Advanced Pediatric Emergency Medicine Assembly

March 23-26 2015
New York, NY

Vascular Access and Treatment of Shock in Children

The speaker will identify the variety of methods to obtain vascular access in the acutely ill pediatric patient, including ultrasound guidance, and a discussion of alternatives to IV placement to include intraosseous placement, and UVC lines. A review of the main causes of shock in pediatric patients and the current literature-based guidelines for their treatment will also be discussed.

OBJECTIVES

- Discuss myths and advantages/complications of standard peripheral line placement vs. IO placement vs. ultrasound guided line placement vs. UVC line in the neonate.
- Discuss the use of goal-directed therapy in pediatrics.

3/23/2015
8:30 AM-9:00 AM
Grand Ballroom
MO-2

DISCLOSURES:
(+ ) No significant financial relationships to disclose

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**Vascular Access and Treatment of Shock in Children**

**Venous Access:**

Establishment of reliable vascular access is a critical step in pediatric resuscitation, but it can be difficult to obtain in a critically ill infant or child. Successful resuscitation is more likely if vascular access is achieved within the first few minutes. (1)

This presentation will discuss technique for ultrasound guided peripheral access, as well as intraosseus, and umbilical venous access.

- Ultrasound-guided venous access
- Intraosseous
- Umbilical vein

**Ultrasound-guided venous access:**

In young children, static ultrasound can be used to localize potential peripheral veins for cannulation. (2) Dynamic ultrasound can be hampered by the small size of the child's extremity and lack of cooperation during the procedure. (3, 4) However, in one study, 40 children were randomly assigned to undergo peripheral access with or without ultrasound guidance. In the ultrasound-guided group, the median time to cannulation was significantly shorter (63.5 versus 420.5 seconds), and the median number of punctures was less (1 versus 2.5). (5)

**Indications**

Ultrasound-guided peripheral intravenous (PIV) cannulation include, but are not limited to, the following:

- Failure to cannulate by using the traditional technique
- Cannulation of a patient who is severely dehydrated
- Cannulation in patients who are obese
- Cannulation in the presence of peripheral edema
- Cannulation in patients who use intravenous drugs or who have had multiple intravenous catheters placed in the past (eg, patients with sickle cell disease)
- Cannulation in the presence of burns that overlie the cannulation site
Contraindications

- Ultrasound-guided access can be difficult and time consuming and should not supplant intraosseous access in a life-threatening situation when peripheral or central access by landmark techniques is not rapidly successful.

Technique

- A high frequency linear transducer (5 to 12 MHz) is most commonly used.
- All vessels should be anechoic (black) tubular structures, while the surrounding tissues will be some level of gray.
- Veins are distinguished from arteries on ultrasound because they have thinner walls, are more easily compressed, and lack arterial pulsations.
- **Transverse (short axis) view** — To obtain the transverse view, place the probe at a 90 degree angle to the course of the vein. The vessels appear in cross-section in this view. Center the target vein on the ultrasound screen. Vein cannulation with the transverse view is easiest for two reasons. First, distinguishing the vein from an adjacent artery with compression technique is best performed with transverse orientation of the probe. The operator can slide off axis from the vessel during compression with a long axis approach, rather than truly compressing the vessel. Second, the transverse approach allows the operator to easily correct the trajectory of the needle during insertion through the tissues prior to venipuncture.
- **Longitudinal (long axis) view** — Before attempting the longitudinal view, the clinician should identify the location of the vein using the transverse view. The probe should then be rotated 90 degrees so that its long axis is parallel to the course of the vein. This view typically permits direct observation of needle penetration into the vein. A potentially important limitation is that the longitudinal view is technically more difficult to perform and to maintain the center of the vessel in view during vascular access procedures. (6)

![Figure 1. Longitudinal (long axis) approach for ultrasound-guided peripheral intravenous cannulation.](image-url)
Figure 2. Longitudinal (long axis) View: needle penetrating the vein.

Figure 3. Anatomy of the vessels of the arm (7)
Complications

- Arterial puncture
- Hematoma
- Infection

Intraosseous Access:

Intraosseous lines are a reliable and rapid way for obtaining vascular access in emergency situations, particularly in children. Their use is recommended when intravenous access cannot be easily secured and there is a need for fluid or pharmacological resuscitation. Intraosseous (IO) infusion is possible because of the presence of veins that drain the medullary sinuses in the bone marrow of long bones. These veins, supported by the bony matrix, do not collapse in patients with shock or hypovolemia. (8,9)

Indications

Infants and children in full cardiopulmonary arrest or severe shock who do not have readily available intravenous access undergo IO cannulation for medication administration, fluid therapy, and diagnostic studies rather than central venous line placement or surgical venous cut down.

Intraosseous cannulation may also be appropriate in emergent or urgent situations where reliable venous access cannot be achieved quickly (e.g. patients with shock, sepsis, status epilepticus, extensive burns, multiple trauma) or in patients for whom intravascular access is medically necessary and cannot be achieved by other means despite multiple attempts. (10)

- Peripheral venous access often difficult in children
- Worse with dehydration and/or hypotension
- Medullary cavity of long bones provide “non-collapsible” vein
Previously only young children
- New PALS guidelines recommend for “any pediatric patient”
- Great for rapid IV access
- Not useful for rapid infusion

**Contraindications**
- **Absolute:** Fracture in bone to be accessed  
  Osteogenesis imperfecta
- **Relative:** Inflammation/infection at insertion site  
  Occurrence of osteomyelitis or growth plate injuries negligible (11)

**Insertion sites**
The following list provides the sites most commonly used sites: Proximal tibia, distal tibia, distal femur.

Figure 5. Insertion sites for intraosseous access.
Proximal tibia
- Preferred site up to 3 to 4 years of age
- Anteromedial surface
- 1-2 cm below tibial tuberosity

**Proximal Tibia**

![Figure 6. Proximal tibia approach for intraosseous insertion.](image)

Distal tibia
- Preferred after 4 years of age
- Proximal to the medial malleolus, 1-2 cm above medial malleolus

![Figure 7. Distal tibia approach for intraosseous insertion.](image)
Distal femur
  - Midline, 2-3 cm above the external condyle

Figure 8. Distal femur approach for intraosseous insertion.

**Needle size:**

*Manual IO* needles include the Jamshidi (Cardinal Health, McGraw Park, IL) and the modified Dieckmann (Cook Critical Care, Bloomington, IN). Important features include a trocar, a short needle length with a handle that provides a resting place for the palm and an adjustable flange or depth marking to guide placement.

- age < 18 months use 18 gauge
- age > 18 months use 15 or 16 gauge
- May use intraosseous, bone marrow, 16- and 18-gauge needles, and 15- and 18-gauge spinal needles
- Intraosseous and bone marrow needles are preferred
Battery-powered driver (EZIO®) (EZ-IO®, VidaCare Corporation, Shavano Park, Texas, USA)
The 15 gauge needles come in three lengths as follows:

- 15 mm (pink) for placement in patients 3 to 39 kg
- 25 mm (blue) for placement in patients ≥40 kg with normal subcutaneous tissue
- 45 mm (yellow) for placement in patients ≥40 kg with excessive subcutaneous tissue
Figure 11. EZ-IO® and different size needles.

**Technique**

**Manual IO needles**
- Identify the placement site based upon anatomic landmarks
- Don appropriate personal protective equipment and prepare the insertion site as for the manual insertion technique.
- Ensure that the appropriate needle is selected based upon the patient’s weight and amount of subcutaneous tissue over the selected insertion site.
- Use back-and-forth screwing motion, not rocking
- Do not point needle toward growth plate
- Steady pressure until sudden reduced resistance
- Avoid puncturing both cortices
- Aspirate blood/marrow
  - Confirms placement
  - May infuse saline and then aspirate
- Secure needle
- Monitor site for increased pressure in soft tissue
  - Can cause compartment syndrome
Figure 12. Manual intraosseous insertion technique.
The physician's fingers and thumb are wrapped around the proximal tibia to stabilize it; the hand should not be placed directly behind the insertion site (to avoid self-puncture). Instead, a towel may be placed behind the knee to support it. The physician holds the needle firmly in the palm of the other hand, directing the point slightly away from the joint space and growth plate. The needle is inserted with moderate pressure and a rotary motion, stopped as soon as a pop indicates penetration of the cortex. Some needles have a plastic sleeve, which can be adjusted to prevent them from being pushed too deeply into or through the bone.

**Battery-powered driver (EZIO®)**

- Identify the placement site based upon anatomic landmarks
- Don appropriate personal protective equipment and prepare the insertion site as for the manual insertion technique.
- Ensure that the appropriate needle is selected based upon the patient’s weight and amount of subcutaneous tissue over the selected insertion site.
- Securely seat the needle on the battery-powered driver.
- Remove the needle safety cap.
- Position the driver with the needle at a 90-degree angle to the bone.
- Gently drive or manually press the needle until the tip touches the bone. Ensure that at least 5 mm of the catheter is visible above the skin at this point.
Figure 13. Optimal size of the EZ-IO® needle.

- Squeeze the driver trigger and apply light but steady downward pressure to penetrate the bone. Excessive pressure may result in the needle not penetrating the bone.
- Release the trigger to stop insertion when a sudden decrease in resistance is felt (“give” or “pop”) or when the appropriate depth, as indicated on the needle, is reached.
- Wait for the driver to stop spinning. Then, while holding the catheter in place, remove the driver by pulling straight up from the catheter and unscrew the needle stylet by rotating it counter-clockwise.
- Aspirate bone marrow to identify correct placement of the IO catheter and, if desired, to obtain a sample for laboratory analysis using a syringe attached directly to the hub or the manufacturer provided extension set.
- If the patient is awake, slowly administer 0.5 mg/kg lidocaine (2 percent [20 mg/mL] preservative-free formulation, maximum dose: 40 mg) through the IO catheter prior to flushing.
- Ultrasound has also been used to confirm intraosseous (IO) needle placement in adults by detection of Doppler flow within the marrow cavity when the ultrasound probe was placed cephalad to the IO site. (12)
- Once proper placement is confirmed, flush the needle with 10 mL of normal saline using the manufacturer supplied IV connector tubing. Some clinicians prefer to flush once with heparinized saline.
- **Removal** – Attach a Luer lock syringe to the catheter hub. While stabilizing the extremity, rotate the catheter and syringe clockwise while pulling straight back. Apply pressure to the IO site. Dress the site using aseptic technique.

**Complications:**
There is a documented low complication rate associated with intraosseous access.
- Vascular: bleeding
- Cardiac: air and fat emboli
- Infection: catheter-related infection
  - Sepsis
  - Osteomyelitis (13, 14)
  - Septic joint
Orthopedic: damage to growth plate (potential decreased bone growth)
Fracture (13)
Compartment syndrome (15)

Umbilical Venous Access:

When critically ill newborns present to the emergency department, peripheral access is preferred. If this is impossible, umbilical vein catheterization may be attempted. Umbilical vein catheterization may be a life-saving procedure in neonates who require vascular access and resuscitation. The umbilical vein remains patent and viable for cannulation until approximately 1 week after birth, may be successful up to 2 weeks of age. After proper placement of the umbilical line, intravenous fluids and medication may be administered to critically ill neonates. (16)

Figure 14. Anatomy Umbilical Vein (17)

Special circumstance for obtaining central venous access
Most likely useful for newborn delivered in ED
Vessels readily accessible after umbilical cord is cut
In emergencies, modified umbilical vein line preferred
- Umbilical venous access: blood drawing, transfusions, and monitoring central venous pressure
- Administration of epinephrine or naloxone
- Administration of volume expanders

**Indications:**
- Newborn requiring immediate venous access, especially when no available alternative
- Alternative uses of the umbilical vein may include exchange transfusions and central venous access (18)
- May successful up to 2 weeks of age

**Contraindications:**
- Absolute: Omphalitis -> Infection of adjacent skin
  - Peritonitis
- Relative: Suspected intestinal hypoperfusion
  - Suspected necrotizing enterocolitis

**Equipment for Umbilical Vein Catheterization:**
- Infusion solution
- Fluid chamber, IV tubing, infusion pumps
- Three-way stopcock
- Umbilical catheter 3.5 to 5 Fr/Feeding tube 5 or 8Fr
- Umbilical tape
- 3-0 silk suture on a curved needle
- Curved iris forceps without teeth
- Small clamps, forceps, scissors, needle holder
- Sterile drapes
- Heparinized flush
- Sterile gloves/PPE

**Technique:**
- Expose (incise) vessel
- Apply purse string suture
- Identify vein (single, larger) vs. arteries
- Insert 5 FR catheter flushed with sterile heparinized solution attached to a three-way stopcock

- Advance 4 to 5 cm or until blood return in an emergency situation
- Tighten suture, secure catheter
- In an emergency resuscitation, the catheter is best advanced only 1-2 cm beyond the point at which good blood return is obtained.
- The ideal location is in the inferior vena cava site with the catheter tip at or just above the diaphragm (at or above the 10th thoracic vertebra). The catheter must be inserted approximately 10-12 cm in a full term infant to reach the inferior vena cava.
Rapid estimation of insertional length of umbilical catheters in newborns may be done by using shoulder-to-umbilicus length (SUL) multiplied by 0.6 to place its tip above the diaphragm at the junction of inferior vena cava and the right atrium.

- Another method to approximate the length of the catheter is to use birth weight (BW)
- UA catheter length = 3xBW + 9
- UV catheter length = ½ UA line calculation + 1

Lengths are measured in centimeters and BW in kilograms

- The UVC line should not be used if the tip as visualized on x-ray is within the shadow of the liver
- Intrahepatic position increases the risk of portal venous thrombosis

(19, 20, 21)

Figure 17. Normal radiographic appearance of umbilical venous catheter and umbilical artery catheter. A, Frontal radiograph of abdomen shows that umbilical venous catheter enters abdomen at umbilicus (small arrowhead), travels in cephalad direction in umbilical vein (double black arrows) (note that catheters cross just above umbilicus), courses through left portal vein and ductus venosus, enters inferior vena cava, and terminates in right atrium. Umbilical artery catheter also enters abdomen at umbilicus (single black arrow) but extends inferiorly (white arrow) and posteriorly into iliac artery before coursing superiorly in aorta (large arrowheads). (17)

Complications:
Early goal-directed therapy:

Goal-directed therapy for septic shock refers to an aggressive systematic approach to resuscitation targeted to improvements in physiologic indicators of perfusion and vital organ function within the first six hours. Effective treatment of septic shock requires rapid correction of circulatory dysfunction with continuous monitoring and re-evaluation at frequent intervals and early administration of empiric broad-spectrum antimicrobial therapy. The 2007 American College of Critical Care Medicine (ACCM) guidelines with emphasis on early goal-directed therapy.

These guidelines are also largely compatible with the algorithm for pediatric septic shock promoted in the Pediatric Advanced Life Support (PALS) course. However, the ACCM guidelines provide a tighter time frame for optimal delivery of initial intravenous fluid boluses. The timing of therapeutic actions in the ACCM guidelines should be viewed as best practices for resuscitation of a child with septic shock. However, meeting the time targets may not always be possible within the first hour of illness depending upon patient factors and available pediatric expertise.

Rapid intravenous (IV) access and Fluid Resuscitation

IV access (preferably two sites and of the largest caliber that can be reliably inserted) should be established within five minutes. If a peripheral IV cannot be obtained in this time, guidelines advise placement of an intraosseous needle. Initial therapy should begin with a bolus of 20 mL/kg of isotonic crystalloid solution (ie, 0.9 percent normal saline or lactated Ringer solution) infused over five minutes or as rapidly as possible, preferably with a manual “push-pull” technique or rapid infuser. After the initial infusion, the child should be quickly reassessed for signs of inadequate end-organ perfusion to determine if additional fluid is needed. Repeated 20 mL/kg fluid boluses should be given until tissue perfusion, oxygen delivery, and blood pressure are adequate, or signs of fluid overload (rales, gallop rhythm, enlarged liver) develop. Experience suggests that patients may require volumes of 60 mL/kg or more in the first hour and up to 120mL/kg or more during the first several hours of fluid administration.

Fluid-refractory shock — Vasoactive agents are frequently necessary in the initial resuscitation of children with septic shock to sustain perfusion pressure while hypovolemia is corrected. The initial choice of vasoactive agents is guided by physical findings:

Cold shock — The American College of Critical Care Medicine (ACCM) guidelines suggest that patients with cold shock (eg, poor perfusion, cold extremities) that do not respond to initial boluses of 40 to 60 mL/kg of fluid receive dopamine infusions (starting dose 5 mcg/kg per minute, titrate to response up to 10 mcg/kg per minute). At lower doses, dopamine improves splanchnic and renal blood flow and, at higher doses, it
provides both inotropic and vasopressor support. Unlike adults, dopamine is still a first-line agent in children because of its wide availability and practitioner familiarity, and no evidence has correlated dopamine use with increased mortality in children with septic shock. However, infants younger than one year of age may be less responsive to dopamine. (32)

Pediatric Advanced Life Support guidelines suggest low-dose dopamine for patients with septic shock but normal blood pressures and epinephrine is suggested for patients with cold shock. (33)

No trials have directly compared dopamine to epinephrine for the treatment of cold shock in children. Thus, the optimal approach is debated and awaits further study.

If cold shock is resistant to dopamine infusion at a dose of 10 mcg/kg per minute, epinephrine infusion at a rate between 0.05 to 0.3 mcg/kg per minute may be added. At doses exceeding 0.1 mcg/kg/minute (and possibly lower in some patients), alpha-adrenergic effects of epinephrine are more pronounced and systemic vasoconstriction may be more evident.

**Warm shock** — For patients with warm shock (e.g., bounding pulses, pink extremities, and “flash” capillary refill) the American College of Critical Care Medicine and Pediatric Advanced Life Support guidelines suggest norepinephrine infusion starting at 0.03 to 0.05 mcg/kg/minute as the first-line drug. If dopamine infusion has already been started then norepinephrine can be added to dopamine.
**Initial resuscitation**: Push boluses of 20 cc/kg isotonic saline or colloid up to & over 60 cc/kg until perfusion improves or unless rales or hepatomegaly develop. Correct hypoglycemia & hypocalcemia. Begin antibiotics.

**Fluid refractory shock**: Begin inotrope IV/IO. Use atropine/ketamine IV/IO/IM to obtain central access & airway if needed. *Reverse cold shock* by titrating central dopamine or, if resistant, *reverse central epinephrine*. *Reverse warm shock* by titrating central norepinephrine.

**Catecholamine resistant shock**: Begin hydrocortisone if at risk for absolute adrenal insufficiency.

- Monitor CVP in PICU, attain normal MAP-CVP & ScvO₂ > 70%

**Cold shock with normal blood pressure**: 1. Titrate fluid & epinephrine, ScvO₂ > 70%, Hgb > 10g/dL 2. If ScvO₂ still < 70% Add vasodilator with volume loading (nitrosovasodilators, milrinonine, imrinnone, & others) Consider levosimendan

**Cold shock with low blood pressure**: 1. Titrate fluid & epinephrine, ScvO₂ > 70%, Hgb > 10 g/dL 2. If still hypotensive consider norepinephrine 3. If ScvO₂ still < 70% consider dobutamine, milrinone, enoximone or levosimendan

**Warm shock with low blood pressure**: 1. Titrate fluid & norepinephrine, ScvO₂ > 70% 2. If still hypotensive consider vasopressin, terlipressin or angiotensin 3. If ScvO₂ still < 70% consider low dose epinephrine

**Persistent catecholamine resistant shock**: Rule out and correct pericardial effusion, pneumothorax, & intra-abdominal pressure >12 mm/Hg. Consider pulmonary artery, PICCO, or FATD catheter, &/or doppler ultrasound to guide fluid, inotrope, vasopressor, vasodilator and hormonal therapies. Goal C.I. > 3.3 & < 6.0 L/min/m²

**Refactory shock**: ECMO
Figure 18. Algorithm for time sensitive, goal-directed stepwise management of hemodynamic support in infants and children. (32)

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