Intraosseous Infusion

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Abstract

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. **Key words**: intraosseous; infusion; needles; vascular access; prehospital; resuscitation.

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Vascular access is a vital task in the resuscitation of the critically ill.[1,2] Although peripheral intravenous (IV) access is the traditional method for gaining vascular access, this route can be challenging to achieve in victims of circulatory collapse. For example, in a series of 66 pediatric cardiac arrest patients, Rosetti et al. demonstrated that experienced emergency department (ED) personnel required more than 10 minutes to gain IV access in 24% of the cases; IV access was never obtained in 6% of victims.[3] The sublingual and endobronchial routes have been used to administer emergency drugs, but these methods are limited by erratic drug absorption and the fact that they do not permit intravenous fluid replacement.[4] Intracardiac injections have also been used for resuscitation, but this method can result in significant morbidity, including iatrogenic pneumothorax or great vessel damage.[4]

Intraosseous infusion (IOI) is an excellent alternate route for providing vascular access to administer fluids, blood products, and medications. Prior studies have demonstrated that the use of IOI can decrease the time needed to obtain vascular access in pediatric patients in cardiac arrest.[5,6] Furthermore, the rate of vascular access in pediatric cardiac arrest patients is higher for IOI (83%) than for all other forms of IV access such as saphenous surgical cutdown (81%), subclavian central venous (77%), and percutaneous peripheral (17%).[7] We review the history, anatomy, technique, and prehospital clinical application of IOI. We recommend that IOI be considered as a viable route for vascular access during resuscitation in the prehospital setting.

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History of IOI

Since the 1830s, the IV route has been used to administer fluids. In 1922, Drinker et al. examined the circulation of the sternum and suggested that it be used as a route for blood transfusion.[8] In 1940 Henning used the sternum to transfuse a patient with granulocytopenia.[9] Tocantins and O'Neill established in 1941 that the bone marrow cavity of a long bone was a possible site of vascular access; they showed that after injection of 5 mL of saline in the long bone of a rabbit, 2 mL could be recovered at the distal end with no signs of infiltration into subcutaneous tissues.[10] Papper demonstrated in 1942 that the circulation times of intraosseous and IV fluids were essentially the same.[11] In the 1940s and early 1950s, IOI was used extensively in children who required repeated blood transfusions and antibiotic therapy.[12] IOI has been shown by radionucleotide technique to deliver fluids as rapidly as intravenous techniques.[13]

Intraosseous infusion fell out of popularity in the 1950s due to the advent of plastic IV catheters.[12] Today IOI is accepted as standard equipment on pediatric and adult rescue carts. IOI is recommended in Advanced Cardiac Life Support and Pediatric Advanced Life Support treatment protocols as alternative means of vascular access in the event that IV cannulation is delayed or not feasible.[2,14]

Anatomy and Physiology of the Bone Medullary Canal

Bone is made up of a dense outer layer surrounding a spongy inner layer that forms a meshwork occupied by bone marrow, fat tissue, nerves, and blood vessels.[15] Bone marrow consists of developing blood cells and a network of fibers that serve as a supporting framework for the vascular complex in the medulla. The purposes of the medullary complex include production of red blood cells and provision of a vascular supply to the bone itself. IOI uses the medullary cavity of long bones as a "noncollapsible vein" for parenteral access. Infused drugs or fluids enter the

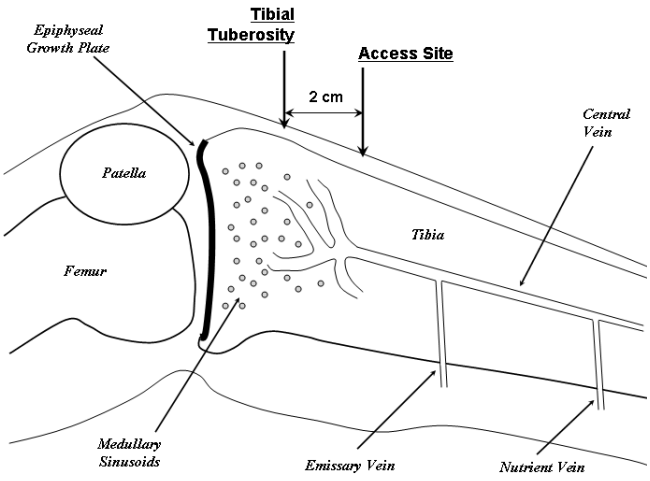

Figure 1. Anatomy of long bone circulation and landmarks for intraosseous needle insertion (access site) on the proximal tibia.

venous sinusoids within the medullary cavity, drain into the central venous channel, and exit the bone via nutrient or emissary veins (Figure 1).

Indications and Contraindications

The basic indication for IOI is the need for emergent vascular access when conventional methods have failed. The American Heart Association recommends the use of IOI in patients under 6 years of age in need of vascular access who have had two failed IV attempts or where more than 2 minutes have elapsed at attempting IV access.[6] Advanced Trauma Life Support protocols recommend the use IOI before central line insertion in pediatric trauma patients younger than age 6.[2] The use of IOI in major trauma in pediatric patients regardless of age has also been supported by Guy et al.[16] IOI has also been recommended for conditions such as cardiopulmonary arrest, profound shock, status epilepticus, overwhelming sepsis, and major burns.[17,18]

The only universally accepted absolute contraindication to IOI is a fracture of the bone near the access site.[19] Some authors feel that osteogenesis imperfecta and osteoporosis should also be considered absolute contraindications.[20] Relative contraindications to IOI include cellulitis over the insertion site and inferior vena caval injury.[19]

Techniques of Insertion and Infusion

The conventionally recommended site for IOI is the proximal tibia.[2] The tibial tuberosity should be located by palpation just below the patella. The recommended insertion site is the relatively flat area approximately 2 cm distally and slightly medial to the tibial tuberosity (Figures 1 and 2). Although this site is usually distal to the growth plate, it is still recommended that the nee-

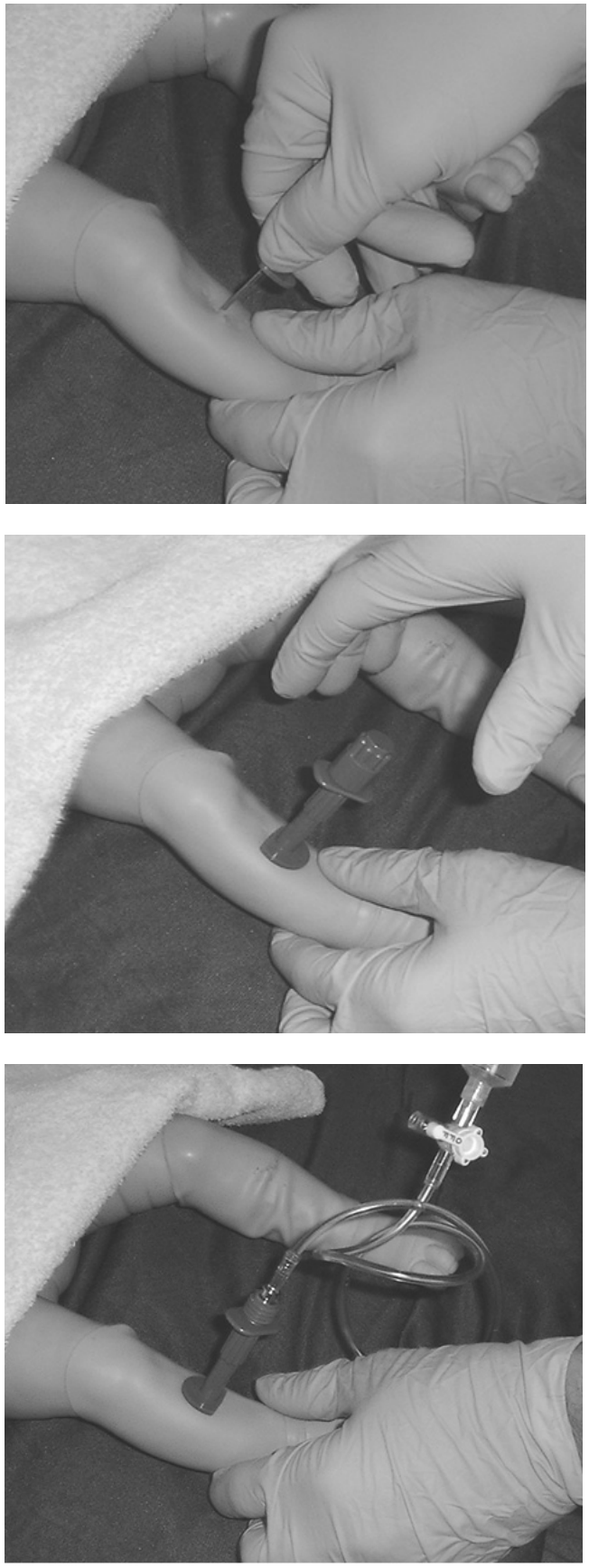

Figure 2. Technique of intraosseous needle insertion in the proximal tibia.

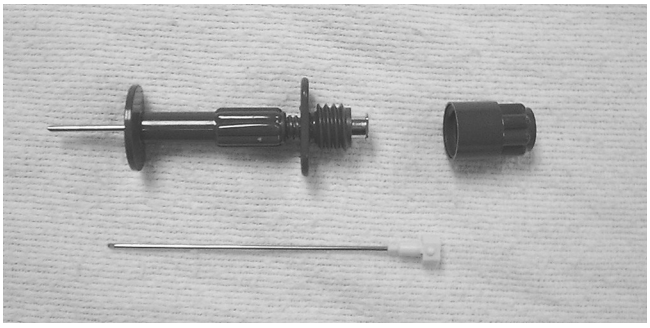

FIGURE 3. The Jamshidi Illinois bone marrow needle (Baxter Allegiance, Inc., McGaw Park, Illinois).

dle be angled 10–15 degrees caudally to avoid injury to the growth plate.

The patient's leg should be restrained and a small sandbag placed under the knee (Figure 2). The area should be cleaned and draped using sterile technique. Local anesthetic is recommended in the conscious patient (1% lidocaine injected subcutaneously and over the periosteum). The IO needle is inserted through the skin and subcutaneous tissues until bone is felt. The needle is then inserted into the bone using a twisting motion until a loss of resistance or "pop" is felt, indicating entry into the marrow. The trocar is removed from the needle and proper placement is verified. Any conventional IV fluid and IV tubing may be connected to the IO needle. The protruding IO needle should be covered and protected; for example, by using a properly sized plastic or paper cup.

Proper IO placement in the marrow canal can be confirmed by three methods. First, the needle should stand on its own without support. Second, after unscrewing the inner trocar from the needle, bone marrow should be able to be aspirated through the needle. Third, a 5–10-mL saline bolus injection should enter with little resistance and without evidence of extravasation; this can be confirmed by carefully observing the calf area for acute swelling or discoloration.

Only one IO attempt should be made in each bone. Multiple punctures in the periosteum may result in extravasation of fluid into the soft tissues. However, if the needle becomes plugged with soft tissue, it may be removed, and a new needle may be inserted through the same cannulation site.[4]

There are several alternative sites for IOI.[4] The distal tibia is an acceptable alternate placement site in children. To avoid the saphenous vein, the distal tibia may be entered 1–2 cm superior to the medial malleolus. As with the proximal tibia, the needle should be angled (10–15 degrees) away from the growth plate (i.e., cephalad in this instance). A case report has demonstrated the successful use of the calcaneus as an alternative IOI site.[21] The sternum has fallen out of favor in the pediatric emergency setting because it interferes with resuscitative efforts and carries a risk of mediastinal injury, pneumothorax, great vessel injury, and death.[20] However, new auto-injector devices have improved the safety of sternal access, making this site an attractive option for IOI (see Types of IO Needles and Alternative IO Devices, below).

Virtually all drugs that can be administered via the IV route can be administered by IOI.[1] Fluids and medications such as epinephrine, sodium bicarbonate, calcium chloride, hydroxyethyl starch, 50% dextrose in water, and lidocaine have all been shown to have drug levels and peak effects equivalent to the IV route, with an equivalent or longer duration of action.[22,23] Warren et al. demonstrated in pigs that different IOI sites (humerus, femur, malleolar, and tibia) are pharmacokinetically equivalent with regard to transit times and serum concentrations.[24] Therefore, it is not necessary to adjust drug dosages based on the IOI insertion site.

Although fluids may infuse by gravity, Voelckel et al. demonstrated the unpredictability of bone marrow blood flow by this method alone; they concluded that it was necessary to use pressure to augment flow in IOI.[25] Flow rates can be dramatically increased by the use of pressure bags and infusion pumps. Flow rates of 10 mL/min by gravity can be increased to 41 mL/min by using pressurized bags.[26] An alternative method for rapid infusion is to manually infuse 30–60-mL boluses via a stopcock.

Blood aspirated from the IOI site may be used for certain laboratory analyses. Hurren demonstrated that when comparing blood drawn from a venous site with blood from an IO site, hemoglobin, hematocrit, sodium, urea, creatinine, and calcium levels were "sufficiently similar to be clinically useful."[27] However, potassium and glucose levels were significantly variable in the bone marrow sample as compared with the venous sample.

TYPES OF IO NEEDLES AND ALTERNATIVE IO DEVICES

Any needle can be used for IOI, including a butterfly needle, a spinal needle with stylet, or a standard bone marrow biopsy needle such as the Cook Osteo-Site (Cook Critical Care, Bloomington, IN).[28] For these needles, a 16–20-gauge needle is recommended for children less than 18 months and 12–16-gauge for older children.[4] There are also needles designed specifically for IOI. These needles have trocars with handles to allow more controlled pressure and short shafts to make placement easier and accidental dislodging less likely. Also, they may be marked to indicate desired depth of penetration. Examples of standard IOI needles include the straight-needle Jamshidi (Baxter Allegiance, Inc., McGaw Park, IL, Figure 3) and Dieckmann (Cook Critical Care). The newer Sur-Fast (Cook Critical Care) and Sussmane-Raszynski (Cook

Critical Care, Figure 4) contain threaded needles that facilitate needle insertion into bone.

Spring-loaded auto-injector IO devices have been recently developed that facilitate easier and quicker IO needle placement. For example, the bone injection gun (BIG, WaisMed, Tri-anim, Sylmar, CA) is a spring-loaded auto-injection device (Figure 5). Depth of insertion can be controlled by the device. Spriggs et al. showed that emergency medical technician trainees found the BIG to be faster (12 sec vs. 17 sec) but similar in ease of use to the traditional Jamshidi IOI needle.[29] However, Gilman et al. found no difference between traditional IO needles and the BIG with respect to placement time and success rate.[30] When compared with saphenous vein cutdown, paramedic students found the BIG to have a shorter time to insertion, a higher success rate, and fewer complications.[31]

The F.A.S.T.1 (Pyng Medical Corporation, Vancouver, BC, Canada) uses the sternum for IO access (Figure 6). It employs a target patch to ensure proper location (15 mm below the sternal notch) and an introducer with a predetermined depth setting to prevent overpenetration of the sternum. It can provide flow rates ranging from 30 mL/min (gravity) to 125 mL/min (pressure cuff or syringe bolus).[32] F.A.S.T.1 is similar to other IOI techniques with regard to mean insertion time (77 seconds) and overall adult vascular access success rate (84%).[33] A study comparing the BIG, Sur-Fast, Jamshidi, and F.A.S.T.1 found all devices to have similar success rates and access times; however, F.A.S.T.1 was slower to insert. All devices were rated as easy to learn, but the BIG was rated as the first or second choice in 65%.[34]

Complications

The risks and complications of IOI are rare and outweighed by the benefits of immediate vascular access for administration of fluids or medications. Extravasation of fluid is the most common complication; this may occur from a misplaced needle, from multiple attempts in the same bone, or from movement of the needle enlarging the penetration site. If caustic medications are being infused (for example, dopamine), this may lead to necrosis of muscle and other subcutaneous tissues. Extravasation may also precipitate compartment syndrome leading to a potential loss of limb. Osteomyelitis is a rare complication, occurring in 0.6% of cases[3]; this occurs most frequently with prolonged needle placement, preexisting bacteremia, and the use of hypertonic fluids. Promptly replacing the IO needle with conventional peripheral or central venous access may minimize these complications.

Figure 4. The Sussmane-Razynski needle (Cook Critical Care, Inc., Bloomington, Indiana).

Figure 5. The bone injection gun (BIG—WaisMed, Tri-anim, Sylmar, California).

Rarely, fractures at the insertion site, compartment syndrome, fat emboli, cellulitis, and local abscess have occurred.[35,36] The theoretical complication of injury to the epiphyseal growth plate has not been supported by long-term prospective radiographic analyses of tibial length. Fiser et al. followed ten subjects radiographically to evaluate tibial length discrepancy one or more years after IOI; they found no difference between the lengths of the tibias with and without the IOI.[37] IOI has not been demonstrated to cause histologic damage to metaphyseal cell lines or morphologic damage to the growth plate of rabbits.[38]

Use of IOI in Adults

The use of IOI in adults is an area of much debate. Vascular red marrow is typically replaced by fat-laden yellow marrow by age 5, suggesting that children under age 6 are the best candidates for IOI.[20] Many authors feel that adults are not suitable candidates for IOI because of the increased difficulty of needle insertion through the thicker cortex of bone and smaller marrow cavity; this may lead to an increase in complications, especially fractures.[39] Although there is conjecture that the relative lack of red bone marrow in the adult may limit infusion rates, modest infusion rates of 20–25 mL/min using fluid bolus injection techniques have been achieved.[40]

Because the sternum retains a relatively large proportion of its red marrow, IOI can be accomplished

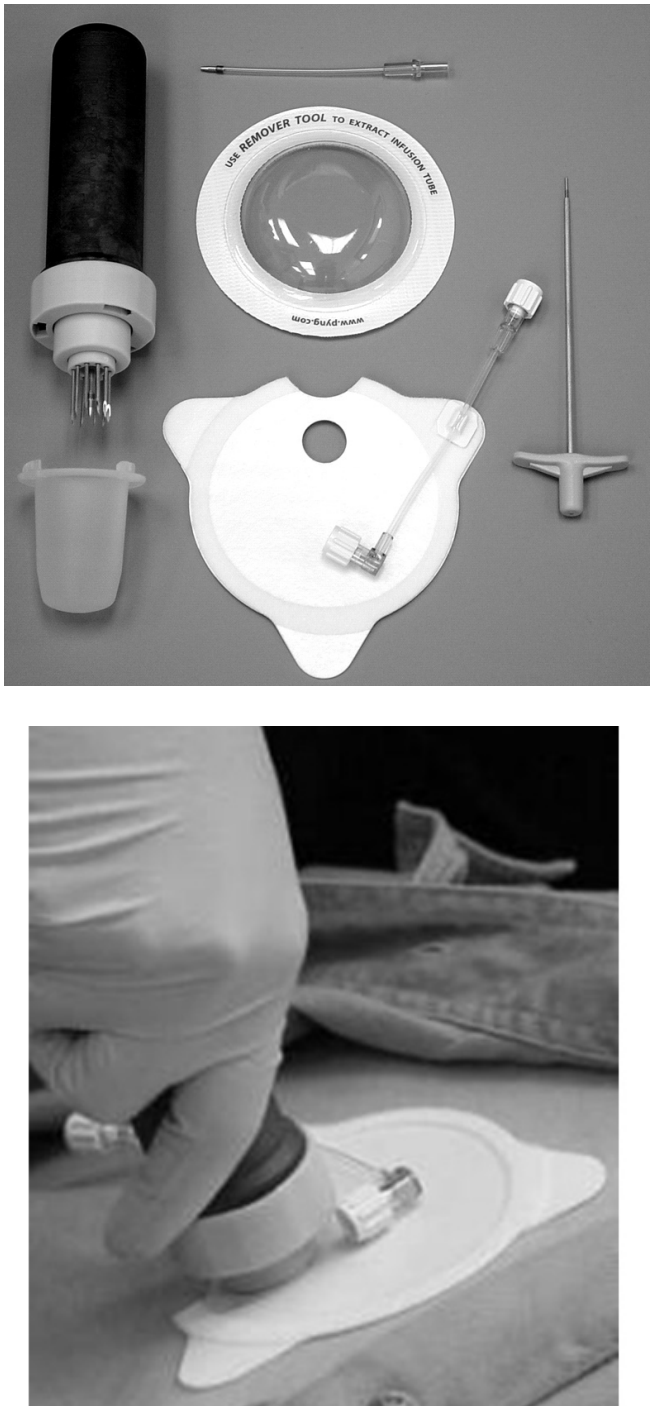

FIGURE 6. The F.A.S.T.1 system. Source: Pyng Medical Corporation, Vancouver, BC, Canada (www.pyng.com/pym/products/description.htm).

through the sternum in adults.[15] The recommended infusion site on the sternum is in the midline of the manubrium, 15 mm below the sternal notch; this offers a large, flat, easily accessible surface that has a relatively thin bone covering for easier penetration.[32] The sternum is also less likely to fracture than extremity bones.[15] Newer needles and placement systems specifically designed for the sternum such as the Jamshidi modified Illinois, SAVE sternal screw (Biologix, Sausalito, CA), and F.A.S.T.1 have improved the safety of this technique.

The BIG has been used successfully in adult extremity bones. Waisman and Waisman demonstrated that the BIG provided a higher success rate of vascular access when compared with manual IO insertion of a trocar needles in adult patients.[41]

PREHOSPITAL APPLICATION OF IOI

Intraosseous infusion is appropriate for the prehospital setting. Although prehospital training curricula focusing on pediatrics have improved vascular access time in young children, IV access still occasionally cannot be accomplished, and thus there is still a need for alternate vascular access options.[42–44] The use of IOI in the prehospital setting has not been universally accepted because of reservations that prehospital personnel will not be proficient with the procedure. However, many studies have demonstrated that paramedic and flight nurses have applied pediatric IOI with rates of successful placement ranging from 76% to 94%.[20,45–47]

Anderson et al. demonstrated that prehospital providers could successfully learn IOI techniques with only a one-hour standardized training session including a 20-minute video presentation followed by a supervised hands-on simulation with chicken bones.[48] Furthermore, it has been shown that IOI can also be successfully and rapidly inserted en route to the hospital.[49] Although concerns exist regarding the ability to maintain proficiency in IOI, Glaeser et al. demonstrated that proficiency could be maintained over a five-year period with minimal training.[46] Despite the potential for IOI use in the prehospital setting, less than half of state emergency medical services (EMS) systems have reported actual prehospital field application.[50] One-third of state EMS services were unaware of future plans to introduce IOI to EMS practice.[50]

CONCLUSION

Although it is an accepted route for emergency vascular access, intraosseous infusion is still not in widespread clinical use. The recent advent of new technology have greatly simplified and improved the safety of the procedure. IOI is a viable method for emergent vascular access in the prehospital setting.

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