WORKSHEET for PROPOSED Evidence-Based GUIDELINE RECOMMENDATIONS

Worksheet Author:	**Home Subcommittee:** NRP
Author's Home Resuscitation Council: NRP	**Date Submitted to Subcommittee:** October 1, 2003; revised November 3, 2004

STEP 1: STATE THE PROPOSAL. State if this is a proposed new guideline; revision to current guideline; or deletion of current guideline.

Existing guideline, practice or training activity:

1. "Catheterization of the umbilical vessels is generally not an option outside the hospital or beyond the first several days after birth. In such cases, prompt cannulation of a peripheral vein or insertion of an intraosseus needle into the tibia are reasonable alternatives. Detailed description of these techniques is beyond the scope of this program." (Neonatal Resuscitaiton Textbook, AHA and AAP,4th edition,2000;p7-23)
2. "During pediatric CPR or treament of severe shock, you should establish IO access if you cannot rapidly achieve venous access." PALS Provider Manual, AHA and AAP,2002: 155.

Step 1A: Refine the question; state the question as a positive (or negative) hypothesis. State proposed guideline recommendation as a specific, positive hypothesis. Use single sentence if possible. Include type of patients; setting (in-/out-of-hospital); specific interventions (dose, route); specific outcomes (ROSC vs. hospital discharge).

Intraosseous access is an alternative safe, effective method of vascular access for providing fluids and medications during resuscitation of newly born infants, both in and out of the hospital.

Step 1B: Gather the Evidence; define your search strategy. Describe search results; describe best sources for evidence.

Electronic databases and bibliographies of journal articles were reviewed for references specific to neonatal application of intraosseous infusions. Key words included neonate, pediatric, intraosseous, vascular access, resuscitation, neonate AND intraosseous, neonate AND vascular access, pediatric AND intraosseous, infant AND intraosseous.

List electronic databases searched (at least MEDLINE (http://igm.nlm.nih.gov/) and hand searches of journals, review articles, and books.

MEDLINE, PUBMED, Bibliographies of journal and review articles

- State major criteria you used to limit your search; state inclusion or exclusion criteria (e.g., only human studies with control group? no animal studies? N subjects > minimal number? type of methodology? peer-reviewed manuscripts only? no abstract-only studies?)

Criteria for review included intraosseous infusions in neonates, infants and children. The search included human and animal studies that pertained to resuscitation and vascular access. Pharmacologic data was anecdotal in human studies so select animal studies regarding drug distribution during intraosseous route of infusion were reviewed. Review papers were also searched, especially for primary references in the bibliography.

- Number of articles/sources meeting criteria for further review: Create a citation marker for each study (use the author initials and date or Arabic numeral, e.g., "Cummins-1"). If possible, please supply file of best references; End Note 4+ preferred as reference manager, though other reference databases acceptable.

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STEP 2: ASSESS THE QUALITY OF EACH STUDY

Step 2A: Determine the Level of Evidence. For each article/source from step 1, assign a level of evidence—based on study design and methodology.

Level of Evidence	Definitions (See manuscript for full details)
Level 1	Randomized clinical trials or meta-analyses of multiple clinical trials with substantial treatment effects

Level 2	Randomized clinical trials with smaller or less significant treatment effects
Level 3	Prospective, controlled, non-randomized, cohort studies
Level 4	Historic, non-randomized, cohort or case-control studies
Level 5	Case series: patients compiled in serial fashion, lacking a control group
Level 6	Animal studies or mechanical model studies
Level 7	Extrapolations from existing data collected for other purposes, theoretical analyses
Level 8	Rational conjecture (common sense); common practices accepted before evidence-based guidelines

Step 2B: Critically assess each article/source in terms of research design and methods.

Was the study well executed? Suggested criteria appear in the table below. Assess design and methods and provide an overall rating. Ratings apply within each Level; a Level 1 study can be excellent or poor as a clinical trial, just as a Level 6 study could be excellent or poor as an animal study. Where applicable, please use a superscripted code (shown below) to categorize the primary endpoint of each study. For more detailed explanations please see attached assessment form.

Component of Study and Rating	Excellent	Good	Fair	Poor	Unsatisfactory
Design & Methods	Highly appropriate sample or model, randomized, proper controls **AND** Outstanding accuracy, precision, and data collection in its class	Highly appropriate sample or model, randomized, proper controls **OR** Outstanding accuracy, precision, and data collection in its class	Adequate, design, but possibly biased **OR** Adequate under the circumstances	Small or clearly biased population or model Weakly defensible in its class, limited data or measures	Anecdotal, no controls, off target end-points Not defensible in its class, insufficient data or measures

A = Return of spontaneous circulation C = Survival to hospital discharge E = Other endpoint
B = Survival of event D = Intact neurological survival

Step 2C: Determine the direction of the results and the statistics: supportive? neutral? opposed?

DIRECTION of study by results & statistics:	SUPPORT the proposal	NEUTRAL	OPPOSE the proposal
Results	Outcome of proposed guideline superior, to a clinically important degree, to current approaches	Outcome of proposed guideline no different from current approach	Outcome of proposed guideline inferior to current approach

Step 2D: Cross-tabulate assessed studies by a) *level*, b) *quality* and c) *direction* (ie, supporting or neutral/ opposing)**; combine and summarize.** Exclude the *Poor* and *Unsatisfactory* studies. Sort the *Excellent, Good,* and *Fair* quality studies by both *Level and Quality of evidence,* and *Direction of support* in the summary grids below. Use citation marker (e.g. author/ date/source). In the *Neutral* or *Opposing* grid use bold font for *Opposing* studies to distinguish them from merely neutral studies. Where applicable, please use a superscripted code (shown below) to categorize the primary endpoint of each study.

Supporting Evidence

Intraosseous access is an alternative safe, effective method of vascular access for providing fluids and medications during resuscitation of newly born infants, both in and out of the hospital.

Quality of Evidence		1	2	3	4	5	6	7	8
	Excellent								
	Good					Ellenmunter (B) Glaeser2 (E) Seigler (E) Heinhild (E)	Fuchs (E) Johnson (E) Kissoon1-3 (E) Velasco (E,B) Boon (E) Voelckel (E)	Jaimovich (E) Rosetti (E) Spivey (E) LaRocco (E) Evans (E) Parrish (E)	
	Fair					Glaeser1 (E) Guy © Schoenfield (E) Moller (B) Tocantins,1,2,3(E) Miner (E) Kelsall (B) Ramet (E) Nasimi (E) Flores (B) Friedman (E) Stoll (E) Fisher (E)	Abe (E) Fiallos (E)	Babl (E)	Macgregor (E) Dubick (E) Orlowski (E) Srovroff (E) Weaver (E) Neal (E) Bohn (E)

Level of Evidence

A = Return of spontaneous circulation C = Survival to hospital discharge E = Other endpoint
B = Survival of event D = Intact neurological survival

Neutral or Opposing Evidence

Intraosseous access is an alternative safe, effective method of vascular access for providing fluids and medications during resuscitation of newly born infants, both in and out of the hospital.

Quality of Evidence	**Excellent**								
	Good								
	Fair								
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
		Level of Evidence							

A = Return of spontaneous circulation C = Survival to hospital discharge E = Other endpoint
B = Survival of event D = Intact neurological survival

REVIEWER'S PERSPECTIVE AND POTENTIAL CONFLICTS OF INTEREST: Briefly summarize your professional background, clinical specialty, research training, AHA experience, or other relevant personal background that define your perspective on the guideline proposal. List any potential conflicts of interest involving consulting, compensation, or equity positions related to drugs, devices, or entities impacted by the guideline proposal. Disclose any research funding from involved companies or interest groups. State any relevant philosophical, religious, or cultural beliefs or longstanding disagreements with an individual.

Academic neonatology with clinical focus, including neonatal resuscitation. Education and clinical research in chronic lung disease, nosocomial infection and feeding extremely low birth weight infants. Member of the Committee on Fetus and Newborn and Liaison to the Neonatal Resuscitation Program, American Academy of Pediatrics. No conflicts of interest.

REVIEWER'S FINAL COMMENTS AND ASSESSMENT OF BENEFIT / RISK: Summarize your final evidence integration and the rationale for the class of recommendation. Describe any mismatches between the evidence and your final Class of Recommendation. "Mismatches" refer to selection of a class of recommendation that is heavily influenced by other factors than just the evidence. For example, the evidence is strong, but implementation is difficult or expensive; evidence weak, but future definitive evidence is unlikely to be obtained. Comment on contribution of animal or mechanical model studies to your final recommendation. Are results within animal studies homogeneous? Are animal results consistent with results from human studies? What is the frequency of adverse events? What is the possibility of harm? Describe any value or utility judgments you may have made, separate from the evidence. For example, you believe evidence-supported interventions should be limited to in-hospital use because you think proper use is too difficult for pre-hospital providers.

Cardiopulmonary resuscitation of neonates in the delivery room is a rare event.(Perlman95,Ellemunter99). Furthermore, umbilical and peripheral vascular access is rarely required during neonatal and pediatric resuscitation.(Babl2001) When vascular access is required in the delivery room, umbilical or peripheral access is nearly always successful. Therefore, the intraosseous route for temporary vascular access in the delivery room is rarely required in neonates. Nevertheless, intraosseous access is an acceptable alternative if other routes of vascular access cannot be successfully established as discussed below.

Some newly born infants require resuscitation outside the delivery room and may require resuscitation by caregivers who have little experience with umbilical or peripheral vascular access in very young infants.(Glaeser93,Ellenmunter99, Kelsall92, Ramet98,Nasimi97,Babl01,Rosetti85,Jaimovich91,Orlowski94,Guy93,Seigler89,Heinild47) Emergency response teams often have expertise with intraosseous access because skills needed for intraosseous needle placement is simple to master and sustainable despite being performed infrequently.(Abe2000,Glaeser93,Schoenfeld93,Fuchs91) Therefore, the intraosseous route is an acceptable alternative in neonates requiring fluids, medications or both by providers outside of the hospital, in situations where equipment or personnel skilled in establishing venous access are not available or if other vascular access sites (especially intravenous) cannot be successfully established within several minutes.(Ellenmuter99,Glaeser88,Schoenfeld93,Heinild47)

Complications associated with using intraosseous access occur infrequently and include infection, fracture, compartment syndrome and fat emboli.(Stoll02,Fiallos97,Moller96,Spivey87,LaRocco03, Heinild47) These rarely encountered risks are outweighed by the benefits of establishing temporary vascular access through the intraosseous route during resuscitation of critically ill neonates.

The evidence to support use of the intraosseous route in neonates being resuscitated is level 5 and lower; it is unlikely that large randomized trials or case-controlled studies will be performed because of the low incidence of resuscitations and the presence of providers skilled in establishing other routes of vascular access in many hospital settings.

Preliminary draft/outline/bullet points of Guidelines revision: Include points you think are important for inclusion by the person assigned to write this section. Use extra pages if necessary.

Attachments:

Printed (paper) bibliography; and on diskette using a reference manager. It is recommended that the bibliography be printed in annotated format. This will include the article abstract and any notes you would like to make providing specific comments on the quality, methodology and/or conclusions of the study.

Key figures or tables from evidence-based analysis

Full hard copies of most critical cited papers

Citation List

Citation Marker	Full Citation*

{Abe, 2000 #1}	Abe, K. K., G. T. Blum, et al. (2000). "Intraosseous is Faster and Easier Than Umbilical Venous Catheterization in Newborn Emergency Vascular Access Models." Am J Emerg Med **18**: 126-129.
{Ellemunter, 1999 #2}	Ellemunter, H., B. Simma, et al. (1999). "Intraosseous lines in preterm and full term neonates." Arch Dis Child Fetal Neonatal Ed **80**(1): F74-5.
{Glaeser, 1993 #3}	Glaeser, P. W., T. R. Hellmich, et al. (1993). "Five-year experience in prehospital intraosseous infusions in children and adults." Ann Emerg Med **22**(7): 1119-24.
{Glaeser, 1988 #4}	Glaeser, P. W., J. D. Losek, et al. (1988). "Pediatric intraosseous infusions: impact on vascular access time." Am J Emerg Med **6**(4): 330-2.
{Guy, 1993 #6}	Guy, J., K. Haley, et al. (1993). "Use of intraosseous infusion in the pediatric trauma patient." J Pediatr Surg **28**(2): 158-61.
{Johnson, 1999 #18}	Johnson, L., N. Kissoon, et al. (1999). "Use of intraosseous blood to assess blood chemistries and hemoglobin during cardiopulmonary resuscitation with drug infusions." Crit Care Med **27**(6): 1147-52.
{Kissoon, 1997 #21}	Kissoon, N., A. Idris, et al. (1997). "Intraosseous and central venous blood acid-base relationship during cardiopulmonary resuscitation." Pediatr Emerg Care **13**(4): 250-3.
{Kissoon, 1994 #19}	Kissoon, N., R. Peterson, et al. (1994). "Comparison of pH and carbon dioxide tension values of central venous and intraosseous blood during changes in cardiac output." Crit Care Med **22**(6): 1010-5.
{Kissoon, 1993 #20}	Kissoon, N., H. Rosenberg, et al. (1993). "Comparison of the acid-base status of blood obtained from intraosseous and central venous sites during steady- and low-flow states." Crit Care Med **21**(11): 1765-9.
{LaRocco, 2003 #26}	LaRocco, B. G. and H. E. Wang (2003). "Intraosseous infusion." Prehosp Emerg Care **7**(2): 280-5.
{Macgregor, 1990 #37}	Macgregor, D. F. and A. J. Macnab (1990). "Intraosseous fluids in emergencies." Pediatrics **85**(3): 386-7.
{Martino Alba, 1994 #11}	Martino Alba, R., M. J. Ruiz Lopez, et al. (1994). "Use of the intraosseous route in resuscitation in a neonate." Intensive Care Med **20**(7): 529.
{Moller, 1996 #16}	Moller, J. C., F. K. Tegtmeyer, et al. (1996). "[Intraosseous puncture as vascular access in pediatric emergency and intensive care medicine]." Anaesthesiol Reanim **21**(4): 103-7.
{Nasimi, 1998 #10}	Nasimi, A., P. Gorin, et al. (1998). "[Use of the intraosseous route in a premature infant]." Arch Pediatr **5**(4): 414-7.
{Neal, 1994 #34}	Neal, C. J. and D. F. McKinley (1994). "Intraosseous infusion in pediatric patients." J Am Osteopath Assoc **94**(1): 63-6.
{Orlowski, 1994 #31}	Orlowski, J. P. (1994). "Emergency alternatives to intravenous access. Intraosseous,

	intratracheal, sublingual, and other-site drug administration." Pediatr Clin North Am **41**(6): 1183-99.
{Rosetti, 1985 #28}	Rosetti, V. A., B. M. Thompson, et al. (1985). "Intraosseous infusion: an alternative route of pediatric intravascular access." Ann Emerg Med **14**(9): 885-8.
{Schoenfeld, 1993 #7}	Schoenfeld, P. S. and M. D. Baker (1993). "Management of cardiopulmonary and trauma resuscitation in the pediatric emergency department." Pediatrics **91**(4): 726-9.
{Seigler, 1989 #5}	Seigler, R. S., F. W. Tecklenburg, et al. (1989). "Prehospital intraosseous infusion by emergency medical services personnel: a prospective study." Pediatrics **84**(1): 173-7.
{Spivey, 1987 #27}	Spivey, W. H. (1987). "Intraosseous infusions." J Pediatr **111**(5): 639-43.
{Stoll, 2002 #14}	Stoll, E., J. Golej, et al. (2002). "Osteomyelitis at the injection site of adrenalin through an intraosseous needle in a 3-month-old infant." Resuscitation **53**(3): 315-8.
{Tocantins, 1941 #39}	Tocantins, L., O'Neil JF, Price AH (1941). "Infusions of Blood and Other Fluids via the Bone Marrow in Traumatic Shock and Other Forms of Peripheral Circulatory Failure." Annals of Surgery **114**(6): 1085-1092.
{Tocantins, 1940 #40}	Tocantins, L. a. O. N., JF (1940). "Infusion of Blood and Other Fluids into the Circulation via the Bone Marrow." Proceedings of the Society for Experimental Biology and Medicine **45**: 782-783.
{Tocantins, 1941 #41}	Tocantins, L. a. O. N., JF (1941). "Infusion of Blood and Other Fluids into the General Circulation via the Bone Marrow." Surgery, Gynecology and Obstetrics **73**: 281-287.
{Velasco, 1991 #23}	Velasco, A. L., C. Delgado-Paredes, et al. (1991). "Intraosseous infusion of fluids in the initial management of hypovolemic shock in young subjects." J Pediatr Surg **26**(1): 4-8.
{Voelckel, 2001 #24}	Voelckel, W. G., K. G. Lurie, et al. (2001). "Comparison of epinephrine with vasopressin on bone marrow blood flow in an animal model of hypovolemic shock and subsequent cardiac arrest." Crit Care Med **29**(8): 1587-92.
{Weaver, 1994 #33}	Weaver, B. L. (1994). "Intraosseous infusions." Neonatal Netw **13**(8): 68-9.
(Perlman,1995,#42_	Perlman JM, Risser R. Cardiopulmonary resuscitation in the delivery room. Associated clinical events. Arch Pediatr Adolesc med. 1995;149(1):20-25.

*Type the citation marker in the first field and then paste the full citation into the second field. You can copy the full citation from EndNote by selecting the citation, then copying the FORMATTED citation using the short cut, Ctrl-K. After you copy the citation, go back to this document and position the cursor in the field, then paste the citation into the document (use Ctrl-V). For each new citation press Enter to move down to start a new paragraph.

Abe, K. K., G. T. Blum, et al. (2000). "Intraosseous is Faster and Easier Than Umbilical Venous Catheterization in Newborn Emergency Vascular Access Models." Am J Emerg Med **18**: 126-129.

Babl, F. E., R. J. Vinci, et al. (2001). "Pediatric pre-hospital advanced life support care in an urban setting." Pediatr Emerg Care **17**(1): 5-9.

Abstract

OBJECTIVE: To describe pediatric advanced life support (PALS) in a single urban environment and clarify educational priorities for ALS pre-hospital providers and pediatric medical control physicians. METHODS: Retrospective observational review of all pediatric pre-hospital PALS transport and medical control records of the two-tiered, unified, municipal emergency medical service of the City of Boston (catchment area 590,000) over a 1-year period. RESULTS: Of the 555 pediatric patients receiving ALS transport, 38% were for respiratory emergencies, 24% for nonrespiratory medical emergencies, 19% for traffic-related blunt trauma, and 10% for penetrating trauma. Two percent involved cardiac arrests. The most frequent procedures performed were intravenous (IV) cannulation (n = 184, 33%), bag-mask ventilation (n = 28, 5%) and intubation (n = 15, 3%). Intraosseous access was only performed in three patients (0.5%). Fifty ALS providers in the EMS system averaged pediatric IV cannulation 3.7 times, intubation 0.3 times, and intraosseous access 0.06 times per provider per year. On-line medical control was requested in 28 % of PALS transports. The chief complaints managed by medical control closely mirrored the distribution of all ALS transports. The most frequent medication ordered by on-line medical control was additional nebulized albuterol after standing orders (off-line medical control) had been exhausted. CONCLUSIONS: A limited number of chief complaints make up the majority of PALS transports. Initial and continuing education for ALS providers needs to reflect the importance of these critical entities. Education for urban pre-hospital providers should reflect that certain procedures will be only executed every few years (eg, pediatric intubation) or once in the career of an ALS pre-hospital provider (eg, intraosseous access). With a limited amount of pediatric teaching time, paramedic education will have to strike a careful balance between teaching about the chief complaints most frequently encountered and teaching rare, high-risk procedures that could provide maximal support for the uncommon critically ill child. On-line medical control physicians need to be prepared to direct and support the management by ALS pre-hospital providers for the chief complaints most frequently seen in pediatric patients.

Level of Evidence 7 Supportive

Bohn, D. (1999). "Intraosseous vascular access: from the archives to the ABC." Crit Care Med **27**(6): 1053-4.

Level of Evidence 8 Supportive

Boon, J. M., D. L. Gorry, et al. (2003). "Finding an ideal site for intraosseous infusion of the tibia: an anatomical study." Clin Anat **16**(1): 15-8.

Abstract

Intraosseous infusion is a technique used for the administration of fluids to a hemodynamically shocked child in whom attempts to access the vascular system have been unsuccessful. Although few complications are seen, injury to the epiphyseal growth plate during the performance of this technique remains a serious problem. This study investigates the relationship between the site of insertion of the intraosseous needle and the epiphyseal growth plate, and the ease of needle insertion into various locations of the tibia in newborn infants. Fourteen newborn infant cadavers (28 tibias in total) were dissected after placement of four needles: 1). through the tibial tuberosity (Site A); 2). 10 mm distal to the tibial tuberosity (Site B); 3).

20 mm distal to the tibial tuberosity (Site C) and; 4). 10 mm proximal to the tibial tuberosity (Site D). Distances from the distal end of the epiphyseal growth plate were measured. A high number of needle placements at Site A were inserted into the epiphyseal growth plate. Most placements at Site B were between 10 and 16 mm from the epiphyseal growth plate on the right side and between 10 and 15 mm on the left side, and all were inserted without difficulty. Although far from the epiphyseal growth plate, most placements at Site C were very difficult to insert because of the thick cortical bone. All placements at Site D entered the epiphysis or the epiphysis and joint space of the knee. An insertion site of at least 10 mm distal to the tibial tuberosity is therefore recommended to avoid epiphyseal growth plate injury and ensure ease of insertion.
Dubick, M. A. and G. C. Kramer (1997). "Hypertonic saline dextran (HSD) and intraosseous vascular access for the treatment of haemorrhagic hypotension in the far-forward combat arena." Ann Acad Med Singapore **26**(1): 64-9.
Level of Evidence 6 Supportive

Ellemunter, H., B. Simma, et al. (1999). "Intraosseous lines in preterm and full term neonates." Arch Dis Child Fetal Neonatal Ed 80(1): F74-5.

AIM: To evaluate the use of intraosseous lines for rapid vascular access in primary resuscitation of preterm and full term neonates. METHODS: Thirty intraosseous lines were placed in 27 newborns, in whom conventional venous access had failed. RESULTS: All the neonates survived the resuscitation procedure, with no long term side effects. CONCLUSION: Intraosseous infusion is quick, safe, and effective in compromised neonates.
Level of Evidence 5 Supportive

Evans, R. J., M. McCabe, et al. (1994). "Intraosseous infusion." Br J Hosp Med **51**(4): 161-4.
Abstract
Intraosseous infusion is recommended for children aged 6 years or less who have life-threatening conditions and require vascular access which cannot be achieved in a timely manner via another route. It is a reliable, safe procedure with a complication rate of less than 1%.
Level of Evidence 7 Supportive
Fiallos, M., N. Kissoon, et al. (1997). "Fat embolism with the use of intraosseous infusion during cardiopulmonary resuscitation." Am J Med Sci **314**(2): 73-9.
Abstract
The objective of this prospective study was to assess the incidence and magnitude of fat emboli after cardiopulmonary resuscitation and intraosseous infusions. An animal laboratory at a university center was used to study 33 mixed-breed piglets. The piglets underwent hypoxic cardiac arrest followed by chest compressions and mechanical ventilation for a minimum of 30 minutes. The animals were divided in groups: group 1 (n = 5), which had no intraosseous cannulas, group 2 (n = 6), which had intraosseous cannulas with infusion, groups 3 (n = 6), 4 (n = 6), and 5 (n = 8), which had intraosseous cannulas with infusion of epinephrine, normal saline, and sodium bicarbonate respectively, and group 6 (n = 2), which was a sham group with no intraosseous cannulas and no cardiopulmonary resuscitation. At cessation of cardiopulmonary resuscitation, representative lung samples were collected from upper and lower lobes of each lung and observed for fat globules and bone marrow elements. Fat globules were seen in the peribronchial blood vessels and intravascular areas throughout all lung fields of groups 1 through 5. There was no difference in appearance or distribution of fat globules among the 5 treatment groups. Analysis of variance showed no statistical significance ($P < 0.05$) within or among groups 1 through 5. The use of the intraosseous cannula for infusion of emergency drugs and fluids did not increase the magnitude of fat embolization over cardiopulmonary resuscitation alone in this animal model. The benefits of using this procedure in critically ill children as a means of rapid vascular access for resuscitation is well established. However, the risk of fat embolism in this population needs further study.
Level of Evidence 6 Supportive

Fisher, R. and D. Prosser (2000). "Intraosseous access in infant resuscitation." Arch Dis Child **83**(1): 87. (Letter)
Level of Evidence 5 Supportive

Friedman, F. D. (1996). "Intraosseous adenosine for the termination of supraventricular tachycardia in an infant." Ann Emerg Med **28**(3): 356-8.

Abstract

In recent years, the intraosseous technique has dramatically improved the speed at which vascular access may be achieved in critically ill children, and adenosine has been shown to rapidly convert supraventricular tachycardia to normal sinus rhythm. Until now, no report has demonstrated that this drug may be effectively given by this route in human beings. This case report describes the successful termination of supraventricular tachycardia in an infant with the intraosseous administration of adenosine

Fuchs, S., D. LaCovey, et al. (1991). "A prehospital model of intraosseous infusion." Ann Emerg Med **20**(4): 371-4.

Level of Evidence 5 Supportive

Glaeser, P. W., T. R. Hellmich, et al. (1993). "Five-year experience in prehospital intraosseous infusions in children and adults." Ann Emerg Med 22(7): 1119-24.

Abstract

STUDY OBJECTIVE: To evaluate the ability of emergency medical technician-paramedic (EMT-P) units to become and remain proficient in the performance of the intraosseous infusion procedure. DESIGN AND SETTING: Descriptive nonrandomized trial open to all patients meeting protocol criteria over a five-year period; prehospital urban and suburban area with a population of 951,000. PARTICIPANTS: One hundred fifty-two consecutive patients (age range, newborn to 102 years) who had intraosseous infusion line placement attempted by EMT-Ps. INTERVENTION: Jamshidi sternal intraosseous infusion needle placed in the proximal tibia bone marrow in patients requiring emergency vascular access for fluid and/or medication administration. RESULTS: EMT-Ps performed 165 attempts on 152 patients with a five-year success rate of 76% per patient and 70% per attempt. Success rates per patient age group were 78%, 0 to 11 months; 85%, 1 to 2 years; 67%, 3 to 9 years; and 50%, 10 years or older. Success rates were significantly higher in children 3 years old compared with children and adults 3 or more years old (P = .04). Proficiency was maintained over the five-year study period. Infiltration was the most common complication, occurring in 14 patients (12%). Errors in landmark identification and needle bending were the most frequent identifiable causes for unsuccessful attempts. Evidence of clinical response to fluid or medication infused was noted in 28 patients (24%). CONCLUSION: EMT-P units can successfully perform the intraosseous infusion line procedure in patients of all ages. Proficiency is maintained over time despite its infrequent use by individual EMT-Ps.

Level of Evidence 5 Supportive

Glaeser, P. W., J. D. Losek, et al. (1988). "Pediatric intraosseous infusions: impact on vascular access time." Am J Emerg Med 6(4): 330-2.

Abstract

A 1-year retrospective chart review was performed to evaluate the effect of intraosseous infusions (IO) on the time required to establish vascular access in pediatric patients requiring immediate vascular access for resuscitation. Eighty-one patients were identified, including 29 pulseless and non-breathing and 52 noncardiopulmonary arrest children, who required intravenous fluids or medication for resuscitation. Comparing the results with a previous review, the IO method effectively reduced the time needed to establish vascular access in the arrested group when standard techniques failed, particularly in the child less than 2 years old. The IO method was not used effectively in the non-arrest group, as evidenced by a significantly greater mean time required to establish vascular access. There were no significant complications related to the IO procedure. Nine (50%) of the patients receiving IO fluids or medication had clinical and/or laboratory evidence that these substances reached the central circulation. Early use of IO infusion in the resuscitation is recommended for not only the arrested patient, but also the critical nonarrested patient requiring immediate vascular access

Level of Evidence 5 Supportive

Guy, J., K. Haley, et al. (1993). "Use of intraosseous infusion in the pediatric trauma patient." J Pediatr Surg 28(2): 158-61.

Abstract

Intraosseous infusions (IO) are frequently used for gaining rapid vascular access in critically ill children.

Few studies exist evaluating the efficacy of this procedure in the injured child. The objective of this study was to describe one pediatric institution's experience with the procedure of IO in young trauma victims. This study evaluated indications, insertion sites, complications, infused pharmacological agents, age, injury severity, and outcome. Fifteen patients received IO placement for cardiopulmonary arrest, seven for hypovolemic shock, and five for neurological compromise. Patient ages ranged from 3 months to 10 years (mean, 2.9 years). Twenty-nine IO lines were attempted in the tibia and three in the femur. Four of 32 attempts were unsuccessful. Of 32 attempts at IO placement (5 patients received multiple attempts), 15 were started in the prehospital setting and 17 in the emergency department. Multiple resuscitation medications as well as large colloid, crystalloid, and blood boluses were successfully infused. Seven of the 27 patients survived without observed IO-related complications. This study supports the use of IO infusion by prehospital as well as hospital personnel in the initial resuscitation of critically injured children. IO has a been established as a rapid, safe, and simple method of obtaining short term vascular access in both critically ill and injured children. This route deserves primary consideration as an alternate route for fluid resuscitation in pediatric trauma patients regardless of age. IO should be placed without delay when venous access is not rapidly obtainable

Level of Evidence 5 Supportive

Heinild, S., T. Sondergaard, et al. (1947). "Bone marrow infusions in childhood: experiences from a thousand infusions." Journal of Pediatrics **30**: 400-11.

Level of Evidence 5 Supportive

Jaimovich, D. G. and S. Kecskes (1991). "Intraosseous infusion: a re-discovered procedure as an alternative for pediatric vascular access." Indian J Pediatr **58**(3): 329-34.

Abstract

The intraosseous infusion has numerous advantages over other techniques that provide vascular access during emergencies. It is a rapid and safe alternate route for fluid and certain drug administration in the infant or child. Few contra-indications or restrictions exist and the success rate for the technique is very high, even when performed by paramedical personnel, and the rate of complications is very low. At this time the technique should be reserved for children in crisis such as cardiac arrest, shock, trauma, life threatening status epilepticus, or any situation in which the potential benefit of rapid venous access outweighs the low incidence of complication. Intraosseous infusion is intended only for emergency resuscitation and stabilization, after which another route of vascular access should be sought. The technique may offer even more promise for those who rarely care for critically ill children, because this skill is easily mastered with even limited opportunity for practice.

Level of Evidence 7 Supportive

Johnson, L., N. Kissoon, et al. (1999). "Use of intraosseous blood to assess blood chemistries and hemoglobin during cardiopulmonary resuscitation with drug infusions." Crit Care Med 27(6): 1147-52.

Abstract

OBJECTIVE: To compare intraosseous with central venous blood samples for biochemical analyses and hemoglobin levels during cardiopulmonary resuscitation (CPR) and during cardiopulmonary resuscitation with infusion of sodium bicarbonate, epinephrine, and saline boluses through the intraosseous site. DESIGN: Prospective, complete repeated measures study. SETTING: An animal laboratory at a university medical center. SUBJECTS: Thirty-two piglets (mean weight, 30 [range, 24-35] kg). INTERVENTIONS: Animals were anesthetized, instrumented, and subjected to hypoxic cardiac arrest. An intraosseous cannula was inserted into the tibia, and animals were randomly assigned to one of five groups: heparinized saline (n = 6), epinephrine infusions only (n = 6), saline infusions only (n = 6), sodium bicarbonate infusions only (n = 8), and epinephrine, saline, and sodium bicarbonate infusions through the same site (n = 6). CPR (chest compressions and mechanical ventilation) was performed in all groups. Simultaneous blood samples were taken from the central venous and intraosseous sites before arrest and after 5 and 30 mins of CPR. MEASUREMENTS AND MAIN RESULTS: There were no differences ($p < .05$) in sodium, potassium, magnesium, lactate, and calcium values of intraosseous and central venous blood at the baseline and during 5 mins of CPR with infusions through the intraosseous cannula. At 30 mins, differences were apparent in magnesium, potassium, and sodium values between groups when the intraosseous cannula was used for infusions as well as sampling. Intraosseous potassium, glucose, and magnesium values were lower and

sodium values were higher than central venous blood levels. No differences were seen at all sampling intervals if small-volume heparinized saline was given through the intraosseous site. Hemoglobin values were lower in the intraosseous group after 30 mins of CPR and infusions through the intraosseous site. After 30 mins of CPR, all hemoglobin values from the intraosseous site were <10 g/100 mL. CONCLUSION: Intraosseous and central venous blood biochemical and hemoglobin values were similar during hemodynamic stability and throughout 30 mins of resuscitation if no drugs were given through the intraosseous site. However, differences existed after 30 mins of CPR and infusions through the intraosseous site. Laboratory values may be erroneous when intraosseous blood is used during periods of resuscitation of >5 mins if drugs and fluid boluses have also been infused through the site. For reliable values, an intraosseous site for sampling only may be reasonable.
Level of Evidence 6 Supportive

Kelsall, A. W. (1993). "Resuscitation with intraosseous lines in neonatal units." Arch Dis Child **68**(3 Spec No): 324-5.
Level of Evidence 5 Supportive

Kissoon, N., A. Idris, et al. (1997). "Intraosseous and central venous blood acid-base relationship during cardiopulmonary resuscitation." Pediatr Emerg Care 13(4): 250-3.
OBJECTIVE: The objectives of this study were: 1) to determine whether obtaining intraosseous (IO) blood samples was practical during cardiopulmonary resuscitation (CPR), and 2) to compare the acid-base status (pH and partial pressure of CO2 (PCO2) of venous and IO blood during CPR. DESIGN: A prospective repeated measure study. SETTING: An animal laboratory at a university medical center. INTERVENTIONS: Nine mixed breed piglets (mean weight 43 kg) were anesthetized, tracheotomized, and placed on a ventilator (Siemens 900C Elema, Sweden). Placement of a pulmonary artery catheter was done via a surgical incision in the neck. An IO cannula was then placed in the tibial marrow cavity. The animals were positioned under a mechanical thumper (Thumper, Michigan Instruments, Grand Rapids, MI) for chest compressions. Blood gases were analyzed during steady state (baseline) after five minutes of ventricular fibrillation and during CPR at seven, nine, 11, 13, 15 and 18 minutes. MAIN RESULTS: Blood samples for acid-base analysis were easily obtained from the IO sites during all sampling times. Mixed venous blood was slightly more acidic than IO blood, especially at 13, 15, and 18 minutes. However, there were no significant differences in pH and Pco2 values between IO and central venous (CV) gases at all time intervals except the PCO2. At nine minutes, a significant difference (P < 0.006) was found in PCO2 (59 +/- 4 vs 47 +/- 5 torr) for the CV versus IO sample, respectively. As the duration of CPR progressed, the differences in PCO2 between IO and CV sites were clinically relevant (though not statistically significant). CONCLUSION: Obtaining blood from the IO site is practical during CPR. The divergence in values as CPR progresses suggests that, during longer periods of CPR, IO blood may reflect local acidosis and yield lower PCO2 and higher pH values that CV blood. This finding may limit the usefulness of IO blood to judge acid base status as CPR progresses.
Level of Evidence 6 Supportive

Kissoon, N., R. Peterson, et al. (1994). "Comparison of pH and carbon dioxide tension values of central venous and intraosseous blood during changes in cardiac output." Crit Care Med 22(6): 1010-5.

OBJECTIVE: To compare the pH and PCO2 values determined from of simultaneously corrected samples of central venous and intraosseous blood during sequential changes in cardiac output. DESIGN: Prospective, descriptive study. SETTING: An animal laboratory in a university medical center. SUBJECTS: Fourteen mixed breed 4-wk-old piglets. INTERVENTIONS: Animals were anesthetized with ketamine hydrochloride and neuromuscular blockade was induced by the administration of pancuronium bromide. After endotracheal intubation and the institution of mechanical ventilation, a 4-Fr pulmonary artery catheter and a carotid artery cannula were inserted via a cutdown into the right neck of each piglet. A 16-gauge intraosseous needle was inserted into the anteromedial surface of the right tibia. MEASUREMENTS AND MAIN RESULTS: Central venous and intraosseous blood gas samples were obtained simultaneously with thermodilution cardiac output measurements. Cardiac output measurements were as follows: during steady state (0.80 +/- 0.14 L/min), after volume loading of 15 mL/kg (1.00 +/- 0.25 L/min), after three successive bleeds of 15 mL/kg each at 30-min intervals (0.70 +/- 0.28, 0.54 +/- 0.22, and

0.43 +/- 0.16 L/min, respectively) and at exsanguination (unrecordable). Paired t-tests demonstrated no significant differences in pH and PCO2 values between intraosseous and central venous samples under all study conditions. Limits of agreement for difference in PCO2 between sites, within the range of cardiac outputs studied, were -12.86 to 11.38 torr (-1.71 to 1.46 kPa) and for pH were -0.09 to 0.15. CONCLUSIONS: Intraosseous blood samples can be obtained without difficulty even during extreme hypovolemia. The pH and PCO2 values of intraosseous and central venous blood samples were similar under all study conditions. Intraosseous blood may be a useful alternative to central venous blood to assess tissue acid-base status during hemorrhagic shock and other low-flow states
Level of Evidence 6 Supportive

Kissoon, N., H. Rosenberg, et al. (1993). "Comparison of the acid-base status of blood obtained from intraosseous and central venous sites during steady- and low-flow states." <u>Crit Care Med</u> 21(11): 1765-9.

OBJECTIVE: To compare the acid-base status of blood obtained from the tibial intraosseous site with that status obtained from a central venous site during stead- and low-flow states in a piglet model. DESIGN: A prospective, observational study. SETTING: Animal laboratory at a university medical center. SUBJECTS: Nine 2-day-old piglets. INTERVENTIONS: Animals were anesthetized, intubated, and mechanically ventilated. A thermodilution pulmonary artery catheter was inserted via the right internal jugular vein and directed into the pulmonary artery. An arterial catheter was inserted into the right carotid artery and an intraosseous needle was inserted into the proximal tibial marrow cavity. Cardiorespiratory arrest was induced by discontinuation of ventilation. The animals were subsequently resuscitated by precordial compressions and ventilation. Blood samples were obtained from central venous and intraosseous sites during steady state and during resuscitation (low-flow state). RESULTS: No significant differences (p < .05) were found for pH, PCO2, and bicarbonate concentration when values that were obtained from the central venous and intraosseous sites were compared during steady- and low-flow states. CONCLUSIONS: The acid-base status of intraosseous blood is similar to that status of central venous blood. Intraosseous blood gas values may be an acceptable alternative to central venous blood gas values in judging central acid-base status during cardiopulmonary resuscitation.
Level of Evidence 6 Supportive

LaRocco, B. G. and H. E. Wang (2003). "Intraosseous infusion." <u>Prehosp Emerg Care</u> 7(2): 280-5.

Establishing vascular access is vital in the resuscitation of critically-ill children and adults. Intraosseous infusion (IOI) is a viable route for providing vascular access when traditional intravenous methods cannot be accomplished. IOI is relatively easy to perform and is a standard recommended intervention for the resuscitation of both adults and children. The authors review the history, anatomy, technique, and clinical application of IOI. They also highlight the use of IOI in the prehospital setting.
Level of Evidence 7 Supportive

Macgregor, D. F. and A. J. Macnab (1990). "Intraosseous fluids in emergencies." <u>Pediatrics</u> **85**(3): 386-7.
Level of Evidence 8 Supportive

Martino Alba, R., M. J. Ruiz Lopez, et al. (1994). "Use of the intraosseous route in resuscitation in a neonate." <u>Intensive Care Med</u> **20**(7): 529.

Moller, J. C., F. K. Tegtmeyer, et al. (1996). "[Intraosseous puncture as vascular access in pediatric emergency and intensive care medicine]." <u>Anaesthesiol Reanim</u> 21(4): 103-7.

In paediatric resuscitation scenarios, emergency physicians have sufficient skills in endotracheal intubation.

They are successful in about 80% of the cases as US studies indicate. However, vascular access is much more of a critical problem and emergency physicians succeed in only 50%. Therefore, intraosseous access has become an internationally widely used and accepted method for venous access. In Germany, however, only case reports concerning this technique have been published. Based on the authors' experience shared with Sussmane and Raszynski in the US, we used the technique of intraosseous access in 18 paediatric resuscitative situations. Eleven patients survived who would not have done so without quick intravenous access. As complications we recorded a minor fracture, one compartment syndrome, which did not require surgical intervention, and a postmortally discovered minor fat embolism, which was of no clinical significance. Courses teaching this method should be offered in Germany to spread knowledge of this life-saving technique.
Level of Evidence 5 Supportive

Nasimi, A., P. Gorin, et al. (1998). "[Use of the intraosseous route in a premature infant]." <u>Arch Pediatr</u> 5(4): 414-7.

BACKGROUND: The intraosseous route (IOR) is a rehabilitated vascular access in emergency situations. Its indications and duration are defined, although the age limit at which it is usable is not clearly established. CASE REPORT: A 34-week-old preterm neonate, without infection, receiving gastric gavage, developed, at 8 days of life, a severe septic shock requiring ventilatory support and emergency volume expansion via a subclavian catheter. During the chest X-ray to check its position, the catheter was unfortunately pulled out. The child presented an acute desaturation with bradycardia, requiring bag ventilation and endotracheal epinephrine. The umbilical vein being unusable, an intraosseous access (20 G, distal hole, Cook) was performed at the upper tibial level to continue resuscitation and left in place for 14 hours to infuse antibiotics, inotropic support, blood products and colloids. Blood cultures grew Klebsiella pneumoniae. After a severe initial phase, course was favorable with normal examination at 3 years without complication of the IOR. DISCUSSION: To our knowledge, it is the youngest child in whom IOR was performed. For neonates and especially preterms, the site of puncture is just below the tibial superior tuberosity, otherwise there is a risk of fracture of the diaphysis. This risk justifies the control of the IOR by X-ray. The place of the IOR among emergency vascular accesses in neonates, seems to us to be reserved to situations when umbilical vein is unusable. CONCLUSION: Although no study compared IOR to superior longitudinal sinus access, we suggest to reserve the sinus access only when IOR has failed, because of its potential cerebral complications.
Level of Evidence 5 Supportive

Neal, C. J. and D. F. McKinley (1994). "Intraosseous infusion in pediatric patients." <u>J Am Osteopath Assoc</u> 94(1): 63-6.
In traumatically injured or medically unstable pediatric patients requiring resuscitation, gaining intravenous access often is frustrating for the physician and agonizing for the patient. Even when cardiopulmonary resuscitation is performed by trained professionals, cardiac arrests in children in the prehospital setting have a mortality of 79% to 100%. Immediate vascular access such as that obtained by intraosseous infusion improves survival. The intraosseous infusion technique uses the medullary cavity in the tibia as a "noncollapsible vein" for parenteral infusion. It is indicated in a child in shock or cardiac arrest when two attempts to access peripheral vasculature have failed or when more than 2 minutes have elapsed in the attempt to gain access. Epinephrine, bicarbonate, calcium, lidocaine, and volume expanders can be infused via the intraosseous route. Complications rarely occur. The technique described here is gaining acceptance in both prehospital and emergency department settings.
Level of Evidence 8 Supportive

Orlowski, J. P. (1994). "Emergency alternatives to intravenous access. Intraosseous, intratracheal, sublingual, and other-site drug administration." <u>Pediatr Clin North Am</u> 41(6): 1183-99.
Difficulties and delays in establishing intravenous access are not uncommon in emergency situations in pediatrics. Alternatives to venous cannulation exist, including intraosseous access, intratracheal drug administration, sublingual and intralingual injection, the intrapenile route, and intracardiac injection. Each of these emergency alternatives to intravenous access is discussed from the historical, technical, utilitarian, and risk-benefit aspects. It is concluded that the intraosseous effective alternative to intravenous access in

emergency situations.
Level of Evidence 8 Supportive

Parrish GA, T. D., Skiendzielewski JJ (1986). "Intraosseous Infusions in the Emergency Department." American Journal of Emergency Medicine **4**: 59-63.
For most emergency physicians and pediatricians, the frustrations encountered when obtaining intravenous access in infants involved in traumatic or medical emergencies are well known. Although it is rare that parenteral access is absolutely unobtainable in a pediatric patient, minutes and sometimes hours are often lost as futile attempts are made to cannulate a collapsed vein of such a patient. Many alternatives to such a crisis situation, including the intratracheal, intracardiac, and sublingual routes of administration, have been proposed and efficaciously used. Disadvantages to these alternatives, however, include the inability to administer volume-expanding colloids or crystalloids, and a relatively narrow spectrum of useful medications. One relatively safe, well-proven, and technically easy method for giving replacement fluids, blood products, and numerous resuscitative drugs is infusion by the intraosseous route. Although not recommended as a replacement for current modes of intravascular access, we feel it has definite utility in selected situations and warrants the awareness of emergency physicians. The value, historical aspects, technique, and complications of this procedure are discussed.
Level of Evidence 7 Supportive

Ramet, J., C. Clybouw, et al. (1998). "Successful use of an intraosseous infusion in an 800 grams preterm infant." Eur J Emerg Med **5**(3): 327-8.
Level of Evidence 5 Supportive

Rosetti, V. A., B. M. Thompson, et al. (1985). "Intraosseous infusion: an alternative route of pediatric intravascular access." Ann Emerg Med 14(9): 885-8.
Substantial difficulties can be encountered when establishing rapid intravascular access in critically ill children. The historic technique of tibial intraosseous infusion is presented as an alternate intravenous route in children less than 3 years old. Review of the literature reveals this technique to be a rapid, reliable method with an acceptably low complication rate. Substances absorbed through the marrow, flow rates, technical difficulties, and complications are discussed.
Level of Evidence 7 Supportive

Schoenfeld, P. S. and M. D. Baker (1993). "Management of cardiopulmonary and trauma resuscitation in the pediatric emergency department." Pediatrics 91(4): 726-9
The etiology and management of critical illness and injury in a pediatric emergency department were reviewed to survey the use of cardiopulmonary and trauma resuscitation and to compare these data with the educational content of Pediatric Advanced Life Support (PALS) courses. The emergency department records of 183 patients treated in the cardiopulmonary/trauma resuscitation room of a pediatric emergency department over a 17-month period were reviewed for data on diagnosis, morbidity, presence of apnea or pulselessness, and utilization of several resuscitation skills: intubation, cardioversion, tibial interosseous line placement, and other resuscitation techniques. Apneic and pulseless pediatric patients had poor survival (10.3%), but apneic patients had excellent survival (96.9%). Endotracheal intubation (57.9%), bag-valve-mask ventilation (63.9%), and medications for rapid-sequence induction of anesthesia prior to endotracheal intubation (25.7%) were used frequently. Inasmuch as asystole was the most common rhythm in pulseless patients, cardioversion and defibrillation were rarely used (2.2%). Specialized vascular access techniques, tibial interosseous lines (24.0%), and femoral intravenous lines (19.7%), were used frequently in pediatric patients. The frequent use of airway management skills and the excellent survival of apneic pediatric patients supports the current emphasis on airway management in PALS courses. Cardioversion/defibrillation should receive less emphasis in PALS courses. The frequent use of rapid-sequence induction of anesthesia prior to endotracheal intubation indicates that these techniques might warrant increased emphasis in the training of pediatric emergency department personnel and in PALS courses..
Level of Evidence 5 Supportive

Seigler, R. S., F. W. Tecklenburg, et al. (1989). "Prehospital intraosseous infusion by emergency

medical services personnel: a prospective study." Pediatrics 84(1): 173-7.
Intraosseous infusion technique by paramedics in the prehospital setting was prospectively evaluated. Intraosseous access was successfully established in 16 of 17 pediatric patients with cardiopulmonary arrest. There were 13 successful first attempts with intraosseous access established within 1 minute. No significant complications occurred. In this study, the ease of establishing intraosseous access by paramedics in the field is documented.
Level of Evidence 5 Supportive

Spivey, W. H. (1987). "Intraosseous infusions." J Pediatr **111**(5): 639-43.
Level of Evidence 7 Supportive

Stoll, E., J. Golej, et al. (2002). "Osteomyelitis at the injection site of adrenalin through an intraosseous needle in a 3-month-old infant." Resuscitation 53(3): 315-8.
Intraosseous (IO) puncture is considered for the administration of drugs and fluids when vascular access cannot be achieved rapidly. Adrenaline/epinephrine, adenosine, crystalloids, colloids and blood products can be applied and administered effectively using this route during resuscitation of children. This technique is relatively simple with complications of <1%. These may include tibial fracture, lower extremity compartment syndrome and osteomyelitis. A case is described in which a 3-month-old male infant presented for emergency resuscitation requiring IO infusion utilising both tibial bones. High doses of adrenaline (1:1000; 0.1 mg/kg) were administered in the right tibial epiphysis only after the standard initial concentration (1:10000; 0.01 mg/kg) had minimal effect. A local inflammatory reaction was noted 24 h later in the right tibial region, which developed into cutaneous necrosis, and was eventually resected. Radiologically, no osseous lesion could be demonstrated, however, a bone scintigram revealed osteomyelitis. Upon surgical revision, purulent destruction was evident requiring removal of the epiphysis and part of the metaphysis. Although osteomyelitis is a rare complication which may be caused by sepsis, or contamination during insertion, we speculate that adrenaline in high concentrations may promote the development of osteomyelitis and the drug should be applied cautiously in more diluted concentrations.
Level of Evidence 5 Supportive

Stovroff, M. and W. G. Teague (1998). "Intravenous access in infants and children." Pediatr Clin North Am **45**(6): 1373-93, viii.

Tocantins, L., O'Neil JF, Price AH (1941). "Infusions of Blood and Other Fluids via the Bone Marrow in Traumatic Shock and Other Forms of Peripheral Circulatory Failure." Annals of Surgery **114**(6): 1085-1092.

Tocantins, L. a. O. N., JF (1940). "Infusion of Blood and Other Fluids into the Circulation via the Bone Marrow." Proceedings of the Society for Experimental Biology and Medicine **45**: 782-783.

Tocantins, L. a. O. N., JF (1941). "Infusion of Blood and Other Fluids into the General Circulation via the Bone Marrow." Surgery, Gynecology and Obstetrics **73**: 281-287.

Velasco, A. L., C. Delgado-Paredes, et al. (1991). "Intraosseous infusion of fluids in the initial management of hypovolemic shock in young subjects." J Pediatr Surg 26(1): 4-8.

Immediate aggressive fluid resuscitation of a child with life-threatening hemorrhagic shock provides the difference between life and death. Obtaining venous access in the hypovolemic child sometimes is difficult and time consuming. In order to evaluate the benefit of prehospital administration of intraosseous fluids into the tibial bone marrow as a method of gaining quick access to the systemic circulation and in resuscitating victims from severe hypovolemic shock, 13 puppies weighing 4.6 to 10 kg were subjected to progressive, controlled exsanguination until their mean arterial pressure (MAP) was 20% or less of their baseline MAP for 5 minutes (maxishock). Then an 18-gauge intraosseous needle was inserted into the tibial bone marrow and lactated Ringer's solution was infused at 300 mm Hg of pressure until a volume three

times the blood loss had been administered. The MAP, central venous pressure, arterial blood gases, hematocrit, serum lactate, and urine output were recorded at 10, 20, 30, 45, 60, 90, and 120 minutes after the onset of maxishock. At the end of the experiment the left lung of each animal was sent to the pathology department to investigate the possibility of bone marrow emboli. The results were compared with a group of control dogs with maxishock and no treatment, and a group of dogs with maxishock treated with a canine military antishock trousers inflated to 50 to 55 mm Hg and no fluids. The average needle insertion time was 16 seconds; the rate of infusion of fluids varied from a maximum of 25.7 mL/min to a minimum of 4.5 mL/min, with a mean of 10.6 mL/min.(ABSTRACT TRUNCATED AT 250 WORDS)

Level of Evidence 6 Supportive

Voelckel, W. G., K. G. Lurie, et al. (2001). "Comparison of epinephrine with vasopressin on bone marrow blood flow in an animal model of hypovolemic shock and subsequent cardiac arrest." Crit Care Med 29(8): 1587-92.

OBJECTIVE: The intraosseous route is an emergency alternative for the administration of drugs and fluids if vascular access cannot be established. However, in hemorrhagic shock or after vasopressors are given during resuscitation, bone marrow blood flow may be decreased, thus impairing absorption of intraosseously administered drugs. In this study, we evaluated the effects of vasopressin vs. high-dose epinephrine in hemorrhagic shock and cardiac arrest on bone marrow blood flow. DESIGN: Prospective, randomized laboratory investigation that used an established porcine model for measurement of hemodynamic variables and organ blood flow. SETTING: University hospital laboratory. SUBJECTS: Fourteen pigs weighing 30 +/- 3 kg. INTERVENTIONS: Radiolabeled microspheres were injected to measure bone marrow blood flow during a prearrest control period and during hypovolemic shock produced by rapid hemorrhage of 35% of the estimated blood volume. In the second part of the study, ventricular fibrillation was induced; after 4 mins of untreated cardiac arrest and 4 mins of standard cardiopulmonary resuscitation, a bolus dose of either 200 microg/kg epinephrine (n = 6) or 0.8 units/kg vasopressin (n = 6) was administered. Defibrillation was attempted 2.5 mins after drug administration, and blood flow was assessed again at 5 and 30 mins after successful resuscitation. MEASUREMENTS AND MAIN RESULTS: Mean +/- sem bone marrow blood flow decreased significantly during induction of hemorrhagic shock from 14.4 +/- 4.1 to 3.7 +/- 1.8 mL.100 g-1.min-1 in the vasopressin group and from 18.2 +/- 4.0 to 5.2 +/- 1.0 mL.100 g-1.min-1 in the epinephrine group (p =.025 in both groups). Five minutes after return of spontaneous circulation, mean +/- sem bone marrow blood flow was 3.4 +/- 1.1 mL.100 g-1.min-1 after vasopressin and 0.1 +/- 0.03 mL.100 g-1.min-1 after epinephrine (p =.004 for vasopressin vs. epinephrine). At the same time, bone vascular resistance was significantly (p =.004) higher in the epinephrine group when compared with vasopressin (1455 +/- 392 vs. 43 +/- 19 mm Hg. mL-1.100 g.min, respectively). CONCLUSIONS: Bone blood flow responds actively to both the physiologic stress response of hemorrhagic shock and vasopressors given during resuscitation after hypovolemic cardiac arrest. In this regard, bone marrow blood flow after successful resuscitation was nearly absent after high-dose epinephrine but was maintained after high-dose vasopressin. These findings emphasize the need for pressurized intraosseous infusion techniques, because bone marrow blood flow may not be predictable during hemorrhagic shock and drug therapy.

Level of Evidence 6 Supportive

Weaver, B. L. (1994). "Intraosseous infusions." Neonatal Netw **13**(8): 68-9.