative to intravenous regional anesthesia. *J Trauma* 1995;39(6):1153-6 200

Clinical study of IO anesthesia during orthopedic surgery. Satisfactory anesthesia was obtained in 106 of 109 patients. Concludes that IO regional anesthesia is a valuable technique when IV anesthesia fails or is not feasible.

YEAR: 1994

Getschman SJ, Dietrich AM, Franklin WH, Allen HD. Intraosseous adenosine. As effective as peripheral or central venous administration? *Arch Pediatr Adolesc Med* 1994;148(6):616-9 183

Preclinical study comparing IO administration of adenosine with peripheral and central venous routes to induce atrioventricular block during pacing. Found that IO administration was effective. Required dose of adenosine was highest for the peripheral venous route, lowest for central venous route.

Golenz MR, Wilson WD, Carlson GP, Craychee TJ, Mihalyi JE, Knox L. Effect of route of administration and age on the pharmacokinetics of amikacin administered by the intravenous and intraosseous routes to 3 and 5 day old foals. *Equine Vet J* 1994;26(5):367-73 177

Veterinary study comparing IO and IV administration of amikacin. Found no significant differences in pharmacokinetic parameters between the 2 administration routes.

Kil'diushov AN. [Use of heparin in the early post-traumatic period in burns and hemorrhage]. *Anesteziol Reanimatol* 1994; Sept-Oct(5):26-8. Russian 163

Preclinical study in 86 injured dogs with hemostasis disorders. Plasma and platelet disorders normalized 3 hours after the onset of infusion therapy. The response was enhanced by IO infusion of isotonic saline.

Article in Russian-abstract only

Intraosseous Vascular Access Bibliography

Pharmacokinetics/Dynamics

Runyon DE, Bruttig SP, Dubick MA, Clifford CB, Kramer GC. Resuscitation from hypovolemia in swine with intraosseous infusion of a saturated salt-dextran solution. J Trauma 1994;36(1):11-9 166

Preclinical study demonstrating IO infusion of a saturated salt-dextran solution restored cardiac output in a pig model of hemorrhage. Suggests that IO-administered concentrated salt-dextran solution is a viable alternative during harsh field conditions where conventional resuscitation techniques may be impractical.

Abstract only

Ummenhofer W, Frei FJ, Urwyler A, Drewe J. Are laboratory values in bone marrow aspirate predictable for venous blood in paediatric patients. Resuscitation 1994;27(2):123-8 560

In this study bone marrow aspirate from the iliac crest and peripheral venous blood samples from 30 pediatric patients were compared to investigate the predictive value of bone marrow aspirate in performing laboratory studies. Laboratory tests with high predictability, moderate but clinically useful predictability are summarized. Tests that were systematically different from venous blood are also summarized.

Warren DW, Kissoon N, Mattar A, Morrissey G, Gravelle D, Rieder MJ. Pharmacokinetics from multiple intraosseous and peripheral intravenous site injections in normovolemic and hypovolemic pigs. Crit Care Med 1994;22(5):838-43 169

Pharmacokinetic study comparing IO and IV administration of both sodium bicarbonate and a radioactive tracer. Found no significant differences in end tidal CO₂ concentrations between the 2 routes of administration. Also found no differences in time for radiotracer to reach the central circulation. Suggests that dosage adjustments are not required for IO administration and that IO is an acceptable alternative to IV drug administration.

Zaritsky A. Endotracheal epinephrine in cardiac arrest. Crit Care Med 1994;22(7):1071-2 161

Review article on endotracheal administration of epinephrine highlighting poor pulmonary drug absorption with this technique.

YEAR: 1991

Jaimovich DG, Kecskes S. Intraosseous infusion: a re-discovered procedure as an alternative for pediatric vascular access. Indian J Pediatr 1991;58(3):329-34 110

Review of indications and benefits of intraosseous infusion. Concludes IO access may be especially valuable for medical personnel who rarely care for critically ill children because the IO technique is easily mastered even with limited practice.

Pollack CV, Pender ES, Woodall BN, Parks, BR. Intraosseous administration of antibiotics: Same-dose comparison with intravenous administration in the weanling pig. Ann Emerg Med 1991;20(7):772-6 683

A pre-clinical study comparing IV and IO blood serum levels of antibiotics: ceftriaxone, cefotaxime, ampicillin and gentamicin in weanling pigs. Blood levels were compared at 15, 30, 45, 60 and 90 minutes and each animal served as their own control. Results showed that IO levels were initially lower than IV levels though the difference became indistinguishable after 30 minutes. Ceftriaxone levels however remained lower throughout the 90 minute sample period. The authors concluded that standard IV doses may be administered intraosseously though further study may suggest higher doses of ceftriaxone may be more beneficial.

YEAR: 1990

Halvorsen L, Bay BK, Perron PR, Gunther RA, Holcroft JW, Blaisdell FW, Kramer GC. Evaluation of an intraosseous infusion device for the resuscitation of hypovolemic shock. J Trauma 1990;30(6):652-9 90

Preclinical study comparing a sternal IO infusion device to IV fluids for resuscitation. Blood pressure and cardiac output were normalized at 10 minute post infusion in both groups. Advocates use of IO infusion as a way for pre-hospital rescuers to consistently incorporate fluid therapy in their scoop and run policies.

Orlowski JP, Gallagher JM, Porembka DT. Endotracheal epinephrine is unreliable. Resuscitation 1990;19(2):103-13 99

Preclinical study of the pharmacokinetics of emergency medications in a canine model of shock. Found that endotracheal administration was unreliable, while IO administration was comparable to central and peripheral venous administration.

Orlowski JP, Porembka DT, Gallagher JM, Lockrem JD, VanLente F. Comparison study of intraosseous, central intravenous, and peripheral intravenous infusions of emergency drugs. Am J Dis Child 1990;144(1):112-7 92

Preclinical study comparing the pharmacokinetics of 6 emergency medications in dogs. Found that IO administration resulted in similar physiologic effect and/or serum drug levels as central and peripheral venous administration.

Tobias JD, Nichols DG. Intraosseous succinylcholine for orotracheal intubation. Pediatr Emerg Care 1990;6(2):108-9 468

This article describes two cases of IO administration of succinylcholine for emergency airway management in children that resulted in adequate intubating conditions within 45 seconds for both cases.

Intraosseous Vascular Access Bibliography

Pharmacokinetics/Dynamics

Vinsel PJ, Moore GP, O'Hair KC. Comparison of intraosseous versus intravenous loading of phenytoin in pigs and effect on bone marrow. Am J Emerg Med 1990;8(3):181-3 429

A 15mg/kg dose of phenytoin was administered over 15 minutes to 6 pigs using the IV route and 6 pigs using the tibial IO route. Blood samples were taken every 5 minutes for 35 minutes to determine phenytoin levels. There was no statistical difference between the two groups. Bone cortex and marrow were microscopically examined and were normal after 5 weeks. Authors concluded the IO route is an effecting alternative to the IV route for administering phenytoin without permanent damage to the marrow.

Zenk KE. Use of intraosseous infusions in infants and children. Clin Pharm 1990;9:90-1 94

Article advocating IO infusion over endotracheal administration of medications. Asserts that IO infusion is equivalent to IV infusion.

YEAR: 1989

Brown CG, Dzwonczyk R, Werman HA, Hamlin RL. Estimating the duration of ventricular fibrillation. Ann Emerg Med 1989;18(11):1181-5 83

Preclinical study in pigs and mathematical model using mean frequency of the ECG during ventricular fibrillation to predict downtime.

Jaimovich DG, Shabino CL, Ringer TV, Peters GR. Comparison of intraosseous and intravenous routes of anticonvulsant administration in a porcine model. Ann Emerg Med 1989;18(8):842-6 592

A pre-clinical study evaluating resultant serum levels when administering phenobarbital and phenytoin via intraosseous infusion as compared to IV administration in domestic swine. Results showed that current IV dosing of phenobarbital 20 mg/kg obtains and maintains therapeutic serum levels when given IO; Phenytoin 15 mg/kg does not maintain therapeutic levels and cannot be recommended for IO administration.

Lathers CM, Jim KF, Spivey WH. A comparison of intraosseous and intravenous routes of administration for antiseizure agents. Epilepsia 1989;30(4):472-9 81

Preclinical study in pigs finding equivalence in physiologic response between IO and IV administration of antiepileptic drugs.

Orlowski JP, Julius CJ, Petras RE, Porembka DT, Gallagher JM. The safety of intraosseous infusions: risks of fat and bone marrow emboli to the lungs. Ann Emerg Med 1989;18(10):1062-7 78

Preclinical study in dogs examining lung samples for fat and bone marrow emboli following IO infusion. Found no significance difference in embolism formation or density between dogs receiving IO infusion of emergency drugs and control group.

YEAR: 1987

Spivey WH, Tilelli JA, Edgren B. Rectal administration of diazepam. Ann Emerg Med 1987;16(11):162-3 556

Letter to the editor written by Dr. Edgren and Dr. Tilelli regarding a prior article by Dr. Spivey in which he suggested use of IO route for administration of diazepam for treatment of status epilepticus. They note a few complications of IO use such as osteomyelitis, epiphyseal damage and pulmonary embolism as reasons to use rectal administration over IO. Dr. Spivey responded noting IO administration should be considered as an option and that the complications they noted are very rare or never reported.

Spivey WH, Unger HD, Lathers CM, McNamara RM. Intraosseous diazepam suppression of pentylenetetrazol-induced epileptogenic activity in pigs. Ann Emerg Med 1987;16(2):156-9 557

A preclinical study comparing IV and IO administration of diazepam in a pentylenetetrazol seizure model in pigs. Results showed that epileptogenic activity was suppressed within 1 minute in the IV group and within 2 minutes in the IO group; the difference was not statistically significant. The authors conclude the IO route is a rapid and effective alternative for diazepam administration.

Spivey WH, Unger HD, McNamara RM, LaManna MM, Ho T, Lathers CM. The effect of intraosseous sodium bicarbonate on bone in swine. Ann Emerg Med 1987;16(7):773-6 555

A preclinical study evaluating the effects of sodium bicarbonate on the medullary cavity following tibial infusion in swine 30 days prior. Results showed all roentgenographs, bone scans and microscopic specimens to be normal with the exception of one small cortical calcification at the site of needle puncture visible in one animal. The authors conclude that the study demonstrates that sodium bicarbonate does not have permanent adverse effects when injected into the marrow cavity of swine.

YEAR: 1986

Hoelzer MF. Recent advances in intravenous therapy. Emerg Med Clin North Am 1986;4(3):487-500 55

Review of medical literature and research on the problem of difficult intravenous access.

Intraosseous Vascular Access Bibliography

Pharmacokinetics/Dynamics

Unger H, Spivey WH, McNamara RM, Lathers CM. Comparison of intraosseous and intravenous CBC and ASTRA 8 in swine. *Ann Emerg Med* 1986;15(5):198

561

This preclinical study compared CBCs and routine blood chemistries drawn from IO and IV blood. The authors concluded that IO blood chemistries reflected venous blood chemistries and may be used if venous blood cannot be obtained; CBC cannot be reliably obtained from IO blood.

YEAR: 1985

Spivey WH, Lathers CM, Malone DR, et al.. Comparison of intraosseous, central, and peripheral routes of sodium bicarbonate administration during CPR in pigs. *Ann Emerg Med* 1985;14(12):1135-40

43

Preclinical study in pigs examining blood pH during CPR with sodium bicarbonate administered via different vascular access routes. Found that pH of blood obtained via central venous access and intraosseous access were significantly different from the peripheral group, and that all three groups were significantly different from the control. Pathology studies showed only minor damage to bone with IO sodium bicarbonate administration.

YEAR: 1984

Thompson BM, Rossetti V, Miller J, Mateer JR, Aprahamian C, Darin JC. Intraosseous administration of sodium bicarbonate: An effective means of pH normalization in the canine model. *Ann Emerg Med* 1984;13(5):405

559

This preclinical study compared pH changes induced by administration of IV and IO sodium bicarbonate. The results showed that the rapidity and effectiveness of sodium bicarbonate administered via IO was clinically equivalent to that given by the IV route.

YEAR: 1979

Shoor PM, Berryhill RE, Benumof JL. Intraosseous infusion: pressure-flow relationship and pharmacokinetics. *J Trauma* 1979;19:772-4

32

Preclinical study of IO flow and pharmacokinetics in the bovine tibia. Mean time to initial effect of IO administration of epinephrine was 17 seconds with 90% maximal effect in 45 seconds. Concludes that experiment provides quantitative evidence of utility of IO infusion for resuscitation.

Intraosseous Vascular Access Bibliography

Pre-Clinical Studies

YEAR: 2019

Burgert JM, Johnson AD, O'Sullivan JC, et al. Pharmacokinetic effects of endotracheal, intraosseous, and intravenous epinephrine in a swine model of traumatic cardiac arrest. *Am J Emerg Med* 2019;(in press). doi: 10.1016/j.ajem.2019.02.035

1046

This pre-clinical study compared various PK parameters, return of spontaneous circulation (ROSC), time to ROSC, and odds of ROSC after epinephrine was administered via endotracheal (ETT), IO, and IV routes in a swine traumatic cardiac arrest model (TCA). IO groups included sternal IO (SIO), humeral IO (HIO), and tibial IO (TIO). CPR only and CPR plus defibrillation (CPRD) groups were included for analyzing ROSC. The Cmax of the IV epinephrine group was significantly higher than that of the IO group ($p=0.049$). The tmax of the TIO group was significantly longer than that of all other groups ($p=0.008$). There were significant differences in mean plasma concentrations over time between the IV and TIO groups at 90, 120, 150, and 180 seconds ($p<0.05$) with the TIO group having an unexpectedly prolonged absorption phase. There was no difference in the rate of ROSC between ETT, TIO, HIO, SIO, IV and CPRD groups. The PK findings relative to ROSC support the concept that neither epinephrine nor the route of administration influenced the outcome. All IO insertions were performed using the EZ-IO device.

Jousi M, Skrifvars MB, Nelskylä A, et al. Point-of-care laboratory analyses of intraosseous, arterial and central venous samples during experimental cardiopulmonary resuscitation. *Resuscitation* 2019;137:124-32. doi: 10.1016/j.resuscitation.2019.02.014

1055

This pre-clinical study compared IO, arterial, and venous point-of-care blood samples taken during cardiac arrest and CPR to pre-arrest arterial values to determine which method best reflected the pre-arrest state in a swine model. IO access was achieved using the EZ-IO device. The following parameters were assessed: partial pressure of oxygen, partial pressure of carbon dioxide, base excess, standard bicarbonate, pH, lactate, sodium, potassium, ionized calcium, glucose, and hemoglobin. The study found that these values change differently during cardiac arrest and CPR depending on the source of the sample. The authors suggest that if arterial or venous samples are not available then IO samples can be considered.

YEAR: 2018

Akman N, Braunschweig T, Honickel M, et al. Reversal of dabigatran by intraosseous or intravenous idarucizumab in a porcine polytrauma model. *Br J Anaesth* 2018;120(5):978-87. doi: 10.1016/j.bja.2018.01.027

956

This study compared the efficacy and safety of IO versus IV idarucizumab for dabigatran reversal in a porcine polytrauma model. Twenty-one male pigs received oral dabigatran for 3 days and on the 4th day received dabigatran infusion while another 7 received a sham treatment. The treated pigs were then randomized to one of three groups; IO saline, IV idarucizumab, IO idarucizumab while the other 7 comprised the sham group. The pigs were subjected to polytrauma (femur fracture and blunt liver injury). Blood loss, hemodynamic values, and blood samples were measured and recorded. Blood loss was highest in the control group, followed by the two idarucizumab groups, and lowest in the sham group. Survival to 240 minutes was 100% in the sham group and both idarucizumab groups, and 14% in the control group. IO and IV idarucizumab promptly normalized global coagulation assays and thrombin generation and were comparable for reversing dabigatran.

Auten J, Mclean JB, Kemp JD, et al. A pilot study of four intraosseous blood transfusion strategies. *J Spec Oper Med* 2018;18(3):50-6

1042

This pilot study compares four different IO blood transfusion strategies with varying degrees of transfusion pressure in a swine model with similar bone density to that of an adult military servicemember. Animals were randomly assigned to one of four transfusion strategies: 1) gravity, 2) pressure-bag, 3) rapid-transfusion device, or 4) manual push-pull. Hemorrhage was simulated then IO access was obtained with the EZ-IO device. Gravity transfusion was the slowest with a flow rate 5 mL/min, followed by rapid transfusion device (31 mL/min), single site pressure bag (78 mL/min), double site pressure bag (103 mL/min), and push-pull technique (109 mL/min). Single site or double site pressure bag was determined to be the best option for IO infusion because of the high flow rate and no associated incidences of overpressure or death.

Beverly M, Mellon S, Kennedy JA, Murray DW. Intraosseous pressure during loading and with vascular occlusion in an animal model. *Bone Joint Res* 2018;7(8):511-6

959

This article studied subchondral intraosseous pressure (IOP) in an animal model during loading and with vascular occlusion. IOP recordings from 5 femoral condyles and 7 proximal tibias in 5 rabbit subjects were obtained. The effect on IOP of loading by 1 body weight, arterial occlusion then loading, and venous occlusion then loading were assessed. A load of 1 body weight caused the basal IOP to rise as well as IOP at various sites. A clip applied to the proximal femoral artery caused the IOP to fall while a clamp on the femoral vein caused the IOP to rise. Saline injected into the femoral head caused pressure at the femoral condyle to increase and vice versa when saline was injected at the femoral condyle. IO injection of saline in the femur had no effect on IOP at the tibia. The authors conclude that IOP is not constant.

Beverly M, Murray D. Factors affecting intraosseous pressure measurement. *J Orthop Surg Res* 2018;13(1):187. doi:10.1186/s13018-018-0877-z

960

This study explored the physiology of normal subchondral perfusion and IOP. Using 21 anesthetized rabbits intraosseous pressure (IOP) was measured using IO needles in the subchondral cancellous bone of the femoral head, femoral condyle, and proximal tibia. A series of experiments investigated the following: normal baseline IOP; method of measuring; IOP wave forms; drug administration; relationship between systemic blood pressure, IOP and pulse pressure; relationship between IOP and pulse pressure; and vascular occlusion. The authors concluded that subchondral cancellous bone behaves as a perfused tissue and that IOP is mainly a reflection of arterial supply. A single measure of IOP can vary and reflects only perfusion at the needle tip.

Intraosseous Vascular Access Bibliography

Pre-Clinical Studies

- Burgert J, Martinez A, O'Sullivan M, Blouin D, Long A, Johnson A. Sternal route more effective than tibial route for intraosseous amiodarone administration in a swine model of ventricular fibrillation. *Prehosp Emerg Care* 2018;22(2):266-75. doi:10.1080/10903127.2017.1358782** 903

This study examined the measured mean plasma concentration, maximum plasma concentration (Cmax), and time to maximum concentration (Tmax) of amiodarone administered by 3 different routes, sternal IO (SIO), tibial IO (TIO), and IV over a time period of 5 minutes in 21 swine who were randomly assigned to one of the 3 routes. The swine were under general anesthesia and ventricular fibrillation was induced and CPR initiated. After 4 minutes in ventricular fibrillation the swine were administered 300 mg of amiodarone and blood samples were taken at 30 second intervals over 300 seconds. Authors concluded that the SIO and IV routes of amiodarone were comparable. The TIO group took almost 3 times longer to reach Tmax than the SIO and IV groups. In the swine model used in this study, the authors concluded that SIO route was more effective than the TIO route for the amiodarone delivery in a swine with VF and ongoing CPR.

- Lallemant MS, Moe DM, McClellan JM, et al. No intravenous access, no problem: Intraosseous administration of tranexamic acid is as effective as intravenous in a porcine hemorrhage model. *J Trauma Acute Care Surg* 2018;84(2):379-85. doi:10.1097/TA.0000000000001741** 988

This article describes a study that compared serum concentrations of tranexamic acid (TXA) when given IV and IO and compared the efficacy of IO administered TXA to IV at reversing hyperfibrinolysis in a porcine hemorrhage and ischemia-reperfusion model. There were no statistically significant differences in serum drug concentrations between IV and IO infusions at any of the measured time points. TXA infusion corrected the lysis index at 30 minutes in both the IO and IV groups.

- Sulava EF, Bianchi W, Krepla A, et al. Performance of single versus double site intraosseous blood transfusion strategies in a swine (sus scrofa) model of hemorrhagic shock. *Ann Emerg Med* 2018;72(4s):S3-4** 1023

This abstract describes interim results of a study in a swine model that discusses the utility of intraosseous blood transfusions for treating hypovolemic battlefield injuries, compares advantages and complications of humeral versus sternal IO access for resuscitation, and identifies flow rates, degree of intravascular hemolysis, and occurrence of coagulopathy in single versus double site intraosseous blood transfusion. The study found that in an animal model of hemorrhagic shock, double site IO transfusion appears to confer a significant advantage in flow rates without significant complications

YEAR: 2017

- Boysen SR, Pang JM, Mikler JR, Knight CG, Semple HA, Caulkett NA. Comparison of tranexamic acid plasma concentrations when administered via intraosseous and intravenous routes. *Am J Emerg Med* 2017;35(2):227-33. doi:http://dx.doi.org/10.1016/j.ajem.2016.10.054** 867

Swine study comparing pharmacokinetic (pK) parameters of TXA given by the IO vs IV route. For the 4 min and 5 min results Cmax plasma concentrations were higher in the IV group but similar from injection completion onwards. Other pK parameters were not significantly different. Limitations included swine model, normotensive animals and proximity of sampling site (jugular vein) to the IV infusion site (auricular). Investigators concluded this study supports the pharmacokinetic bioequivalence of IO and IV administration of TXA in this animal model.

- Burgert JM, Johnson AD, Garcia-Blanco J, Fulton LV, Loughren MJ. The resuscitative and pharmacokinetic effects of humeral intraosseous vasopressin in a swine model of ventricular fibrillation. *Prehosp Disaster Med* 2017;32(3):305-10. doi:10.1017/S1049023X17000140** 940

This preclinical study reported data evaluating the pharmacokinetics of HIO and IV vasopressin and the ROSC in a swine model of ventricular fibrillation cardiac arrest. For the parameters of occurrence of ROSC, odds of ROSC, time to ROSC, Cmax, Tmax, and plasma concentrations over time, the IO and IV routes results were comparable.

- Montez DF, Puga TA, Ruiz S, Philbeck TE. Accuracy of intraosseous lab values drawn after fluid infusion. *Ann Emerg Med* 2017;70(4 Suppl):S27. https://doi.org/10.1016/j.annemergmed.2017.07.088** 923

This abstract describes a preclinical study conducted to determine how long an infusion must be stopped before drawing an IO specimen for analysis; to determine if there is a difference between IO specimen results when the first 2 mL of IO blood were discarded and not discarded; and add to existing data comparing lab results from IO vs. CVC access. Lab specimens were drawn following infusion of 0.9% NS and analyzed using a point-of-care analyzer and cartridge system. Results indicated the initial specimen drawn from the IO catheter for tested analytes may be considered for sampling, if those values are needed, and IO infusion is occurring, a wait time of two minutes post-stopping the infusion may be adequate for analysis; and IO specimen values are comparable to CVC values. This study was sponsored by Teleflex Incorporated.

- Shina A, Baruch EN, Shlaifer A, et al. Comparison of two intraosseous devices: The NIO versus the EZ-IO by novice users- a randomized cross over trial. *Prehosp Emerg Care* 2017;21(3):315-21. doi:10.1080/10903127.2016.1247201** 817

Using a porcine hind leg model authors compared the success rate and ease-of-use ratings of an IO device, the NIO® in comparison to the Arrow® EZ-IO by novice users. NIO success rates were comparable to those of EZ-IO; 54% of the participants preferred using the EZ-IO over the NIO.

Intraosseous Vascular Access Bibliography

Pre-Clinical Studies

YEAR: 2016

- Adams TS, Blouin D, Johnson D. Effects of tibial and humerus intraosseous and intravenous vasopressin in porcine cardiac arrest model. Am J Disaster Med 2016;11(3):211-8. doi:10.5055/ajdm.2016.0241** 896
- This study compared maximum concentration time (Cmax) to maximum concentration mean (Tmax) of mean serum concentration of vasopressin, return of spontaneous circulation (ROSC), time to ROSC, with odds of survival to vasopressin administration by tibial intraosseous, proximal humerus intraosseous (PHIO), and intravenous (IV) routes in a cardiac arrest model. Authors concluded TIO and PHIO provide rapid and reliable access in administration of life-saving medications during cardiac arrest and may be faster due to IV difficulty.
- Blouin D, Gegel BT, Johnson D, Garcia-Blanco JC. Effects of intravenous, sternal, and humerus intraosseous administration of hextend on time of administration and hemodynamics in a hypovolemic swine model. Am J Disaster Med 2016;11(3):183-92. doi:10.5055/ajdm.2016.0238** 900
- This study was to determine if there were any significant differences between humerus intraosseous (PHIO), sternal intraosseous (SIO) and intravenous (IV) administration of Hextend on the hemodynamics or administration time in a hypovolemic swine model. Time of administration of the Hextend on effects on systolic and diastolic blood pressure, mean arterial pressure, heart rate, cardiac output and stroke volume. After administration of Hextend, data was collected every 2 minutes for 8 minutes total. Results found no significant difference in these measures among the PHIO, SIO or IV groups.
- Burgert JM, Johnson AD, Garcia-Blanco J, et al. The effects of proximal and distal routes of intraosseous epinephrine administration on short-term resuscitative outcome measures in an adult swine model of ventricular fibrillation: A randomized controlled study. Am J Emerg Med 2016;34:49-53. doi:10.1016/j.ajem.2015.09.007** 778
- Preclinical RCT evaluating the relationships between the anatomical distance of IO epinephrine and measures of resuscitative outcome in an adult swine model of ventricular fibrillation (VF). There were no significant differences between the HIO, TIO, and IV groups relative to the occurrence of ROSC, 30-minute post-ROSC survival, and time to ROSC. The anatomical distance of IO epinephrine injection from the heart did not affect short-term measures of resuscitative outcome in an adult swine model of VF including the occurrence of ROSC, 30 minute post-ROSC survival, and time to ROSC. Rapidly administered epinephrine, irrespective of route of administration, increased the chance of ROSC and survival to 30 minutes post-ROSC in this study.
- Eriksson M, Strandberg G, Lipcsey M, Larsson A. Evaluation of intraosseous sampling for measurements of alanine aminotransferase, alkaline phosphatase, aspartate aminotransferase, creatinine kinase, gamma-glutamyl transferase and lactate dehydrogenase. Scand J Clin Lab Invest 2016;76(8):597-600. doi:10.1080/00365513.2016.1230774** 809
- This preclinical study compared arterial and intraosseous derived biomarkers to determine if the results would correlate well enough over a period of 6 hours to consider use of IO derived blood when traditional samples are difficult to obtain. Authors noted there were no clinically relevant average differences between alanine aminotransferase, alkaline phosphatase, aspartate aminotransferase, creatinine kinase and gamma-glutamyl transferase values which may be good enough for initial estimates of these markers analyzed in intraosseous and arterial samples. However the lactate dehydrogenase levels showed less correlation; and the precision of IO samples may be limited.
- Fulkerson J, Lowe R, Anderson T, Moore H, Craig W, Johnson D. Effects of intraosseous tibial vs. intravenous vasopressin in a hypovolemic cardiac arrest model. West J Emerg Med 2016;17(2):222-8. doi:10.5811/westjem.2015.12.28825** 777
- Randomized, prospective preclinical study that examined the differences in pharmacokinetics and pharmacodynamics of tibial IO (TIO) and IV-delivered vasopressin during cardiac arrest and CPR until ROSC was achieved. No difference was noted for ROSC between TIO and IV delivered vasopressin. Authors concluded the use of IO access could avoid the time delay associated with IV access, and that it is effective for treatment of hypovolemic cardiac arrest and should be first line for rapid vascular access.
- Hampton K, Wang E, Argame JI, Bateman T, Craig W, Johnson D. The effects of tibial intraosseous versus intravenous amiodarone administration in a hypovolemic cardiac arrest porcine model. Am J Disaster Med 2016;11(4):253-60** 829
- This study compared IV to tibial IO administration of amiodarone. Investigators found no significant differences for the endpoints of Cmax, Tmax and time to/ rate of ROSC between IO and IV.
- Holloway MM, Jurina SL, Orszag JD, et al. Effects of humerus intraosseous versus intravenous amiodarone administration in a hypovolemic porcine model. Am J Disaster Med 2016;11(4):261-9** 828
- In a swine study comparison of the humeral IO and IV amiodarone administration routes investigators found no difference in time to ROSC or rate, time to maximum concentration (Tmax) $p = 0.501$ or in maximum plasma drug concentration (Cmax) ($p = 0.232$).
- Miao CH. Hemophilia A gene therapy via intraosseous delivery of factor VIII-lentiviral vectors. Thromb J 2016;14(Suppl1):93-9** 995
- This paper discusses a recently developed novel approach of IO delivery of lenti-viral vectors to correct hemophilia A. Ex vivo hematopoietic stem cell (HSC) transduction/transplantation has been shown to successfully deliver Factor 8 (FVIII) into HemA mice but the procedure requires pre-conditioning using potentially toxic, myelosuppressive agents. IO delivery to transduce HSCs bypasses this step and potential thrombocytopenia associated with pre-conditioning. When compared to IV infusion of LVs, IO delivery directly introduced LVs into the bone marrow significantly enhancing transduction efficiency of HSCs. In mice, a single infusion of G-F8-LVs produced long-term stable expression of hFVIII in platelets and corrected hemophilia phenotype for the long term.

Intraosseous Vascular Access Bibliography

Pre-Clinical Studies

- Montez DF, Puga TA, Davlantes C, Higgins R, Miller LJ, Philbeck TE. Blood transfusion via intraosseous access: A pre-clinical study. J Vasc Access 2016;17(4):e5-6** 783
- A preclinical study evaluating blood transfusion via IO vascular access in anesthetized swine. Results showed pressurized blood transfusion through IO vascular access resulted in acceptable flow rates and did not result in appreciable hemolysis as indicated by free hemoglobin values. This study was sponsored by Teleflex Incorporated.
- Muir SL, Sheppard LB, Maika-Wilson A, et al. A comparison of the effects of intraosseous and intravenous 5% albumin on infusion time and hemodynamic measures in a swine model of hemorrhagic shock. Prehosp Disaster Med. 2016;31(4):436-42** 1058
- This pre-clinical study compared the performance of IO and IV administered albumin. IO access was obtained via the tibia using an EZ-IO device. Mean infusion time for TIO was 7 minutes, 35 seconds. Mean infusion time for IV was 4 minutes, 32 seconds. There were no significant differences between groups relative to mean arterial pressure, cardiac output, heart rate, or stroke volume. Hemodynamic parameters were measured for only 3 minutes.
- O'Sullivan M, Martinez A, Long A, et al. Comparison of the effects of sternal and tibial intraosseous administered resuscitative drugs on return of spontaneous circulation in a swine model of cardiac arrest. Am J Disaster Med 2016;11(3):175-82. doi:10.5055/ajdm.2016.0237** 1006
- This study compared the effects of IO and IV administered resuscitative drugs (vasopressin, amiodarone, and epinephrine) on return of spontaneous circulation (ROSC) in a swine model of sudden cardiac arrest (SCA) with ongoing resuscitation. Swine were randomized to 1 of 5 groups; tibial IO, sternal IO, IV, CPR+defibrillation, and CPR-only. There was no significant difference in ROSC between SIO, TIO, and IV groups. However time to ROSC was significantly less for the SIO group compared to the TIO group ($p=0.003$). This is possibly related to higher fat content in tibial bone marrow relative to the sternum and the lipophilicity of amiodarone.
- Puga TA, Montez DF, Davlantes C, Miller LJ, Philbeck TE. Swine study shows no intramedullary effects of power-injected contrast media using intraosseous access. J Vasc Access 2016;17(4):e16** 785
- A preclinical study evaluating the immediate effects of power injected contrast media on the medullary space of anesthetized swine. Contrast media (150 mL) was administered at a rate of 5 mL/second. For each limb receiving power injection a control limb was submitted for evaluation. The pathologist was blinded to which limb received power injection. Results showed no histological difference in limbs receiving and not receiving power injection. This study was sponsored by Teleflex Incorporated.
- Smith S, Borgkvist B, Kist T, Annelin J, Johnson D, Long R. The effects of sternal intraosseous and intravenous administration of amiodarone in a hypovolemic swine cardiac arrest model. Am J Disaster Med 2016;11(4):271-7. doi:10.5055/ajdm.2016.0249** 830
- A pre-clinical study comparing the effects of IV and sternal IO administered amiodarone in a swine cardiac arrest model. Following 2 minutes of cardiac arrest, CPR was initiated and after an additional 2 minutes, amiodarone was administered via sternal IO or IV access. Blood samples were collected over 5 minutes. Results showed no statistical difference between routes for return of spontaneous circulation (ROSC), time to ROSC, T-max, or C-max. The authors concluded sternal IO route provides rapid and reliable access to administer life-saving medications during cardiac arrest.
- Strandberg G, Lipcsey M, Eriksson M, Lubenow N, Larsson A. Analysis of thromboelastography, PT, APTT and fibrinogen in intraosseous and venous samples-an experimental study. Scand J Trauma Resusc Emerg Med 2016;24:131. doi:10.1186/s13049-016-0318-0** 814
- In this porcine study IO and venous samples were analyzed for thromboelastography (TEG), prothrombin time (PT), activated partial thromboplastin time (APTT) and fibrinogen concentration. The IO samples were clinically hypercoagulable, rendering some samples unevaluable; clinically relevant differences were observed for APTT but not for PT and fibrinogen and the TEG demonstrated a shortened reaction time. The ability to use IO drawn blood for coagulation studies may be limited.
- Uwaydah NI, Hoskins SL, Bruttig SP, et al. Intramuscular versus intraosseous delivery of nerve agent antidote pralidoxime chloride in swine. Prehosp Emerg Care 2016;20(4):485-92. doi:10.3109/10903127.2014.942479** 842
- A preclinical study comparing delivery of nerve agent antidote when administered via intramuscular (IM) and proximal tibia intraosseous (IO) routes, in normovolemic and hypovolemic swine. IO and IV administration of the antidote achieved and surpassed therapeutic levels in normovolemic groups; time to therapeutic level with IM was 2 minutes versus 15 seconds with IO access. Combined administration via IO route initially, followed by IM injection 60 minutes post IO injection resulted in therapeutic levels for a prolonged time, most closely mimicking standard hospital care of poisoned patients. The authors concluded the rapid increase in plasma concentrations, coupled with the sustainability of the drug in plasma supported advantages of IO over IM delivery.
- Vallier DJ, Torrence AD, Stevens, III R, Arcinue PN, Johnson D. The effects of sternal and intravenous vasopressin administration on pharmacokinetics. Am J Disaster Med 2016;11(3):203-9. doi:10.5055/ajdm.2016.0240** 841
- A preclinical study comparing the maximum concentration (Cmax), time to maximum concentration (Tmax) when administering vasopressin via intravenous (IV) and sternal intraosseous (SIO) access in a cardiac arrest swine model. Anesthetized swine were put into cardiac arrest, after 2 minutes CPR was initiated for 2 minutes, then 40 units of vasopressin was administered via IV or SIO route. Results showed no significant difference in SIO and IV groups for Cmax or Tmax.

Intraosseous Vascular Access Bibliography

Pre-Clinical Studies

Wilson J, Passmore A, Leger S, Lannan J, Bentley M, Johnson D. Effects of tibial intraosseous and intravenous administration of Hextend on time of administration and hemodynamics in a hypovolemic swine model. Am J Disaster Med 2016;11(3):193:201. doi:10.5055/ajdm.2016.0239

836

A preclinical study comparing administration of Hextend via IV and tibial intraosseous (IO) access routes for time for administration and hemodynamic measures in a hypovolemic swine model. Following exsanguination, 500 mL of Hextend was administered via both routes; a control group received no Hextend. Hemodynamic measures data were collected every 2 minutes for 8 minutes. The mean time for administration in the IV group was 10 minutes 16 seconds (\pm 2 minutes 47 seconds), and for the IO group it was 10 minutes 12 seconds (\pm 1 minutes 36 seconds). There was no significant difference in systolic blood pressure, diastolic blood pressure, mean arterial pressure, cardiac output, and stroke volume.

Wimmer MH, Heffner K, Smithers M, et al. The comparison of humeral intraosseous and intravenous administration of vasopressin on return of spontaneous circulation and pharmacokinetics in a hypovolemic cardiac arrest swine model. Am J Disaster Med 2016;11(4):237-42. doi:10.5055/ajdm.2016.0245

827

A preclinical study comparing IV and humeral intraosseous (IO) access administration of vasopressin in a hypovolemic swine model in cardiac arrest. Following exsanguination, the swine were placed in cardiac arrest for 2 minutes, then resuscitated for 2 minutes in accordance with ACLS guidelines. Vasopressin was administered. Blood samples were collected at various time points following vasopressin injection and analyzed for maximum concentration (Cmax) and time to maximum concentration (Tmax) between groups; return of spontaneous circulation was also captured. ROSC was achieved for all HIO subjects (n=7) and in seven out of eight IV subjects; mean time to ROSC was 9.8 minutes for HIO and 10.7 for the IV group. However, statistically there was no significant difference between HIO and IV administration of vasopressin for achievement of ROSC, time to ROSC, Cmax, Tmax, concentration over time, survivability, or odds ratio.

Wong MR, Reggio MJ, Morocho FR, et al. Effects of intraosseous epinephrine in a cardiac arrest swine model. J Surg Res 2016;201(2):327-33. doi:10.1016/j.jss.2015.11.015

776

Preclinical study that examined the differences in pharmacokinetics and pharmacodynamics of tibial IO (TIO) and IV-delivered epinephrine during cardiac arrest and CPR. There were no significant differences between IV versus TIO epinephrine in achieving ROSC, time to ROSC, and Cmax. In the context of ROSC, epinephrine delivered via TIO route was a clinically relevant alternative to IV administration. The authors concluded that when IV access cannot be immediately obtained in cardiac arrest patients, TIO access should be considered.

YEAR: 2015

Frascone RJ, Salzman JG, Adams AB, Bliss P, Wewerka SS, Dries DJ. Evaluation of intraosseous pressure in a hypovolemic animal model. J Surg Res 2015;193(1):383-90. http://dx.doi.org/10.1016/j.jss.2014.07.007

736

Preclinical study to determine whether intraosseous pressure (IOP) could be consistently recorded and similarity of IOP to central venous and arterial pressure in a porcine hemorrhagic shock model. IOP tracings were tracked reliably from the proximal humerus, distal femur, and proximal tibia. Baseline IOP ranged from 16-18 mm Hg among the three sites, which was approximately 23% of arterial pressure. This study was sponsored by Vidacare Corporation, acquired by Teleflex Incorporated.

Hill SL, Thomas SHL, Flecknell PA, et al. Rapid and equivalent systemic bioavailability of the antidotes HI-6 and dicobalt edetate via the intraosseous and intravenous routes. Emerg Med J 2015;32(8):626-31. doi: 10.1136/emmermed-2014-204171

751

A preclinical study evaluating the bioavailability of antidotes HI-6 oxime and dicobalt edetate when given via proximal tibia intraosseous (IO) access, established via the EZ-IO, compared to intravenous administration via central access in minipigs. Results showed rapid and similar systemic bioavailability of the antidotes when given by both routes and that IO access is an appropriate access route when IV access is impractical.

Johnson D, Garcia-Blanco J, Burgert J, et al. Effects of humeral intraosseous versus intravenous epinephrine on pharmacokinetics and return of spontaneous circulation in a porcine cardiac arrest model: A randomized control trial. Ann Med Surg 2015;4(3):306-10. doi:10.1016/j.amsu.2015.08.005

802

Prospective preclinical study by to determine the effects of humeral IO (HIO) and IV epinephrine administration during cardiac arrest on pharmacokinetics, ROSC, and odds of survival. There were no significant differences in ROSC, maximum concentration; except at 30 s, and time-to-concentration-maximum between the HIO and IV groups. Significant differences existed between the experimental groups and the control. The HIO delivered a higher concentration of epinephrine than the IV route at 30 s, which they noted may be a survival advantage. Authors suggested clinicians consider using the IO route to administer epinephrine when IV access is unobtainable.

Puga T, Hanes MA, Miller LJ, et al. Intramedullary effects of power-infused contrast by intraosseous access. Ann Emerg Med 2015;66(4s):s95

786

A preclinical study evaluating the immediate effects of power injected contrast media on the medullary space of anesthetized swine. Contrast media (150 mL) was administered at a rate of 5 mL/second. For each limb receiving power injection a control limb was submitted for evaluation. The pathologist was blinded to which limb received power injection. Results showed no histological difference in limbs receiving and not receiving power injection. This study was sponsored by Teleflex Incorporated.

Intraosseous Vascular Access Bibliography

Pre-Clinical Studies

Saul T, Siadecki SD, Berkowitz R, Rose G, Matilsky D. The accuracy of sonographic confirmation of intraosseous line placement vs physical examination and syringe aspiration. *Am J Emerg Med* 2015;33(4):586-8. doi: 10.1016/j.ajem.2014.12.034

746

A preclinical study comparing three methods used to confirm intraosseous (IO) catheter tip placement within the IO space. Using an immature anesthetized swine, 8 IO needles were inserted, 4 properly placed within the IO space and 4 placed in the subcutaneous tissue. Physician sonographers (n=32) participated in the study and determine IO proper and improper IO line placement using physical examination, syringe aspiration, and ultrasonography after administering 5 cm3 of normal saline through each IO line. Confirmation via physical examination resulted in 32/32 successful evaluations; syringe aspiration resulted in 22/32 successful evaluations; and ultrasonography resulted in 30/32 successful evaluations.

Strandberg G, Larsson A, Lipcsey M, Michalek J, Eriksson M. Intraosseous and intravenous administration of antibiotics yields comparable plasma concentrations during experimental septic shock. *Acta Anaesthesiol Scand* 2015;doi: 10.1111/aas.12454

738

Preclinical study using a porcine model to determine whether there were differences in intraosseous (IO) and intravenous (IV) antibiotic (cefotaxime and gentamicin) concentrations during septic shock. Both methods of administration yielded comparable concentrations. Authors concluded in an emergency, IO administration of these antibiotics may be considered in severe infections when venous access is difficult

Sweden

Young SW, Roberts T, Johnson S, Dalton JP, Coleman B, Wiles S. Regional intraosseous administration of prophylactic antibiotics is more effective than systemic administration in a mouse model of TKA. *Clin Orthop Relat Res* 2015;473(11):3573-84. doi: 10.1007/s11999-015-4464-x

1035

This study compared the effectiveness of prophylactic intraosseous regional administration (IORA) of antibiotics with systemic administration using an in vivo murine model of total knee arthroplasty (TKA). Mice were randomized into 1 of 6 groups: control, IV vancomycin 110 mg/kg, IV vancomycin 25 mg/kg, IORA vancomycin 25 mg/kg, IORA cefazolin 100 mg/kg, or IV cefazolin 100 mg/kg. TKA was performed and an aliquot containing *S aureus* was pipetted into the joint. At 4 days post-surgery the bioluminescent signals as well as CFUs from the extracted joints obtained from mice administered IV vancomycin 110 mg/kg, IORA vancomycin 25 mg/kg, and IORA cefazolin 100 mg/kg were lower than those of the control group. Overall, in mice, IO antibiotic administration was more effective at reducing bacterial burden than the same dose of IV antibiotic.

YEAR: 2014

Bebarta VS, Pitotti RL, Bondreau S, Tanen DA. Intraosseous versus intravenous infusion of hydroxocobalamin for the treatment of acute severe cyanide toxicity in a swine model. *Aca Emerg Med* 2014;21(11):1203-11

865

Randomized swine study with the objective to compare the efficacy of IO delivery of hydroxocobalamin to intravenous (IV) injection for the management of acute cyanide toxicity. The survival rate, physiologic parameters such as reversal of hypotension, and pharmacokinetic results were similar between the IV and IO group. The primary limitation was use of a swine model. Investigators concluded intraosseous hydroxocobalamin may be as effective as the intravenous route in treatment of cyanide toxicity.

Borovnik-Lesjak V, Whitehouse K, Baetiong A, et al. Effects of intraosseous erythropoietin during hemorrhagic shock in swine. *PLoS One* 2014;9(11):e110908. doi: 10.1371/journal.pone.0110908

1044

This preclinical study investigated whether erythropoietin (EPO) given during hemorrhagic shock improved resuscitation and increased survival in a swine model. Swine were randomized to one of three groups: loss of 50% blood volume, loss of 65% blood volume, or loss of 65% blood volume plus vasopressin. Within each group half of the swine also received intraosseous EPO. EPO failed to improve initial resuscitability and 72 hour survival, however, EPO did attenuate acute organ injury. Additionally, vasopressin proved effective in improving survival.

Puga T, Montez D, Davlantes C, et al. Whole blood transfusion via IO access does not result in gross hemolysis in a pre-clinical study. *Crit Care Med* 2014;42(12):A1421. abstract 251

760

In this pre-clinical study, 18 units of blood were transfused into 10 anesthetized swine via intraosseous (IO) access. Venous specimens were collected to evaluate free hemoglobin levels as an indicator of hemolysis. Seventeen transfusions were given via the proximal humerus site and 1 via the proximal tibia, using a pressure bag set to 300 mmHg. Mean transfusion flow rate was 61.6 ± 37.3 mL/min and the mean blood volume transfused was 266 ± 74 mL (n=18). The authors concluded that blood transfusion via IO access resulted in high flow rates and did not result in appreciable hemolysis as indicated by free hemoglobin values. This study was sponsored by Teleflex Incorporated.

YEAR: 2013

Lairet J, Bebarta V, Lairet K, et al. A comparison of proximal tibia, distal femur, and proximal humerus infusion rates using the EZ-IO intraosseous device on the adult swine (*Sus scrofa*) Model. *Prehosp Emerg Care* 2013;17:280-4. Doi:10.3109/10903127.2012.755582

642

Pre-clinical study comparing flow rates achieved after insertion with the EZ-IO in the proximal tibia, distal femur, and proximal humerus in a swine model. IO catheters were placed in each site and normal saline was infused for 10 minutes using a pressure bag at the highest achievable pressures greater than 300mmHg. The flow rates through the proximal humerus were statistically greater than that of the femur or proximal tibia. The femur flow rates were higher than the proximal tibia but similar. Post-mortem histopathologic evaluations done to assess for damage due to the high infusion pressures were consistent with IO catheter placement.

Intraosseous Vascular Access Bibliography

Pre-Clinical Studies

YEAR: 2010

Lima R, Navarro L, Cesani F, et al. Repeated doses of adriamycin may be safely delivered through the intraosseous route in different bones in swine. *Blood* 2010;116(21):4344. Accessed May 25, 2017. Retrieved from <http://www.bloodjournal.org/content/116/21/4344>

949

This abstract describes a follow-up swine study to an earlier study done using concentrated doses of Adriamycin over 72 days in which bone complications occurred. Investigators studied different drug administration regimens that might be used to prevent complications. After the study was completed authors concluded that IO delivery of lower dose and diluted concentrations of Adriamycin was determined to be safer and resulted in less tissue abnormality when compared with higher dose/higher concentration; and use of the IO route with rotation of sites may be a feasible option for Adriamycin or other vesicant delivery.

Mader TJ, Walterscheid JK, Kellog AR, Lodding CC. The feasibility of inducing mild therapeutic hypothermia after cardiac resuscitation using iced saline infusion via an intraosseous needle. *Resuscitation* 2010;81(1):82-6

440

In this study, using a swine model, investigators concluded that mild therapeutic hypothermia can be effectively induced after successful resuscitation of prolonged ventricular fibrillation through infusion of chilled saline via the IO catheter.

YEAR: 2007

Pugh JA, Tyler J, Churchill TA, Fox RJ, Aronyk KE. Intraosseous infusion into the skull: potential application for the management of hydrocephalus. *J Neurosurg* 2007;106(2 Suppl):120-5

859

A pre-clinical study evaluating use of intraosseous infusion into the skull, in large adult swine, for the purpose of cerebrospinal fluid (CSF) reabsorption. The authors created intraosseous infusion devices designed specifically for use in this study. Results showed IO infusion demonstrated similarities to systemic absorption characteristics; and authors concluded IO skull infusion may eventually provide another alternative in the management of hydrocephalus.

Canada

YEAR: 1995

Watson WC, Ryan DM, Dubick MA, et al .. High pressure delivery of resuscitation fluid through bone marrow [abstract 186]. *Acad Emerg Med*. 1995;2(5):402

1031

This is an abstract of a study to determine whether the current pressure limit (300 mm Hg) of IV infusions can be significantly increased for IO infusion. Pressure flow in anesthetized and freshly killed swine, anesthetized sheep, and human cadavers were measured. The study concluded that pressures as high as 2500 mm Hg could be used to deliver lactated Ringer's via the IO route to resuscitate hypovolemic shock.

YEAR: 1993

Ronning G, Busund R, Revhaug A. Resuscitation of pigs with haemorrhagic shock by an intraosseous hyperosmotic solution and transfusion of autologous whole blood. *Eur J Surg* 1993;159(9):133-9

145

Preclinical study in 18 piglets finding significant improvement in hemodynamic variables after IO infusion of hyperosmotic saline and IO transfusion of whole blood in an animal model of hemorrhagic shock. Concludes that IO infusion is easy to establish and holds utility for treatment of shock victims.

Intraosseous Vascular Access Bibliography

Proximal Humerus

YEAR: 2019

Burgert JM, Johnson AD, O'Sullivan JC, et al. Pharmacokinetic effects of endotracheal, intraosseous, and intravenous epinephrine in a swine model of traumatic cardiac arrest. *Am J Emerg Med* 2019;(in press). doi: 10.1016/j.ajem.2019.02.035 1046

This pre-clinical study compared various PK parameters, return of spontaneous circulation (ROSC), time to ROSC, and odds of ROSC after epinephrine was administered via endotracheal (ETT), IO, and IV routes in a swine traumatic cardiac arrest model (TCA). IO groups included sternal IO (SIO), humeral IO (HIO), and tibial IO (TIO). CPR only and CPR plus defibrillation (CPRD) groups were included for analyzing ROSC. The Cmax of the IV epinephrine group was significantly higher than that of the IO group (p=0.049). The tmax of the TIO group was significantly longer than that of all other groups (p=0.008). There were significant differences in mean plasma concentrations over time between the IV and TIO groups at 90, 120, 150, and 180 seconds (p<0.05) with the TIO group having an unexpectedly prolonged absorption phase. There was no difference in the rate of ROSC between ETT, TIO, HIO, SIO, IV and CPRD groups. The PK findings relative to ROSC support the concept that neither epinephrine nor the route of administration influenced the outcome. All IO insertions were performed using the EZ-IO device.

Sørgjerd R, Sunde GA, Heltne JK. Comparison of two different intraosseous access methods in a physician-staffed helicopter emergency medical service - A quality assurance study. *Scand J Trauma Resusc Emerg Med* 2019;27(1):15 doi: 10.1186/s13049-019-0594-6 1062

This study compared IO insertions with the EZ-IO device (tibial/humeral insertions) to the FAST-R device (sternal insertions only) in a physician-staffed helicopter emergency medical service. Insertion time, insertion site, flow, indication for IO access, and complications were compared. Median insertion time was 15 seconds for EZ-IO and 20 seconds for FAST-R. Overall, 35.1% of EZ-IO insertions resulted in poor flow and required a pressure bag while 85.7% of FAST-R insertions had good or very good flow. EZ-IO complications included extravasation (2.4%), aspiration failure (11.9%), and insertion time >30 seconds (4.8%). Complications associated with FAST-R included user failure (12.5%) and insertion time >30 seconds (12.5%). The authors suggest that although EZ-IO is faster the FAST-R device may be more useful when high-flow infusion rates are required. The authors indicate that a low number of insertions were made with the FAST-R device and many outliers were observed in the data. However, the article does not present the total number of insertions per device.

YEAR: 2018

Bjerkvig CK, Fosse TK, Apelseth TO, et al. Emergency sternal intraosseous access for warm fresh whole blood transfusion in damage control resuscitation. *J Trauma Acute Care Surg* 2018;84(6S):S120-4. doi:10.1097/TA.0000000000001850. (Norway) 962

This article describes a prospective, comparative, nonrandomized study to compare flow rates using the sternal IO route with two different devices (EZ-IO and Fast1) when transfusing warm fresh whole blood as well as measuring post-infusion hemolysis when compared to IV infusion. Post procedure blood samples from all patients were within normal ranges with no statistically significant differences between groups. This study had a high catheter insertion failure rate in the IO groups. This was most likely due to subjects, healthy Norwegian military volunteers, performing the procedures on each other. The results suggest that infusion of fresh whole blood via the IO route is safe and reliable.

Burgert J, Martinez A, O'Sullivan M, Blouin D, Long A, Johnson A. Sternal route more effective than tibial route for intraosseous amiodarone administration in a swine model of ventricular fibrillation. *Prehosp Emerg Care* 2018;22(2):266-75. doi:10.1080/10903127.2017.1358782 903

This study examined the measured mean plasma concentration, maximum plasma concentration (Cmax), and time to maximum concentration (Tmax) of amiodarone administered by 3 different routes, sternal IO (SIO), tibial IO (TIO), and IV over a time period of 5 minutes in 21 swine who were randomly assigned to one of the 3 routes. The swine were under general anesthesia and ventricular fibrillation was induced and CPR initiated. After 4 minutes in ventricular fibrillation the swine were administered 300 mg of amiodarone and blood samples were taken at 30 second intervals over 300 seconds. Authors concluded that the SIO and IV routes of amiodarone were comparable. The TIO group took almost 3 times longer to reach Tmax than the SIO and IV groups. In the swine model used in this study, the authors concluded that SIO route was more effective than the TIO route for the amiodarone delivery in a swine with VF and ongoing CPR.

Sulava EF, Bianchi W, Krepela A, et al. Performance of single versus double site intraosseous blood transfusion strategies in a swine (sus scrofa) model of hemorrhagic shock. *Ann Emerg Med* 2018;72(4s):S3-4 1023

This abstract describes interim results of a study in a swine model that discusses the utility of intraosseous blood transfusions for treating hypovolemic battlefield injuries, compares advantages and complications of humeral versus sternal IO access for resuscitation, and identifies flow rates, degree of intravascular hemolysis, and occurrence of coagulopathy in single versus double site intraosseous blood transfusion. The study found that in an animal model of hemorrhagic shock, double site IO transfusion appears to confer a significant advantage in flow rates without significant complications

YEAR: 2017

Hodgetts JM, Johnston A, Kendrew J. Long-term follow-up of two patients with retained intraosseous sternal needles. *J R Army Med Corps* 2017;163(3):221-2. doi: 10.1136/jramc-2016-000699 872

This article describes two cases in which FAST1 intraosseous needle tips were retained in the sternal manubrium of patients following device removal. In each case, there were no long-term complications.

Intraosseous Vascular Access Bibliography

Proximal Humerus

U.S. Army, CoTCCC, TCCC Working Group. Tactical combat casualty care: Lessons and best practices. Tactical combat casualty care (TCCC): Lessons and best practices. Handbook. No. 17-13: Version 5. May 2017

1072

The CoTCCC handbook was created as a guide to best practices created by the Committee on Tactical Combat Casualty Care (CoTCCC) which includes representatives from all the U.S. Armed Services that are part of the Tactical Combat Casualty Care (TCCC) Working Group. The recommendations are based on input from the battlefield as well as evidence in the civilian literature, examined and put together to provide guidelines for care. The recommendations and required skill sets include IO access as an alternative to IV access in multiple sections. The TCCC- Medical provider skill set specifically includes the ability to demonstrate the use of IV/IO blood product administration (medical officers and operating room special operations medics) and the use of IV/IO tranexamic acid (TXA).

YEAR: 2016

Montez D, Puga T, Davlantes C, Philbeck T. IO infusion pain mitigation in the sternum and proximal humerus: Establishing a regimen. Crit Care Med 2016;44(12 Suppl):154

822

A prospective study with 30 evaluable healthy volunteers receiving PH and sternal IO access (Arrow® EZ-IO® Vascular Access System and T.A.L.O.N.™, Teleflex, Wayne, PA) was conducted to determine if there is a significant difference between pain after a total of 60mg or 40mg of 2% preservative- free and epinephrine- free lidocaine. Endpoints were subject reported pain scores during 5 minutes of rapid infusion at 300 mmHg and 15 and 30 minutes at a rate of 125 mL/hour per pump. Authors concluded infusion pain through a PH IO may be managed with a single 40mg lidocaine prior to infusion, but a total of 60mg may be considered for sternal IO infusion. This study was sponsored by Teleflex Incorporated.

O'Sullivan M, Martinez A, Long A, et al. Comparison of the effects of sternal and tibial intraosseous administered resuscitative drugs on return of spontaneous circulation in a swine model of cardiac arrest. Am J Disaster Med 2016;11(3):175-82. doi:10.5055/ajdm.2016.0237

1006

This study compared the effects of IO and IV administered resuscitative drugs (vasopressin, amiodarone, and epinephrine) on return of spontaneous circulation (ROSC) in a swine model of sudden cardiac arrest (SCA) with ongoing resuscitation. Swine were randomized to 1 of 5 groups; tibial IO, sternal IO, IV, CPR+defibrillation, and CPR-only. There was no significant difference in ROSC between SIO, TIO, and IV groups. However time to ROSC was significantly less for the SIO group compared to the TIO group (p=0.003). This is possibly related to higher fat content in tibial bone marrow relative to the sternum and the lipophilicity of amiodarone.

Philbeck TE, Montez DF, Puga TA, Davlantes C, Miller LJ. Infusion flow rates and insertion success through the sternum using a multi-site intraosseous device. J Vasc Access 2016;17(4):e131

784

This abstract describes the results of a healthy volunteer study evaluating use of the EZ-IO TALON in the sternal IO insertion site. IO infusion flowrate was measured and reported for gravity infusion, as well as pressured infusions at 100, 200, and 300 mmHg. The authors concluded the TALON device may be used safely and successfully in the sternum with excellent infusion flow rates. This study was sponsored by Teleflex Incorporated.

Puga T, Montez D, Philbeck T, Davlantes C. Adequacy of intraosseous vascular access insertion sites for high-volume fluid infusion. Crit Care Med 2016;44(12 Suppl):143

821

This study was completed on 30 healthy subjects to evaluate infusion rates via the sternum (SIO) and proximal humerus (PH) sites under 300 mmHg via pressure bag. The mean SIO infusion rate was 9,587±2,706mL/hr (n=27); mean PH infusion rate was 6,292 ±3,277mL/hr (n=52). There were no serious complications; minor complications were 5 cases of excess pain, 2 cases vagal response, and mammary tissue engorgement. The mean PH flow rate was significantly lower than that of SIO, but placing IO catheters in each humeri with simultaneous infusion could result in fluid delivery of 13,000mL/hr, surpassing that of the sternum. This study was sponsored by Teleflex Incorporated.

Savell S, Mora AG, Perez CA, Bebart VS, Maddry JK. En route intraosseous access performed in the combat setting. Am J Disaster Med 2016;11(4):225-31. doi:10.5055/ajdm.2016.0243

847

A retrospective study evaluating vascular access routes used for US Military personnel injured in combat and transported by MEDEVAC. Medical records were reviewed for intravenous (IV) and intraosseous (IO) use including, number of attempts and rates of success; along with events occurring in transit, hospital and ICU stays and 30 day outcomes. Results showed IV and/or IO access was attempted in 832 patients. PIV was first line of attempt in 758 cases with 93% success; IO access was first line of attempt in 74 cases with 85% success. There were 25 attempts to establish IO as the second line of access with 100% successful placement. Success rates were 100% with tibia (29); 94% with humerus (21/22); and 89% with the sternum (41/46). The overall IO success rate was 88% for all attempts made.

Smereka J, Madziala M, Szarpak L. Are firefighters able to perform intraosseous access and start fluid resuscitation in an anaphylactic patient. Am J Emerg Med 2016;34(8):1707-8. doi: 10.1016/j.ajem.2016.05.068

851

This letter to the editor describes a simulation study evaluating use of the NIO device by 47 firefighters in a simulated anaphylactic shock model. The firefighters were trained on use of the device and standard anaphylactic shock management. An improvement in knowledge of intraosseous vascular access and anaphylactic shock protocol was demonstrated by the group.

Intraosseous Vascular Access Bibliography

Proximal Humerus

Smith S, Borgkvist B, Kist T, Annelin J, Johnson D, Long R. The effects of sternal intraosseous and intravenous administration of amiodarone in a hypovolemic swine cardiac arrest model. Am J Disaster Med 2016;11(4):271-7. doi:10.5055/ajdm.2016.0249

830

A pre-clinical study comparing the effects of IV and sternal IO administered amiodarone in a swine cardiac arrest model. Following 2 minutes of cardiac arrest, CPR was initiated and after an additional 2 minutes, amiodarone was administered via sternal IO or IV access. Blood samples were collected over 5 minutes. Results showed no statistical difference between routes for return of spontaneous circulation (ROSC), time to ROSC, T-max, or C-max. The authors concluded sternal IO route provides rapid and reliable access to administer life-saving medications during cardiac arrest.

Vallier DJ, Torrence AD, Stevens, III R, Arcinue PN, Johnson D. The effects of sternal and intravenous vasopressin administration on pharmacokinetics. Am J Disaster Med 2016;11(3):203-9. doi:10.5055/ajdm.2016.0240

841

A preclinical study comparing the maximum concentration (Cmax), time to maximum concentration (Tmax) when administering vasopressin via intravenous (IV) and sternal intraosseous (SIO) access in a cardiac arrest swine model. Anesthetized swine were put into cardiac arrest, after 2 minutes CPR was initiated for 2 minutes, then 40 units of vasopressin was administered via IV or SIO route. Results showed no significant difference in SIO and IV groups for Cmax or Tmax.

YEAR: 2015

Hammer N, Möbius R, Gries A, Hossfeld B, Bechmann I, Bernhard M. Comparison of the fluid resuscitation rate with and without external pressure using two intraosseous infusion systems for adult emergencies, the CITRIN (comparison of intraosseous infusion systems in emergency medicine)- study. PLoS ONE 2015;10(12):e0143726. doi:10.1371/journal.pone.0143726

791

A cadaveric study performed by twenty-seven medical students, inexperienced with IO vascular access, that compared use of the EZ-IO for access in the proximal humerus and proximal tibia insertion sites and the FASTR for access in the sternum. First pass insertion success, insertion times, and one minute flow rates using external pressures from 0 to 300 mmHg were evaluated. The authors concluded that both the EZ-IO and FASTR devices may be effective IO devices and are likely suitable for fluid resuscitation using a pressure bag.

Pasley J, Miller CHT, DuBose J, et al. Intraosseous infusion rates under high pressure: a cadaveric comparison of anatomic sites. J Trauma Acute Care Surg 2015;78(2):295-9. DOI: 10.1097/TA.0000000000000516

750

A cadaveric study evaluating intraosseous (IO) vascular access insertion sites for attainable flow rates under 300 mmHg. The EZ-IO was used to establish IO access at the proximal humerus and proximal tibia sites; the FAST1 was used to establish sternal IO access. The total volume of fluid infused at the three IO access sites was 469 ± 190 mL for the sternum; 286 ± 218 mL for the humerus; and 154 ± 94 mL for the tibia. The mean flow rate infused at each site was as follows: 93.7 ± 37.9 mL/min for the sternum; 57.1 ± 43.5 mL/min for the humerus; and 30.7 ± 18.7 mL/min for the tibia. First attempt placement success was 100% for the sternum and proximal humerus and 81% for the tibia.

Philbeck TE, Puga T, Montez DF, Miller LJ, Saussy J, Davlantes C. Sternal flow rates and insertion success using a multisite intraosseous device. Ann Emerg Med 2015;66(4s):s48

787

A healthy volunteer study evaluating use of the EZ-IO TALON in the sternal IO insertion site. Military trained medics performed all device insertions. IO infusion flowrate was measured and reported for gravity infusion, as well as pressured infusions at 100, 200, and 300 mmHg. The authors concluded the TALON device may be used by military and tactical medicine personnel to safely and successfully establish IO access in the sternum with excellent infusion flow rates. This study was sponsored by Teleflex Incorporated.

YEAR: 2014

Barnard EBG, Moy RJ, Kehoe AD, Bebart VS, Smith JE. Rapid sequence induction of anesthesia via the intraosseous route: a prospective observational study. Emerg Med J 2014;32(6):449-52. doi:10.1136/emered-2014-203740

702

A prospective observational study that evaluated use of intraosseous vascular access for delivery of rapid sequence intubation (RSI) drugs. Data was collected between January and May 2012 at a combat hospital in Afghanistan. Thirty-four (34) patients underwent RSI with drug delivery via the IO route. Access was established in the proximal humerus and tibia using the EZ-IO and in the sternum using the FAST-1. All placements were successful on first attempt; first pass intubation success rate was 97%; a Cormack-Lehane (C-L) laryngoscopic grade view of 1 was reported 91%. Authors concluded that IO access is a safe and feasible route for delivery of anesthetic drugs for RSI.

Lewis P, Wright C. Saving the critically injured trauma patient: a retrospective analysis of 1000 uses of intraosseous access. Emerg Med J 2014;31(9):784. doi:10.1136/emered-2014-203588

714

This retrospective study reported IO use over a 7-year period during combat operations in Afghanistan by the UK Defence Medical Services. The EZ-IO and FAST1 IO devices were available for use; IO use data was collected from the front line, during helicopter evacuation and at the combat hospital. A total of 1014 IO devices were inserted into 830 adult patients; various medications infused via IO access are listed. Across all cases there were no serious IO complications and 14 minor complications. The author concluded that in the pre-hospital setting in particular and in severely injured trauma patients, IO access should be considered a primary method of obtaining vascular access.

Intraosseous Vascular Access Bibliography

Proximal Humerus

Pasley J, Miller C, Dubose J, et al. Intraosseous infusion rates under high pressure: a cadaveric comparison of anatomic sites. 2014 Annual Scientific Assembly for the Eastern Assoc for the Surgery of Trauma meeting. <http://www.dtic.mil/cgi-bin/GetTRDoc?AD=ADA597324>. Published January 2014. Accessed May 12, 2014

728

This report describes a study conducted by the Air Force Research Laboratory comparing intraosseous infusion rates between IO sites in a cadaveric model to determine if there is a site that is most effective for volume resuscitation. Using 16 cadavers procured within 72 hours of death, IO access was established in the proximal tibia and proximal humerus using the EZ-IO and in the sternum using the FAST1. Results showed the mean flow rate in the sternum was 1.6 times greater than the humerus and 3.1 times greater than the tibia. An abstract describing this report was presented by oral presentation at the 2014 annual scientific assembly for the Eastern Association for the Surgery of Trauma meeting.

Vassallo J, Horne S, Smith JE. Intraosseous access in the military operational setting. J R Nav Med Serv 2014;100(1):36-9

794

This article describes a prospective, observational study conducted March – July 2011 at the emergency department, Camp Bastion, Afghanistan evaluating use of IO access in 117 patients established using the EZ-IO and the FAST1 devices (76% EZ-IO).

YEAR: 2012

Helm M, Goller R, Hackenbroch C, Hossfeld B. A complication of the use of an intra-osseous needle. Emerg Med J 2012;29:923. doi: 10.1136/emered-2011-200139

1054

This is a case report of needle sheering associated with the use of the FAST-1 intraosseous infusion system. A soldier successfully placed a FAST-1 needle in the sternum of a healthy volunteer soldier during a training session. Upon completion of the training session, the soldier was unable to remove the needle. The retained needle was later removed surgically at a field hospital.

YEAR: 1942

Doud E, Tysell, J. Massive intramedullary infusions JAMA 1942;120(15):1212. doi:10.1001/jama.1942.82830500006010c

914

This article discusses use of the medullary route for massive replacement therapy when the usual methods of administration and not available or practical. The article also reviews a case study of a man in receipt of a sternal puncture needle inserted into the medullary cavity where he received the infusions through this needle of whole blood and fluids.

Intraosseous Vascular Access Bibliography

Sternum

YEAR: 2019

Burgert JM, Johnson AD, O'Sullivan JC, et al. Pharmacokinetic effects of endotracheal, intraosseous, and intravenous epinephrine in a swine model of traumatic cardiac arrest. *Am J Emerg Med* 2019;(in press). doi: 10.1016/j.ajem.2019.02.035 1046

This pre-clinical study compared various PK parameters, return of spontaneous circulation (ROSC), time to ROSC, and odds of ROSC after epinephrine was administered via endotracheal (ETT), IO, and IV routes in a swine traumatic cardiac arrest model (TCA). IO groups included sternal IO (SIO), humeral IO (HIO), and tibial IO (TIO). CPR only and CPR plus defibrillation (CPRD) groups were included for analyzing ROSC. The Cmax of the IV epinephrine group was significantly higher than that of the IO group (p=0.049). The tmax of the TIO group was significantly longer than that of all other groups (p=0.008). There were significant differences in mean plasma concentrations over time between the IV and TIO groups at 90, 120, 150, and 180 seconds (p<0.05) with the TIO group having an unexpectedly prolonged absorption phase. There was no difference in the rate of ROSC between ETT, TIO, HIO, SIO, IV and CPRD groups. The PK findings relative to ROSC support the concept that neither epinephrine nor the route of administration influenced the outcome. All IO insertions were performed using the EZ-IO device.

Sørgjerd R, Sunde GA, Heltne JK. Comparison of two different intraosseous access methods in a physician-staffed helicopter emergency medical service - A quality assurance study. *Scand J Trauma Resusc Emerg Med* 2019;27(1):15 doi: 10.1186/s13049-019-0594-6 1062

This study compared IO insertions with the EZ-IO device (tibial/humeral insertions) to the FAST-R device (sternal insertions only) in a physician-staffed helicopter emergency medical service. Insertion time, insertion site, flow, indication for IO access, and complications were compared. Median insertion time was 15 seconds for EZ-IO and 20 seconds for FAST-R. Overall, 35.1% of EZ-IO insertions resulted in poor flow and required a pressure bag while 85.7% of FAST-R insertions had good or very good flow. EZ-IO complications included extravasation (2.4%), aspiration failure (11.9%), and insertion time >30 seconds (4.8%). Complications associated with FAST-R included user failure (12.5%) and insertion time >30 seconds (12.5%). The authors suggest that although EZ-IO is faster the FAST-R device may be more useful when high-flow infusion rates are required. The authors indicate that a low number of insertions were made with the FAST-R device and many outliers were observed in the data. However, the article does not present the total number of insertions per device.

YEAR: 2018

Bjerkvig CK, Fosse TK, Apelseth TO, et al. Emergency sternal intraosseous access for warm fresh whole blood transfusion in damage control resuscitation. *J Trauma Acute Care Surg* 2018;84(6S):S120-4. doi:10.1097/TA.0000000000001850. (Norway) 962

This article describes a prospective, comparative, nonrandomized study to compare flow rates using the sternal IO route with two different devices (EZ-IO and Fast1) when transfusing warm fresh whole blood as well as measuring post-infusion hemolysis when compared to IV infusion. Post procedure blood samples from all patients were within normal ranges with no statistically significant differences between groups. This study had a high catheter insertion failure rate in the IO groups. This was most likely due to subjects, healthy Norwegian military volunteers, performing the procedures on each other. The results suggest that infusion of fresh whole blood via the IO route is safe and reliable.

Burgert J, Martinez A, O'Sullivan M, Blouin D, Long A, Johnson A. Sternal route more effective than tibial route for intraosseous amiodarone administration in a swine model of ventricular fibrillation. *Prehosp Emerg Care* 2018;22(2):266-75. doi:10.1080/10903127.2017.1358782 903

This study examined the measured mean plasma concentration, maximum plasma concentration (Cmax), and time to maximum concentration (Tmax) of amiodarone administered by 3 different routes, sternal IO (SIO), tibial IO (TIO), and IV over a time period of 5 minutes in 21 swine who were randomly assigned to one of the 3 routes. The swine were under general anesthesia and ventricular fibrillation was induced and CPR initiated. After 4 minutes in ventricular fibrillation the swine were administered 300 mg of amiodarone and blood samples were taken at 30 second intervals over 300 seconds. Authors concluded that the SIO and IV routes of amiodarone were comparable. The TIO group took almost 3 times longer to reach Tmax than the SIO and IV groups. In the swine model used in this study, the authors concluded that SIO route was more effective than the TIO route for the amiodarone delivery in a swine with VF and ongoing CPR.

Sulava EF, Bianchi W, Krepela A, et al. Performance of single versus double site intraosseous blood transfusion strategies in a swine (sus scrofa) model of hemorrhagic shock. *Ann Emerg Med* 2018;72(4s):S3-4 1023

This abstract describes interim results of a study in a swine model that discusses the utility of intraosseous blood transfusions for treating hypovolemic battlefield injuries, compares advantages and complications of humeral versus sternal IO access for resuscitation, and identifies flow rates, degree of intravascular hemolysis, and occurrence of coagulopathy in single versus double site intraosseous blood transfusion. The study found that in an animal model of hemorrhagic shock, double site IO transfusion appears to confer a significant advantage in flow rates without significant complications

YEAR: 2017

Hodgetts JM, Johnston A, Kendrew J. Long-term follow-up of two patients with retained intraosseous sternal needles. *J R Army Med Corps* 2017;163(3):221-2. doi: 10.1136/jramc-2016-000699 872

This article describes two cases in which FAST1 intraosseous needle tips were retained in the sternal manubrium of patients following device removal. In each case, there were no long-term complications.

Intraosseous Vascular Access Bibliography

Sternum

U.S. Army, CoTCCC, TCCC Working Group. Tactical combat casualty care: Lessons and best practices. Tactical combat casualty care (TCCC): Lessons and best practices. Handbook. No. 17-13: Version 5. May 2017

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The CoTCCC handbook was created as a guide to best practices created by the Committee on Tactical Combat Casualty Care (CoTCCC) which includes representatives from all the U.S. Armed Services that are part of the Tactical Combat Casualty Care (TCCC) Working Group. The recommendations are based on input from the battlefield as well as evidence in the civilian literature, examined and put together to provide guidelines for care. The recommendations and required skill sets include IO access as an alternative to IV access in multiple sections. The TCCC- Medical provider skill set specifically includes the ability to demonstrate the use of IV/IO blood product administration (medical officers and operating room special operations medics) and the use of IV/IO tranexamic acid (TXA).

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Montez D, Puga T, Davlantes C, Philbeck T. IO infusion pain mitigation in the sternum and proximal humerus: Establishing a regimen. Crit Care Med 2016;44(12 Suppl):154

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A prospective study with 30 evaluable healthy volunteers receiving PH and sternal IO access (Arrow® EZ-IO® Vascular Access System and T.A.L.O.N.™, Teleflex, Wayne, PA) was conducted to determine if there is a significant difference between pain after a total of 60mg or 40mg of 2% preservative- free and epinephrine- free lidocaine. Endpoints were subject reported pain scores during 5 minutes of rapid infusion at 300 mmHg and 15 and 30 minutes at a rate of 125 mL/hour per pump. Authors concluded infusion pain through a PH IO may be managed with a single 40mg lidocaine prior to infusion, but a total of 60mg may be considered for sternal IO infusion. This study was sponsored by Teleflex Incorporated.

O'Sullivan M, Martinez A, Long A, et al. Comparison of the effects of sternal and tibial intraosseous administered resuscitative drugs on return of spontaneous circulation in a swine model of cardiac arrest. Am J Disaster Med 2016;11(3):175-82. doi:10.5055/ajdm.2016.0237

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This abstract describes the results of a healthy volunteer study evaluating use of the EZ-IO TALON in the sternal IO insertion site. IO infusion flowrate was measured and reported for gravity infusion, as well as pressured infusions at 100, 200, and 300 mmHg. The authors concluded the TALON device may be used safely and successfully in the sternum with excellent infusion flow rates. This study was sponsored by Teleflex Incorporated.

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This letter to the editor describes a simulation study evaluating use of the NIO device by 47 firefighters in a simulated anaphylactic shock model. The firefighters were trained on use of the device and standard anaphylactic shock management. An improvement in knowledge of intraosseous vascular access and anaphylactic shock protocol was demonstrated by the group.

Intraosseous Vascular Access Bibliography

Sternum

Smith S, Borgkvist B, Kist T, Annelin J, Johnson D, Long R. The effects of sternal intraosseous and intravenous administration of amiodarone in a hypovolemic swine cardiac arrest model. Am J Disaster Med 2016;11(4):271-7. doi:10.5055/ajdm.2016.0249

830

A pre-clinical study comparing the effects of IV and sternal IO administered amiodarone in a swine cardiac arrest model. Following 2 minutes of cardiac arrest, CPR was initiated and after an additional 2 minutes, amiodarone was administered via sternal IO or IV access. Blood samples were collected over 5 minutes. Results showed no statistical difference between routes for return of spontaneous circulation (ROSC), time to ROSC, T-max, or C-max. The authors concluded sternal IO route provides rapid and reliable access to administer life-saving medications during cardiac arrest.

Vallier DJ, Torrence AD, Stevens, III R, Arcinue PN, Johnson D. The effects of sternal and intravenous vasopressin administration on pharmacokinetics. Am J Disaster Med 2016;11(3):203-9. doi:10.5055/ajdm.2016.0240

841

A preclinical study comparing the maximum concentration (Cmax), time to maximum concentration (Tmax) when administering vasopressin via intravenous (IV) and sternal intraosseous (SIO) access in a cardiac arrest swine model. Anesthetized swine were put into cardiac arrest, after 2 minutes CPR was initiated for 2 minutes, then 40 units of vasopressin was administered via IV or SIO route. Results showed no significant difference in SIO and IV groups for Cmax or Tmax.

YEAR: 2015

Hammer N, Möbius R, Gries A, Hossfeld B, Bechmann I, Bernhard M. Comparison of the fluid resuscitation rate with and without external pressure using two intraosseous infusion systems for adult emergencies, the CITRIN (comparison of intraosseous infusion systems in emergency medicine)- study. PLoS ONE 2015;10(12):e0143726. doi:10.1371/journal.pone.0143726

791

A cadaveric study performed by twenty-seven medical students, inexperienced with IO vascular access, that compared use of the EZ-IO for access in the proximal humerus and proximal tibia insertion sites and the FASTR for access in the sternum. First pass insertion success, insertion times, and one minute flow rates using external pressures from 0 to 300 mmHg were evaluated. The authors concluded that both the EZ-IO and FASTR devices may be effective IO devices and are likely suitable for fluid resuscitation using a pressure bag.

Pasley J, Miller CHT, DuBose J, et al. Intraosseous infusion rates under high pressure: a cadaveric comparison of anatomic sites. J Trauma Acute Care Surg 2015;78(2):295-9. DOI: 10.1097/TA.0000000000000516

750

A cadaveric study evaluating intraosseous (IO) vascular access insertion sites for attainable flow rates under 300 mmHg. The EZ-IO was used to establish IO access at the proximal humerus and proximal tibia sites; the FAST1 was used to establish sternal IO access. The total volume of fluid infused at the three IO access sites was 469 ± 190 mL for the sternum; 286 ± 218 mL for the humerus; and 154 ± 94 mL for the tibia. The mean flow rate infused at each site was as follows: 93.7 ± 37.9 mL/min for the sternum; 57.1 ± 43.5 mL/min for the humerus; and 30.7 ± 18.7 mL/min for the tibia. First attempt placement success was 100% for the sternum and proximal humerus and 81% for the tibia.

Philbeck TE, Puga T, Montez DF, Miller LJ, Saussy J, Davlantes C. Sternal flow rates and insertion success using a multisite intraosseous device. Ann Emerg Med 2015;66(4s):s48

787

A healthy volunteer study evaluating use of the EZ-IO TALON in the sternal IO insertion site. Military trained medics performed all device insertions. IO infusion flowrate was measured and reported for gravity infusion, as well as pressured infusions at 100, 200, and 300 mmHg. The authors concluded the TALON device may be used by military and tactical medicine personnel to safely and successfully establish IO access in the sternum with excellent infusion flow rates. This study was sponsored by Teleflex Incorporated.

YEAR: 2014

Barnard EBG, Moy RJ, Kehoe AD, Bebarta VS, Smith JE. Rapid sequence induction of anesthesia via the intraosseous route: a prospective observational study. Emerg Med J 2014;32(6):449-52. doi:10.1136/emered-2014-203740

702

A prospective observational study that evaluated use of intraosseous vascular access for delivery of rapid sequence intubation (RSI) drugs. Data was collected between January and May 2012 at a combat hospital in Afghanistan. Thirty-four (34) patients underwent RSI with drug delivery via the IO route. Access was established in the proximal humerus and tibia using the EZ-IO and in the sternum using the FAST-1. All placements were successful on first attempt; first pass intubation success rate was 97%; a Cormack-Lehane (C-L) laryngoscopic grade view of 1 was reported 91%. Authors concluded that IO access is a safe and feasible route for delivery of anesthetic drugs for RSI.

Lewis P, Wright C. Saving the critically injured trauma patient: a retrospective analysis of 1000 uses of intraosseous access. Emerg Med J 2014;31(9):784. doi:10.1136/emered-2014-203588

714

This retrospective study reported IO use over a 7-year period during combat operations in Afghanistan by the UK Defence Medical Services. The EZ-IO and FAST1 IO devices were available for use; IO use data was collected from the front line, during helicopter evacuation and at the combat hospital. A total of 1014 IO devices were inserted into 830 adult patients; various medications infused via IO access are listed. Across all cases there were no serious IO complications and 14 minor complications. The author concluded that in the pre-hospital setting in particular and in severely injured trauma patients, IO access should be considered a primary method of obtaining vascular access.

Intraosseous Vascular Access Bibliography

Sternum

Pasley J, Miller C, Dubose J, et al. Intraosseous infusion rates under high pressure: a cadaveric comparison of anatomic sites. 2014 Annual Scientific Assembly for the Eastern Assoc for the Surgery of Trauma meeting. <http://www.dtic.mil/cgi-bin/GetTRDoc?AD=ADA597324>. Published January 2014. Accessed May 12, 2014

728

This report describes a study conducted by the Air Force Research Laboratory comparing intraosseous infusion rates between IO sites in a cadaveric model to determine if there is a site that is most effective for volume resuscitation. Using 16 cadavers procured within 72 hours of death, IO access was established in the proximal tibia and proximal humerus using the EZ-IO and in the sternum using the FAST1. Results showed the mean flow rate in the sternum was 1.6 times greater than the humerus and 3.1 times greater than the tibia. An abstract describing this report was presented by oral presentation at the 2014 annual scientific assembly for the Eastern Association for the Surgery of Trauma meeting.

Vassallo J, Horne S, Smith JE. Intraosseous access in the military operational setting. J R Nav Med Serv 2014;100(1):36-9

794

This article describes a prospective, observational study conducted March – July 2011 at the emergency department, Camp Bastion, Afghanistan evaluating use of IO access in 117 patients established using the EZ-IO and the FAST1 devices (76% EZ-IO).

YEAR: 2012

Helm M, Goller R, Hackenbroch C, Hossfeld B. A complication of the use of an intra-osseous needle. Emerg Med J 2012;29:923. doi: 10.1136/emered-2011-200139

1054

This is a case report of needle sheering associated with the use of the FAST-1 intraosseous infusion system. A soldier successfully placed a FAST-1 needle in the sternum of a healthy volunteer soldier during a training session. Upon completion of the training session, the soldier was unable to remove the needle. The retained needle was later removed surgically at a field hospital.

YEAR: 1942

Doud E, Tysell, J. Massive intramedullary infusions JAMA 1942;120(15):1212. doi:10.1001/jama.1942.82830500006010c

914

This article discusses use of the medullary route for massive replacement therapy when the usual methods of administration and not available or practical. The article also reviews a case study of a man in receipt of a sternal puncture needle inserted into the medullary cavity where he received the infusions through this needle of whole blood and fluids.

Intraosseous Vascular Access Bibliography

Tibia

YEAR: 2019

Burgert JM, Johnson AD, O'Sullivan JC, et al. Pharmacokinetic effects of endotracheal, intraosseous, and intravenous epinephrine in a swine model of traumatic cardiac arrest. *Am J Emerg Med* 2019;(in press). doi: 10.1016/j.ajem.2019.02.035

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Smith S, Borgkvist B, Kist T, Annelin J, Johnson D, Long R. The effects of sternal intraosseous and intravenous administration of amiodarone in a hypovolemic swine cardiac arrest model. *Am J Disaster Med* 2016;11(4):271-7. doi:10.5055/ajdm.2016.0249

830

A pre-clinical study comparing the effects of IV and sternal IO administered amiodarone in a swine cardiac arrest model. Following 2 minutes of cardiac arrest, CPR was initiated and after an additional 2 minutes, amiodarone was administered via sternal IO or IV access. Blood samples were collected over 5 minutes. Results showed no statistical difference between routes for return of spontaneous circulation (ROSC), time to ROSC, T-max, or C-max. The authors concluded sternal IO route provides rapid and reliable access to administer life-saving medications during cardiac arrest.

Vallier DJ, Torrence AD, Stevens, III R, Arcinue PN, Johnson D. The effects of sternal and intravenous vasopressin administration on pharmacokinetics. *Am J Disaster Med* 2016;11(3):203-9. doi:10.5055/ajdm.2016.0240

841

A preclinical study comparing the maximum concentration (Cmax), time to maximum concentration (Tmax) when administering vasopressin via intravenous (IV) and sternal intraosseous (SIO) access in a cardiac arrest swine model. Anesthetized swine were put into cardiac arrest, after 2 minutes CPR was initiated for 2 minutes, then 40 units of vasopressin was administered via IV or SIO route. Results showed no significant difference in SIO and IV groups for Cmax or Tmax.

YEAR: 2015

Hammer N, Möbius R, Gries A, Hossfeld B, Bechmann I, Bernhard M. Comparison of the fluid resuscitation rate with and without external pressure using two intraosseous infusion systems for adult emergencies, the CITRIN (comparison of intraosseous infusion systems in emergency medicine)- study. *PLoS ONE* 2015;10(12):e0143726. doi:10.1371/journal.pone.0143726

791

A cadaveric study performed by twenty-seven medical students, inexperienced with IO vascular access, that compared use of the EZ-IO for access in the proximal humerus and proximal tibia insertion sites and the FASTR for access in the sternum. First pass insertion success, insertion times, and one minute flow rates using external pressures from 0 to 300 mmHg were evaluated. The authors concluded that both the EZ-IO and FASTR devices may be effective IO devices and are likely suitable for fluid resuscitation using a pressure bag.

Pasley J, Miller CHT, DuBose J, et al. Intraosseous infusion rates under high pressure: a cadaveric comparison of anatomic sites. *J Trauma Acute Care Surg* 2015;78(2):295-9. DOI: 10.1097/TA.0000000000000516

750

A cadaveric study evaluating intraosseous (IO) vascular access insertion sites for attainable flow rates under 300 mmHg. The EZ-IO was used to establish IO access at the proximal humerus and proximal tibia sites; the FAST1 was used to establish sternal IO access. The total volume of fluid infused at the three IO access sites was 469 ± 190 mL for the sternum; 286 ± 218 mL for the humerus; and 154 ± 94 mL for the tibia. The mean flow rate infused at each site was as follows: 93.7 ± 37.9 mL/min for the sternum; 57.1 ± 43.5 mL/min for the humerus; and 30.7 ± 18.7 mL/min for the tibia. First attempt placement success was 100% for the sternum and proximal humerus and 81% for the tibia.

Philbeck TE, Puga T, Montez DF, Miller LJ, Saussy J, Davlantes C. Sternal flow rates and insertion success using a multisite intraosseous device. *Ann Emerg Med* 2015;66(4s):s48

787

A healthy volunteer study evaluating use of the EZ-IO TALON in the sternal IO insertion site. Military trained medics performed all device insertions. IO infusion flowrate was measured and reported for gravity infusion, as well as pressured infusions at 100, 200, and 300 mmHg. The authors concluded the TALON device may be used by military and tactical medicine personnel to safely and successfully establish IO access in the sternum with excellent infusion flow rates. This study was sponsored by Teleflex Incorporated.

YEAR: 2014

Barnard EBG, Moy RJ, Kehoe AD, Bebarta VS, Smith JE. Rapid sequence induction of anesthesia via the intraosseous route: a prospective observational study. *Emerg Med J* 2014;32(6):449-52. doi:10.1136/emered-2014-203740

702

A prospective observational study that evaluated use of intraosseous vascular access for delivery of rapid sequence intubation (RSI) drugs. Data was collected between January and May 2012 at a combat hospital in Afghanistan. Thirty-four (34) patients underwent RSI with drug delivery via the IO route. Access was established in the proximal humerus and tibia using the EZ-IO and in the sternum using the FAST-1. All placements were successful on first attempt; first pass intubation success rate was 97%; a Cormack-Lehane (C-L) laryngoscopic grade view of 1 was reported 91%. Authors concluded that IO access is a safe and feasible route for delivery of anesthetic drugs for RSI.

Lewis P, Wright C. Saving the critically injured trauma patient: a retrospective analysis of 1000 uses of intraosseous access. *Emerg Med J* 2014;31(9):784. doi:10.1136/emered-2014-203588

714

This retrospective study reported IO use over a 7-year period during combat operations in Afghanistan by the UK Defence Medical Services. The EZ-IO and FAST1 IO devices were available for use; IO use data was collected from the front line, during helicopter evacuation and at the combat hospital. A total of 1014 IO devices were inserted into 830 adult patients; various medications infused via IO access are listed. Across all cases there were no serious IO complications and 14 minor complications. The author concluded that in the pre-hospital setting in particular and in severely injured trauma patients, IO access should be considered a primary method of obtaining vascular access.

Intraosseous Vascular Access Bibliography

Tibia

Pasley J, Miller C, Dubose J, et al. Intraosseous infusion rates under high pressure: a cadaveric comparison of anatomic sites. 2014 Annual Scientific Assembly for the Eastern Assoc for the Surgery of Trauma meeting. <http://www.dtic.mil/cgi-bin/GetTRDoc?AD=ADA597324>. Published January 2014. Accessed May 12, 2014

728

This report describes a study conducted by the Air Force Research Laboratory comparing intraosseous infusion rates between IO sites in a cadaveric model to determine if there is a site that is most effective for volume resuscitation. Using 16 cadavers procured within 72 hours of death, IO access was established in the proximal tibia and proximal humerus using the EZ-IO and in the sternum using the FAST1. Results showed the mean flow rate in the sternum was 1.6 times greater than the humerus and 3.1 times greater than the tibia. An abstract describing this report was presented by oral presentation at the 2014 annual scientific assembly for the Eastern Association for the Surgery of Trauma meeting.

Vassallo J, Horne S, Smith JE. Intraosseous access in the military operational setting. J R Nav Med Serv 2014;100(1):36-9

794

This article describes a prospective, observational study conducted March – July 2011 at the emergency department, Camp Bastion, Afghanistan evaluating use of IO access in 117 patients established using the EZ-IO and the FAST1 devices (76% EZ-IO).

YEAR: 2012

Helm M, Goller R, Hackenbroch C, Hossfeld B. A complication of the use of an intra-osseous needle. Emerg Med J 2012;29:923. doi: 10.1136/emered-2011-200139

1054

This is a case report of needle sheering associated with the use of the FAST-1 intraosseous infusion system. A soldier successfully placed a FAST-1 needle in the sternum of a healthy volunteer soldier during a training session. Upon completion of the training session, the soldier was unable to remove the needle. The retained needle was later removed surgically at a field hospital.

YEAR: 1942

Doud E, Tysell, J. Massive intramedullary infusions JAMA 1942;120(15):1212. doi:10.1001/jama.1942.82830500006010c

914

This article discusses use of the medullary route for massive replacement therapy when the usual methods of administration and not available or practical. The article also reviews a case study of a man in receipt of a sternal puncture needle inserted into the medullary cavity where he received the infusions through this needle of whole blood and fluids.