Emergency Vascular Access:

Technology, Economics, and Deployment in a Multi-Dimensional Setting

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Overview

Emergency resuscitation and stabilization have been a major focus of patient care since the evolution of emergency medical services (EMS) began some forty years ago in what has become a colorful and rich history.

In the first half of the 20th century, many ambulances were operated by community funeral homes, with patients being transported via hearses because they were large enough to accommodate long stretchers. In 1966, the National Academy of Sciences published a report entitled "Accidental Death and Disability: The Neglected Disease of Modern Society."[1] The report not only cited the incidence of traffic-related death and disability but also described the deficiencies in pre-hospital care. The authors called for standards regarding the operation of ambulance systems, the institution of state-level policies, and the provision of consistent ambulance services at the local level. The National Highway Safety Act, passed that same year, contributed to the beginnings of what was to become today's emergency medical systems and established the first guidelines for a national system.

Today, EMS providers treat nearly 20 million out-of-hospital patients a year in the U.S., many of whom have complex conditions requiring considerable skill and judgment.[2] Because of the importance of the front-line intervention that EMS managers of large agencies provide, they have been recruited as consultants to those operations of Homeland Security concerned with disaster medicine protocols.

While pre-hospital medicine has evolved into a super specialty, several of the practices employed in "the golden hour —" the unit of time widely recognized to be when the potential for saving critically ill or injured patients is at its optimum — are being deployed in other segments of critical care. These include the emergency department, as well as in areas of the hospital where code teams are called, or where fragile patients are being monitored by newly formed Rapid Response Teams (see section below).

A standard of emergency care, along with airway management, is vascular access. It is essential for resuscitation in many groups of patients. The delivery of fluid and medications in a timely way can affect the morbidity or even the mortality of a patient in need of treatment for injuries or underlying disease, yet under certain conditions — usually those in which it is needed most — peripheral vein access can be difficult. In shock or cardiac arrest patients, or in combative patients, peripheral access can actually be impossible. In pediatric patients in a state of shock or cardiac arrest, vascular access may not be attainable in 6% or more of cases, despite the skill of those attempting it.[3] In those situations, the time spent trying to insert a peripheral line, often as long as ten minutes,[4] can consume valuable equipment and human resources. Most importantly, it can compromise care.

Fortunately, the technology available for rapid vascular access when peripheral lines cannot be used has evolved to make it a cost-effective, easily administered, less traumatic procedure for all age groups. It remains for those involved in the management and funding of emergency care to consider that the need for this new technology is far greater than has previously been recognized.

Difficult or Impossible Vascular Access: An Underestimated Problem

The preferred method of vascular access in most instances is the intravenous (IV) route. Peripheral access represents the technique that is the least invasive for the patient, and when it is readily accomplished, the optimum for the clinician. However, when it cannot be achieved either for reasons of time, skill, or patient condition, another solution is needed. Of the thousands of patients treated in the out-of-hospital setting every year in the United States, a significant number do not receive necessary IV therapy because of inadequate access to peripheral veins.[5] It is well recognized that one of the major limitations of out-of-hospital resuscitation relates to the time delays and failure rates associated with vascular access.[6] Depending upon the distance between these patients and a hospital, or the prevailing traffic, or other conditions beyond the control of transport unit personnel, delay could be fatal.

The epidemiology of the problem of difficult vascular access in the hospital is far less well studied. It would logically vary from hospital to hospital, depending upon staffing and available specialists. Most urban and large community hospitals have on staff anesthesiologists, emergency physicians, and intensivists who daily insert lines even under the most difficult circumstances. Their usual alternative to IV access is central vein access, in some part because they possess the skills to insert these lines. However, from an economic, risk management, and patient trauma standpoint, an alternative to central lines would frequently be advantageous. Smaller community hospitals, depending upon the time of day, are somewhat dependent upon on-call specialists who may not be present at the critical moment when an alternative to IV access is required, or who may be overwhelmed by a multi-casualty event.

Mass casualties present an entirely new scenario. In these situations, the need for another method of emergency vascular access when IV lines cannot be employed or when the use of central lines is impossible or inadvisable is mandatory. There are few medical professionals who would disagree that when an equally effective, more economical, minimally invasive method of dealing with a time-critical need becomes available, it should be deployed in appropriate circumstances, especially when access could be achieved in under a minute without the attendant complications that central lines represent.[7]

Intraosseous Access: The First Alternative to IV Access

Intraosseous (IO) infusion is a technique for access to the circulation through blood vessels within the bone marrow that are held open by a rigid, non-collapsible bony wall. Unlike peripheral veins, these vessels do not collapse in shock.[4,8] From the early studies of Drinker and Lund,[9] it is known that substances infused into the intraosseous space are quickly absorbed into the central circulation. Papper established that the circulation times for fluids and medications administered by IO and IV routes were nearly identical, about one second to reach the central circulation.[10] This factor is critical to IO's usefulness as an emergency alternative to IV access.

During World War II, IO infusion was widely used by medics to resuscitate patients in hemorrhagic shock.[11] The practice largely disappeared after the war, when those trained to use it faded back into the civilian population. The rediscovery of IO access as an alternative to the intravenous route was the result of a Cleveland Clinic pediatrician, James Orlowski, visiting India during a cholera epidemic. There he observed the use of IO infusion in severely dehydrated patients who might have died had it not been available. Because of his specialty, he reignited research and interest into IO infusion in infants and children. His classic editorial, "My Kingdom for an Intravenous Line,"[12] advocated the use of IO infusion in pediatric patients where it has remained a standard of practice since the late 1980s, published in the American Heart Association Pediatric Life Support (PALS) guidelines.[13]

IO access in the adult patient has been less widely practiced, largely due to the dearth of available technologies. Recently, several IO devices have been cleared by the Food and Drug Administration for a variety of insertion sites. As a consequence, the emergency medicine community is viewing IO access with new interest. Newly released Advanced Cardiac Life Support guidelines published by the American Heart Association recommend the intraosseous route to be the first alternative to difficult or impossible intravenous access in cardiac arrest patients.[14] The European Resuscitation Council's 2005 guidelines make similar, but broader, recommendations regarding the use of IO in emergency patients when IV access is critically delayed.[15] The endotracheal route for administration of medications is no longer recommended as an alternative to IV access since plasma concentrations using this route are variable and substantially lower than those achieved by intravenous or intraosseous routes. Central line placement for resuscitations is also discouraged.[15]

Available Devices for Pediatric and Adult IO Access

There are three distinct approaches to IO access: manual, impact driven, and powered drill. The last category is the newest entry to the armamentarium of available devices.

Both manual devices[16] and impact driven devices[17] have been available for some time. These devices include hollow steel needles with removable trocars, which prevent bone fragments plugging the needles during insertion. Insertion times vary from device to device, but range between 17 and 50 seconds.[18] In the case of the bone injection gun, an impact-driven device, investigators recommend careful stabilization of the device during insertion to prevent inappropriate placement, and have noted that a potential exists for operator of patient injury if the device is accidentally triggered or mistargeted.[19]

A new technology class in the form of a powered drill utilizes a hand-held, battery-powered device to drill an IO needle into the intraosseous space to an appropriate depth.[20] The average insertion time is less than 10 seconds.[7] The precise needle-to-bone ratio allows an efficient insertion and is designed to minimize trauma to the bone during insertion as an alternative to entering the bone by manual force.

Insertion sites also vary among devices and with age groups, although the tibia is the most popular site in pediatric patients.[21] Sternal access is more often used in military applications, given the nature of war-related injuries, although with FDA clearance of one device inserted in the humeral head, this is changing. It is likely that other anatomic sites will be cleared for IO needle placement. There is also research proceeding on whether first responders could administer IO auto-injectors preloaded with drugs, guided by modified AEDs.[22] The training required for first responders to use IO access is within the parameters of techniques appropriate to first responders in critical situations. Paramedics, emergency medicine residents, and nurses report that the technique is easily learned, even by observation.[23,24]

The Economics of Vascular Access

When peripheral IV access is possible without time-critical delay, it is the most economical method of vascular access in every dimension: cost of equipment, use of clinician time, and usually least trauma to the patient. The cost of an intravenous line is approximately $3 to $5, and if the line can be placed easily, it is a cost effective, safe method of accessing the circulation.

When IV access is difficult, multiple attempts might be made, which will require the use of several IV sets and demand the attention of the clinician for prolonged times with the attendant frustration of being under time pressure. Then there is the potential for patients to arrive in the Emergency Department in a less viable condition, perhaps in acidosis, as a consequence of the delay in attention to airway management, arrhythmias, medication, fluid administration, and transport. In such patients, the cost of vascular access becomes significantly higher in terms of equipment cost, operator cost, and ultimately, treatment cost.

IO catheters cost between $65-$165 each but if IV access is difficult or impossible, the time savings for the EMS organization is much greater, especially if multiple patients are involved. The IO alternative to difficult or failed IV access is an economical choice, compared with a sicker patient, a stressed paramedic, and an inefficiently used transport unit.

Central venous access is the most expensive alternative, costing around $200 for the infusion kit plus around $200 for the post-placement x ray. The procedure cost to the patient is approximately $500. However, the real cost of central lines is two-fold: one, in potential exposure to liability, and second the cost of additive care. The major complication of central lines is infection. A total of 250,000 cases of central venous line-associated blood stream infections have been estimated to occur annually if entire hospitals are assessed rather than ICUs exclusively. In this case, attributable mortality is an estimated 12% —25% for each infection, and the marginal cost to the health-care system is $25,000 per episode.[25] Given the additional cost of care and the exposure to liability far in excess of this number, the choice of central venous lines when not indicated becomes unacceptably high. In contrast, serious complications resulting from IO access are rare.[26] The choice of central venous access when a clinically acceptable alternative is available may subject the clinician to questions by both risk managers and hospital administrators, whose job it is to protect the assets of the institution involved.

The economic evaluation of any procedure or therapy must be based on a combination of factors, which include the direct costs of the procedure or therapy, the time in which it can be delivered, the additional resources that may be required, the risk or liability involved, the quality of care rendered, and the ability of those responsible for further care of the patient to provide that care more efficiently as a benefit of the procedure or therapy. Critical care is by definition expensive care. In the ultimate analysis, direct cost of equipment is often the smallest line item in that expense. Still, in EMS care, reimbursement is either small or non-existent, which changes the economic calculus. In this case, effective use of personnel, transport vehicles, and medications must be included as part of the financial analysis. When these are figured, IO infusion becomes a cost-saving alternative to delayed or failed IV access.

Emergency Vascular Access in the Hospital Setting: Who is at Risk?

The majority of the recent literature on IO infusion is in the out-of-hospital setting where most patients are first seen with shock, cardiac arrest, and trauma. However, IO vascular access may be appropriate in the hospital setting in any area where patients are at risk for emergent conditions that could require vascular access. Delay could be critical to outcome.

The Emergency Department. According to 2002 statistics from the CDC, approximately 114 million patients are admitted to the emergency department in the U.S.[27] Of these, 8 million require vascular access.[5] The estimated number of those in whom access is deemed difficult (meaning more than five IV attempts or ten minutes are required) or impossible is somewhere between 10 and 20 per cent.[19] Many of these patients are automatically given central lines, in part because the personnel in most emergency departments have the skills to install them. Vascular access is required mainly for resuscitation and stabilization, in preparation for emergency department staff to treat the underlying illness or injury. The vital role of the clinician in this situation is to address the core problem at hand, so that patients who can be rapidly stabilized are treated more quickly. Having to attend to supportive measures such as vascular access only delays attention to life-threatening conditions.

Emergency physicians are well qualified to insert lines, and often choose to use central venous access when IV access has failed. The question is, do patients need central access, or would IO access provide the means through which fluids and medications can be adequately administered? Every medication that can be administered through an IV line can be infused via IO, and fluid volume is generally adequate for resuscitation purposes. In addition, it is possible to cross match blood and to obtain standard laboratory values through the IO route.[28] There is a question as to whether central venous access exceeds the needs of many of the patients in whom it is used. Given the aforementioned costs and risks of central lines to both patients and institutions, it is reasonable to suggest that the decision regarding which type of vascular access to use should not be more influenced by the skills of the personnel than by the needs of the patient.

General Care Floors. As a result of the cost of caring for intensive care or postoperative patients, some patients are admitted to step-down units or general care floors earlier than they might have been in previous years. In these patients, clinicians rely on technologies that can give early warning of declining condition.

Increasing support for monitoring patients is being provided by Rapid Response Teams. These teams are specifically targeted at preventing hospital complications, including central line complications. Specialists participating on the teams are those who can bring critical care expertise to the patient's beside, evaluating those who are showing signs of deteriorating status. While they aim to prevent the need for resuscitation, they are trained to do so. Studies have shown that as many as 70 percent of patients exhibit signs of physiological instability for some period of time prior to a cardiac arrest[29] and while 66 percent of patients show abnormal signs within 6 hours of a cardiac arrest, physicians are alerted in only 25% of these patients.[30] According to two studies, Rapid Response Teams have reduced non-ICU arrests by 50 percent, reduced post-operative emergency ICU transfers by 58 percent, and deaths by 37 percent.[31,32]

Depending upon the location of the teams (university based vs. community hospitals), the specialties included on them can vary. Generally there is a respiratory therapist and a "crisis" nurse — a nurse certified in Advanced Cardiac Life Support — with a critical care or emergency physician on call. However, there are situations where access to physicians, depending upon the time of day, is limited. The teams require the same array of equipment used for emergency resuscitation, which could include IO needles for rapid vascular access, especially given that respiratory therapists are generally members of the Rapid Response Team. They could be trained in IO access as an extension of their current training.

Rapid Response Teams are becoming recognized as playing a vital role in protecting both patients and healthcare institutions from avoidable deaths, and are now resident in more than 58% of the country's 3,000 hospitals.[33] Equipping and training them for maximum performance includes the ability to carry out IO access when intravenous access is difficult or impossible so that central venous access can be avoided.

In-Hospital Resuscitation. "Code Blue" teams are called to patients' bedsides where they exert all-out efforts to resuscitate patients in cardiac arrest. These teams are contacted by means of a telephone or paging system that calls doctors, respiratory technicians, and other hospital staff to areas where they are needed. When a patient goes into cardiac arrest, the Code Blue team must be summoned within seconds. Except in major teaching hospitals, physicians may not be readily available in these situations, particularly during night shifts and on weekends.

Many of the patients for whom Code Blue teams are called do not have vascular access in place, and since these patients are with few exceptions in cardiac arrest, the chances of being able to achieve IV access in a timely way if at all, are small. In these patients IO access is a practical alternative, avoids the time and invasiveness required for central venous access, and obviates the complications of central lines used for emergency resuscitation but not required after the patient has been stabilized. On the basis of available data, some investigators recommend stocking IO infusion systems on crash carts.[21]

Intraosseous Access in Mass Casualty Situations

Disaster Medicine. In the post 9-11 world with the threat of terrorist attacks as well as global pandemics, scenarios in which mass casualties may result is a public health issue for which planning cannot wait. Homeland Security medical advisors are in the process of devising logistical systems that will deliver emergency vehicles, clinicians, staff, drugs, and supplies to the areas where patients would be collected and treated. Such logistics require a military-style organization carried out by police, firefighters or EMS personnel with the goal of achieving rapid emergency resuscitation or stabilization.

A situation like the one confronting James Orlowski, the pediatrician previously mentioned who first saw IO access being employed during a cholera epidemic in India, could be duplicated in our time with another causative agent, equally lethal and possibly even more widespread. Such a situation would require the ability to achieve emergency vascular access for rapid delivery of drugs and fluids for hundreds if not thousands of patients. Moreover, in these circumstances, there would likely be a shortage of physicians trained in emergency care and trauma. In this context, IO infusion could represent the first level of vascular access since paramedics and even first responders could provide it. IV access may take too long to achieve, and central venous access would not be a possibility in a mass casualty scenario.

Military Medicine. The conditions under which clinicians provide care in the battlefield are among the most challenging in emergency medicine. Remote locations, poor lighting, fire and explosions, poor road conditions, and the presence of mass casualties can lead to excessive delays in obtaining vascular access.

Acute hemorrhage is the major cause of battlefield deaths in war, accounting for 50 percent of all fatalities.[34] Given the conditions under which patients are treated as described above, the use of IO access has become a useful alternative to IV access. Over recent years IO infusion has been used to treat the spectrum of trauma scenarios, such as dehydration, hemorrhage, and traumatic injury, cardiovascular collapse, and burns. All of these are injuries or conditions that are expected in military casualties.[35] Almost all of them will result in difficulty or impossibility of achieving peripheral venous access and require another route.

According to military experts, the ideal device for military applications should be small, lightweight, and easily inserted under any conditions, and be rugged enough to function under battlefield conditions.[28] A new family of IO products which includes IO auto-injectors preloaded with drugs such as nerve gas antidotes are making their way through the regulatory process.[36] In fact, the military has started to employ the powered drill device (EZ-IO, Vidacare Corporation) for insertion at the tibia and humeral head sites in Iraq and Afghanistan, with positive reports.[36] It is possible to contemplate similar devices for mass casualty situations in any environment, including those for which Homeland Security advisors are planning, or for natural disasters such as those experienced during hurricane seasons.

Training and Education

Training paramedics in the technique of intraosseous access has proven to be relatively easy. In most studies, a one-hour lecture followed by one hour of hands-on experience has been considered sufficient training,[28] and recall of this training a year following has proved to be remarkably durable. As previously noted, trainers report that the technique is even easily learned by observation.[24]

Aseptic technique is required for insertion of all intraosseous needles. For some manual insertion devices, strength may be needed to drive the trocar into the bone. Further, in both the manually inserted and impact-driven devices, training is important to assure proper placement.[19] For all IO devices, when insertion is performed in a conscious patient, administration of 20–40 mg of 2% preservative-free lidocaine for adults and 0.5 mg/kg in children is recommended prior to initiating the infusion. Only about 15% of patients requiring IO are conscious.

Limitations, Contraindications, and Complications

In obese patients, the needles may not be long enough to reach the bone marrow space. The need for ongoing chest compressions may be a factor in determining the best insertion site.

Patients with lower extremity amputations present further challenges.

Contraindications to IO placement include previous sternotomy, fractures above the IO site on the affected extremity, previous orthopedic surgical procedures in the area of insertion, such as total knee replacement, infection at the insertion site, and local vascular compromise.[21,37]

There have been few complications reported with IO access.[38,39] In more than 4200 cases of IO access in children, osteomyelitis occurred in only 0.6%, and usually only if the infusion continued for a prolonged period or if the patient had bacteremia at the time of infusion.[40] In a prospective, 250 patient, multi-center study of the powered drill device, no observed cases of osteomyelitis, fat embolism, fracture, infection, extravasation, or compartment syndrome were found.[7]

Conclusion

Despite the fact that delayed or impossible vascular access is a significant problem in both out-of-hospital as well as in some in-hospital settings, there has been a gap in the adoption of technology that could solve the problem economically, effectively, and with minimal patient trauma. Specifically, emergency departments, Rapid Response Teams, and those charged with in-hospital resuscitations, should consider the importance of intraosseous vascular access as the first alternative to delayed or impossible peripheral intravenous access. In some cases, it should be regarded as a primary modality.[41]

The financial and medico legal costs of avoidable morbidity and mortality as a result of using central venous lines when they may be unnecessary for resuscitation or stabilization are becoming increasingly recognized.

Intraosseous access is a clear alternative to IV access, as recognized by both the 2005 American Heart Association and the European Resuscitation Council guidelines,[13,15] and should be widely deployed in any area of patient care where critical vascular access is a factor in increased morbidity and/or survival. The evolution of technology appropriate to patients suffering trauma, severe illness, and deteriorating conditions that could lead to the need for emergency care has ensured a greater degree of patient safety, risk management, and efficacy of treatment.

Intraosseous vascular access in out-of-hospital patients is the leading edge of its utilization in emergency department and non-ICU areas of the hospital, especially with the emphasis on preventing cardiac emergencies requiring code team calls. For hospitals with limited staffing on night shifts and weekends, an available IO device that could be deployed by respiratory therapists could help to prevent patients from further deterioration or demise.

Last, planning for mass casualty scenarios for civilian and military use points clearly to expanded use of IO access devices. Rather than representing insurmountable economic challenges, they point to better patient care at reasonable cost.

References

1. Accidental Death and Disability: The neglected disease of modern society. Division of Medical Sciences, National Academy of Sciences/National Research Council, 1966

2. Dalbey, S. EMS history. Division of Public Safety web site, Iowa City, Iowa, 2006.

3. Rosetti, V, Thompson, RM, Abrahamian C, et al. Difficulty and delay in intravascular access in pediatric patients. Ann Emerg Med 1984; 13: 406.

4. Orlowski, JP, Porembka, DO, Gallagher, JM, et al. Comparison study of intraosseous, central intravenous, and peripheral intravenous infusions of emergency drugs. AJDC 1990; 144: 112-117.

5. Unpublished study performed by market research group, Inside Track, June 2002.

6. Lewis, FRL. Prehospital IV fluid therapy: physiology and computer modeling. J Trauma 1986; 26: 804-11.

7. Davidoff, J, Fowler, R, Gordon, D, et al. Clinical evaluation of a novel intraosseous device for adults. JEMS Suppl 2005: 20-23.

8. Hughes, WT, Buescher, ES. Pediatric procedures, 2nd ed. WB Saunders Co 1980: 117-121.

9. Drinker, CK, Drinker, KR, Lund, CC. The circulation in mammalian bone marrow. Am J Physiology 1922; 62: 1-92.

10. Papper, EM. The bone marrow route for injecting fluids and drugs into the general circulation. Anesthesiology 1942; 3: 307-313.

11. Morrison, GM. The initial care of casualties. Am Practitioner 1946; 1: 183-4.

12. Orlowski, J. My kingdom for an intravenous line. Am J Dis Child 1984; 138: 803.

13. American Heart Association and American Academy of Pediatrics: Textbook of pediatric advanced life support 1988; 43-44.

14. Advanced cardiac life support guidelines. Management of cardiac arrest. Circ 2005; 112-IV, 57-66.

15. European Resuscitation Guidelines. Resuscitation 2005; 6751: 51-52.

16. Jamshidi™ (Cardinal Health Care), Ilinois Iliac Sternal™ (Cardinal Health Care), Dieckman™ (Cook Critical Care).

17. F.A.S.T. 1™ (Pyng Medical Corp), B.I.G™ (Waismed)

18. Miller, DD, Guimond, G, Hostler, DP, et al. Feasibility of sternal intraosseous access by emergency medical technician students. PreHosp Emerg Care 2005; 9: 73-79.

19. Calkins, MD, Fitzgerald, G, Bentley, TB, et al. Intraosseous infusion devices: a comparison for potential use in special operations. J Trauma 2000; 48: 70-74.c

20. EZ-IO™ (Vidacare Corporation)

21. Sawyer, RW, Bodai BI, Blaisell, FW, et al. The current status of intraosseous infusion. J Am Coll Surg 1994; 179: 353-60.

22. Miller, L, Kramer, GC, Bolleter, S. Rescue access made easy. JEMS Suppl 2005; 8-20.

23. Siegler, RS, Tecklenberg, FW, Shealy, R. Prehospital intraosseous infusion by emergency medical services personnel: a prospective study. Ped 1989; 84: 173-7.

24. Siegler, RS. Intraosseous infusion performed in the prehospital setting: South Carolina's six-year experience. J South Carolina Med Assoc 1997; 93: 209-15.

25. Guidelines for the prevention of intravascular catheter-related infections. MMWR Recomm Rep 2002; 51:1-29.

26. Gillam, L, Kovar, J. Powered intraosseous access in the prehospital setting. JEMS Suppl 2005; 24-27.

27. National Center for Health Statistics, cdc.gov.

28. Dublick, MA. A review of intraosseous vascular access: current status and military application. Military Med 2000; 165, 7: 552.

29. Shein, RM, Hazday, N, Pena, M, et al. Clinical antecedents to in hospital cardiopulmonary arrest. Chest 1990; 98(6): 1388-1392.

30. Franklin, C, Mathew, J. Developing strategies to prevent in hospital cardiac arrest: analyzing responses of physicians and nurses in the hours before the event. Crit Care Med 1994; 22(2): 244-247.

31. Bellomo, R, Goldsmith, D, Buckmaster, J, et al. Prospective controlled trial of effect of emergency teams on postoperative morbidity and mortality rates. Crit Care Med 2004; 32(4): 916-921.

32. Buist, MD, Moore, GE, Bernard, SA, et al. Effects of a medical emergency team on reduction of incidence of and mortality from unexpected cardiac arrests in hospital: preliminary study. BMJ 2002; 324: 387-390.

33. Institute for Healthcare Improvement 2006. (ihi.org)

34. Bellamy, RF. The causes of death in conventional land warfare: implications for combat casualty care research. Milit Med 1984; 149: 55-62.

35. Fiser, DH. Intraosseous infusion. N Engl J Med 1990; 322: 1579-81.

36. Timboe, HL, Bruttig, SP. Adult IO in the combat zone. JEMS Supp 2005; 27-29.

37. Orlowski ,JP. Emergency alternative to intravenous access: intraosseous, intratracheal, sublingual and other-site drug administration. Pediatr Clin North Am 1994; 41: 1183-99.

38. Orlowski, JP, Julius, CJ, Petras ,RE, et al. The safety of intraosseous infusions: risks of fat and bone marrow emboli to the lungs. Ann Emerg Med 1989; 18: 1062-7.

39. Manufacturer's database, VidaCare Corporation

40. Rosetti, VA, Thompson, BM, Miller, J, et al. Intraosseous infusion: an alternative route of pediatric intravenous access. Ann Emerg Med 1985; 14: 885-8.

41. Wayne, M. Adult

Selected Bibliography

Intraosseous Infusion — Overview

Koschel MJ. Sternal intraosseous infusions: emergency vascular access in adults. Am J Nurs 2005; 105:66-8.

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; 12:782-5.

Eslami P. Intraosseous access. http://www.emedicine.com/ped/topic3053.htm Last updated October 22, 2004.

Gluckman, W, Forti RJ. Intraosseous Cannulation. www.emedicine.com/ped/topic2557.htm Last Updated: Jan 14, 2003.

Haas NA. Clinical review: vascular access for fluid infusion in children. Crit Care 2004;8:478-84. Epub 2004 Jun 03.

LaRocco BG, Wang HE. Intraosseous infusion. Prehosp Emerg Care. 2003 7:280-5.

Day MW. Using intraosseous access in children. Nursing 2000; 30:68.

Dubick MA, Holcomb JB. A review of intraosseous vascular access: current status and military application. Mil Med. 2000; 165:552-9.

Foex BA. Discovery of the intraosseous route for fluid administration. J Accid Emerg Med 2000;17:136-7.

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; 25:38-48.

Vreede E, Bulatovic A, Rosseel P, Lassalle X. Intraosseous infusion. Update in Anaesthesia. 2000; 12 (Article 10):1 Available at: www.nda.ox.ac.uk/wfsa/index.htm.

Bohn D. Intraosseous vascular access: from the archives to the ABC. Crit Care Med 1999: 27:1053-4.

Stovroff M, Teague WG. Intravenous access in infants and children. Pediatr Clin North Am 1998; 45:1373-93.

Shoemaker WC, Peitzman AB, Bellamy R, Bellomo R, Bruttig SP, Capone A, Dubick M, Kramer GC, McKenzie JE, Pepe PE, Safar P, Schlichtig R, Severinghaus JW, Tisherman SA, Wiklund L. Resuscitation from severe hemorrhage. Crit Care Med 1996; 24: S12-S23.

Moller JC, Reiss I, Schaible T.Vascular access in neonates and infants—indications, routes, techniques and devices, complications. Intensive Care World. 1995; 12:48-53.

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.

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

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: 728-9.

Neal CJ, McKinley DF. Intraosseous infusion in pediatric patients. J Am Osteopath Assoc 1994; 94:63-6.

Orlowski JP. Emergency alternatives to intravenous access. Intraosseous, intratracheal, sublingual, and other-site drug administration. Pediatr Clin North Am 1994; 41:1183-99.

Sawyer RW, Bodai BI, Blaisdell FW, McCourt MM. The current status of intraosseous infusion. J Am Coll Surg 1994; 179:353-60.

Weaver BL. Intraosseous infusions. Neonatal Netw 1994; 13:68-9.. Erratum in: Neonatal Netw 1995; 14:73.

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.

Cilley RE. Intraosseous infusion in infants and children. Semin Pediatr Surg 1992;1:202-7.

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; 24:137-42..

Hoekstra JH, van Kempen AA. Intraosseous infusions in children. Tijdschr Kindergeneeskd 1992; 60:123-6. In Dutch.

Clarke P. Making sense of intraosseous infusion. Nurs Times 1991; 87:40-1.

Driggers DA, Johnson R, Steiner JF, Jewell GS, Swedberg JA, Goller V. Emergency resuscitation in children. The role of intraosseous infusion. Postgrad Med 1991; 89:129-32.

Jaimovich DG, Kecskes S. Intraosseous infusion: a re-discovered procedure as an alternative for pediatric vascular access. Indian J Pediatr 1991; 58:329-34.

Von Hoff DD. Intraosseous infusions: an important but forgotten method of vascular access. Cancer Invest 1991; 9:521-8..

Fiser DH. Intraosseous infusion. N Engl J Med 1990; 322:1579-81.

Intraosseous Infusion in Emergency Care

Benson P, Eckstein M. Pulseless electrical activity: A diagnostic challenge for EMS. Prehospital Emergency Care 2005; 9: 231-235.

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; 6:50-3.

Gillum L, Kovar J. Powered intraosseous access in the prehospital setting: MCHD EMS puts the EZ-IO to the test. JEMS 2005; 30:s24-6.

Koschel MJ. Sternal intraosseous infusions: emergency vascular access in adults. Am J Nurs 2005; 105:66-8.

Mackinnon MA. Permissive hypotension: a change in thinking. Air Medical Journal 2005; 24:70-72.

Smith R, Davis N, Bouamra O, Lecky F. The utilisation of intraosseous infusion in the resuscitation of paediatric major trauma patients. Injury 2005; 36:1034-1038

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

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.

Lavis M. Prehospital adult intraosseous infusion. Prehospital Immedicate Care 1999; 3:89-92.

Seigler RS. Intraosseous infusion performed in the prehospital setting: South Carolina’s six-year experience. J S C Med Assoc 1997; 93:209-15.

Shoemaker WC, Peitzman AB, Bellamy R, Bellomo R, Bruttig SP, Capone A, Dubick M, Kramer GC, McKenzie JE, Pepe PE, Safar P, Schlichtig R, Severinghaus JW, Tisherman SA, Wiklund L. Resuscitation from severe hemorrhage. Crit Care Med 1996; 24: S12-S23.

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; 23:52-5.

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.

Dubick MA, Kramer GC Studies on fluid resuscitation for the far-forward combat arena. Proceedings from the International Resuscitation Research Conference 1994, May 6-8, University of Pittsburgh, Trauma 1.4, 1994.

Losek JD, Szewczuga D, Glaeser PW. Improved prehospital pediatric ALS care after an EMT-paramedic clinical training course. Am J Emerg Med 12, 429-432, 1994

Neal CJ, McKinley DF. Intraosseous infusion in pediatric patients. J Am Osteopath Assoc 1994; 94:63-6.

Orlowski JP. Emergency alternatives to intravenous access. Intraosseous, intratracheal, sublingual, and other-site drug administration. Pediatr Clin North Am 1994; 41:1183-99.

Rieger A, Berman JM, Striebel HW. Initial resuscitation and vascular access. Int Anesthesiol Clin 1994; 32:47-77.

Glaeser PW, Hellmich TR, Szewczuga D, Losek JD, Smith DS. Five-year experience in prehospital intraosseous infusions in children and adults. Annals of Emergency Medicine 1993; 22: 1119-1124.

Guy J, Haley K, Zuspan SJ. Use of intraosseous infusion in the pediatric trauma patient. J Pediatr Surg 1993; 28:158-61.

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

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.

Fiser DH. Intraosseous infusion. N Engl J Med 1990; 322:1579-81.

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: 652-8; discussion 658-9.

Salassi-Scotter M, Fiser DH. Adoption of intraosseous infusion technique for prehospital pediatric emergency care. Pediatr Emerg Care 1990; 6:263-5.

Seigler RS, Tecklenburg FW, Shealy R. Prehospital intraosseous infusion by emergency medical services personnel: a prospective study. Pediatrics 1989; 84:173-7.

Zimmerman JJ, Coyne M, Logsdon M. Implementation of intraosseous infusion technique by aeromedical transport programs. J Trauma 1989; 29: 687-9.

Smith RJ, Keseg DP, Manley LK, Standeford T. Intraosseous infusions by prehospital personnel in critically ill pediatric patients. Ann Emerg Med 1988; 17:491-5.

Kanter RK, Zimmerman JJ, Strauss RH, Stoeckel KA. Pediatric emergency intravenous access. Evaluation of a protocol. Am J Dis Child 1986; 140:132-4.

Intraosseous Infusion in Military Applications

Butler FK, Holcomb JB. The Tactical Combat Casualty Care Transition Initiative. Army Medical Department Journal PB 8-0504/5/6 Apr/May/Jun-33-37.

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.

Gawande A. Casualties of war-military care for the wounded from Iraq and Afghanistan. NEJM 2004; 351:2471-2475.

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 Jun;98(6):1753-8.

Walls, RM. Adult Intraosseous Device Aids Terrorism Response. Journal Watch Emergency Medicine July 28, 2004. http://emergency-medicine.jwatch.org/content/vol2004/issue728.

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.

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. Anesthesia & Analgesia 2003; 96: 1739-42.

Dubick MA, Atkins JL. Small-volume fluid resuscitation for the far-forward combat environment: current concepts. J Trauma 2003; 54:S43-5.

Holcomb JB. Fluid resuscitation in modern combat casualty care: lessons learned from Somalia. J Trauma 2003; 54: S46-51.

Dubick MA, Holcomb JB. A review of intraosseous vascular access: current status and military application. Mil Med 2000; 165: 552-9. Review.

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 :64-9.

Intraosseous Infusion Guidelines

Dries DJ, Sample MA. Recent advances in emergency life support. Nurs Clin North Am 2002; 37:1-10.

Atkins DL, Chameides L, Fallat ME, Hazinski MF, Phillips B, Quan L, Schleien CL, Terndrup TE, Tibballs J, Zideman DA; American Heart Association; International Liaison Committee on Resuscitation. Resuscitation science of pediatrics. Ann Emerg Med 2001; 37(4 Suppl):S41-8.

Cain BS, Shannon-Cain J. Vasopressin in advanced cardiac life support? Crit Care Med 2001; 29:1649.

Chameides L, Hazinski MF, eds. Intraosseous Cannulation. In: Textbook of Pediatric Advanced Life Support. Chameides L, Hazinski MF, Eds.. Dallas: American Heart Association; 1990.

Sawyer RW, Bodai BI, Blaisdell FW, McCourt MM. The current status of intraosseous infusion. J Am Coll Surg 1994; 179:353-60.

American Heart Association. Guidelines for cardiopulmonary resuscitation and emergency cardiac care: chain of survival. JAMA 1992; 268: 2171-2302.

Mofenson HC, Tascone A, Caraccio TR. Guidelines for intraosseous infusions. J Emerg Med 1988; 6:143-6.

Melker RJ. Intraosseous infusions. Am J Emerg Med 1986; 4:490.

Advanced cardiac life support guidelines. Management of cardiac arrest. Circ 2005; 112-IV, 57-66.

European Resuscitation Guidelines. Resuscitation 2005; 6751: 51-52.