Single-access ultrasound-guided tunneled femoral lines in critically ill pediatric patients

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Abstract
Central venous access is an essential aspect of critical care for pediatric patients. In the critically ill pediatric population, image-guided procedures performed at the bedside expedite care and may reduce risks and logistical challenges associated with patient transport to a remote procedure suite such as interventional radiology. We describe our institutional technique for ultrasound-guided tunneled femoral venous access in neonates and infants and provide technical pearls from our experience, with an intended audience including specialists performing point-of-care ultrasound–guided procedures as well as interventional radiologist making their services available in the intensive care unit.

Keywords
Intensive care, interventional radiology, techniques and procedures, neonatology, pediatrics

Date received: 9 April 2020; accepted: 16 May 2020

Introduction
Indications for central venous access in the intensive care unit (ICU) are broad, ranging from inotropic infusion, parenteral nutrition, apheresis, and hemodynamic monitoring. In the critically ill pediatric population, procedures performed at the bedside expedite care and may reduce risks and logistical challenges associated with patient transport to a remote procedure suite such as interventional radiology (IR).

The use of ultrasound (US) guidance for central venous access is a readily learnable skillset with studies demonstrating short learning curve in trainees or less-experienced operators.¹,² Point-of-care ultrasound (POCUS) performed and interpreted by non-radiologist clinicians affords focused, expedient imaging assessment, may answer a clinical question, or may be used to provide procedural guidance. POCUS use in the pediatric intensive care unit (PICU) continues to increase as US become less expensive and more portable, as well as it becomes more incorporated into daily workflow.

In institutions with nascent POCUS-guided procedural experience, services may rely heavily on IR and transport of patients outside of the ICU for their procedural needs. IR services may be inadequately resourced for expanding services to the wards, inexperienced with line placement in the absence of fluoroscopic guidance, or both. Non-radiology specialists performing POCUS-guided procedures may benefit from the perspectives of interventional radiologists frequently performing bedside procedures using US alone. With this in mind, we present our institutional technique for US-guided tunneled femoral access in critically ill pediatric patients.

Technique

Patient selection and sedation considerations
Indications for central venous access, most often including inotropic infusion, parenteral nutrition, apheresis, and
hemodynamic monitoring, as well as optimal line size, optimal lumen number, point of access and patient mobility are verified interdisciplinary consensus following consultation. Initially, the proceduralist reviews the medical records and prior imaging to identify any procedural contraindications (e.g. known bilateral iliac venous or inferior vena cava (IVC) occlusions). While gaining experience, the authors have found it helpful to use prior abdominal radiographs to estimate appropriate catheter length. A sum of distances from the mid thigh to right-sided lumbosacral junction and lumbosacral junction to right atrium is determined. This expected length is then cross-referenced with measurements obtained intra-procedurally until the operator has developed a gestalt of appropriate line length for a given patient size.

A spectrum of situs abnormalities and variations in the retroperitoneal venous vasculature occur and will be encountered with greater frequency particularly in the cardiac intensive care population. These are best identified prospectively when possible. Techniques to overcome anatomic challenges are subsequently discussed.

**Planning imaging**

At a minimum, patency of the suprarenal IVC and common femoral vein (CFV) must be confirmed. Additional time invested confirming patency of the infrarenal IVC and iliac veins reduces technical failures resulting from unknown venous occlusions or congenital anatomic variation. The imaging techniques subsequently described balance expeditious procedural planning in the supine patient position used during line placement; they are not intended as a substitute for formal Doppler US evaluation.

Right-sided, mid-axillary US probe placement reliably produces excellent transhepatic visualization of the suprarenal IVC (Figure 1(a) and (b)). Axial and coronal US beam orientation provide transverse and longitudinal IVC views, respectively. While color Doppler imaging may be used to differentiate the IVC and aorta, a transhepatic course and continuity with the hepatic veins confirms IVC identification (Figure 1(c) and (d)). Continuity to the right atrium with US imaging is a less-reliable way to confirm the IVC due to diaphragmatic and pulmonary artifact. Choosing a transducer requires balancing the need for higher spatial resolution of high-frequency transducers and the increased depth of visualization with low-frequency transducers. Small footprint transducers are ideal when intercostal probe placement is necessary. For infants weighing less than 2 kg, the authors use microlinear L15-7 MHz or linear L18-4 MHz transducer (Philips Medical Systems, Andover, MA, USA), and for infants and children weighing 2–20 kg a curvilinear C9-2 MHz or micro-curvilinear C8-5 MHz transducer (Philips Medical Systems). Many ICUs have access to an US machine but usually only have a few transducers from which to choose. An intermediate frequency transducer such as a curvilinear or phased array transducer can generate the necessary images to evaluate the IVC. From the longitudinal suprarenal IVC view, panning inferiorly toward the iliac crest is used to assess the infrarenal IVC all the way to the level of the iliac venous confluence unless obscured by overlying bowel gas. While the procedure is primarily performed in children less than 1 year of age, it may be accomplished in older children who are too unstable to leave the ICU. For children weighing more than 20 kg, a wide variety of low-frequency transducers may be used for greater depth of visualization.

For femoral vein evaluation, the authors evaluate the vessel in longitudinal and axial views with a microlinear L15-7 MHz transducer (Philips Medical Systems), but another high-frequency linear transducer can also be used. The confluence of the greater saphenous vein demarcates the junction of femoral vein of the thigh and CFV. In a longitudinal view, panning superiorly toward the umbilicus brings the external and common iliac veins (CLVs) into view.

**Patient preparation**

At the authors’ institution, patient sedation is performed under the supervision of the intensivist and balances procedural success with patient safety. In children less than 1 month of age, single use 24%-sucrose solution (Sweet-ease) and local anesthetic may suffice for procedural sedation. For patients older than 1 month, intravenous opiate and/or benzodiazepine increase procedural tolerance. Intranasal midazolam may be administered in those without vascular access. Neuromuscular blockade, infrequently needed for children who are less than 6 months of age or otherwise opiate-naive, is reserved for patients with secured airways and ongoing agitation compromising procedural success. A mobile sedation team, utilizing nitrous oxide in addition to the above agents, is currently being explored.

Skin preparation is performed in accordance with institutional guidelines. Soft restraints are important to limit extremity motion, particularly hip flexion, for patients who will not be receiving deep sedation and or paralytic. A single field extending from knee of the accessed extremity inferiorly to the mid chest superiorly affords imaging of the entire access and line course (Figure 2(a)). Silicone foam dressing (Mepilex®, Mölnlycke Health Care, Gothenburg, Sweden) may be applied as an additional skin barrier in cases of prematurity or other skin fragility.

**Tunnel planning**

The microlinear L15-7 MHz transducer is placed at the level of the CFV and oriented for longitudinal imaging of the vessel to determine the level of vessel entry. A coplanar
tunnel is planned and demarcated on the skin, extending from the anteromedial surface of the lower thigh. The tunnel is anesthetized with lidocaine 1% (maximum dose 3.5 mg/kg).

Vascular access
A 7 cm 21 gauge needle (Micropuncture Introducer Set: Cook, Bloomington, IN, USA) provides sufficient tunneling length in most cases. The long bevel needle option
Figure 2. Vascular Access: A 1-month old, former 23-week premature infant requiring venous access for respiratory failure. Long bevel (lower) compared to standard variety (upper) of a 7 cm 21-gauge access needle (a) before and after a gentle curve has been applied to the proximal segment of the needle (b) (Cook, Bloomington, IN, USA). A soft restraint is placed on the right lower extremity followed by prep and drape of the extremity and right abdomen. A 5- to 6-cm tunnel demarcated on the skin, anesthetized and created using a curved 7 cm 21-gauge needle (c). Longitudinal grayscale ultrasound image centered at the saphenofemoral junction (d). The 21-gauge access needle is advanced in plane and into the common femoral vein (e). The 0.018-inch measuring wire is introduced and observed to course smoothly into the external iliac vein (f). Longitudinal grayscale ultrasound image of the inferior vena cava (IVC) demonstrating wire tip at the hepatic vein confluence (g) followed by placement of a 1.9 French single lumen catheter to the same level (h). Orthogonal, transverse view further confirms position and visualizes the relation of IVC to aorta (i).
makes it well suited for longitudinal plane access of small vessels (Figure 2(a)). Placing a gentle curve along the proximal third of the needle shaft allows for flattening and advancement of the needle coaxially along the vessel at the point of entry (Figure 2(b)); sufficient flattening of a straight needle may be infeasible due to contact with hub and the thigh or knee.

The needle is advanced in a subdermal, extra-fascial plane visually until the margin of the US field of view (Figure 2(c)), steepened and directed to the point of vessel entry under US guidance (Figure 2(d)), then flattened and advanced into the vessel (Figure 2(e)). A 0.018-inch measuring wire is advanced to a depth of 12–20 cm based on patient size; sonographic visualization of wire entry and tactile feedback provide confirmation of initially appropriate course (Figure 2(f)).

Transabdominal visualization then confirms IVC access (Figure 2(g)). Gentle, sub-centimeter inward and outward wire movements are useful to differentiate wire tip visualization, ideally positioned adjacent to the hepatic venous outflow. After IVC access is confirmed, a small dermatotomy is made over the needle. When multiple US probes are in use, an assistant changes probe selection and settings. Others may prefer a sterile US control cover to make these adjustments themselves.

**Line placement**

Line selection balances acute intravascular therapy needs and risk of thrombosis and chronic occlusion. The authors typically place 1.9 French single lumen, 2.6 French double lumen, 3 French single lumen, and 4 French double lumen non-cuffed polyurethane catheters. Exchange of the measuring wire for a 0.010-inch stainless steel wire is performed prior to over-the-wire placement of 1.9 French or 2.6 French catheter. The 3 French catheter may be placed directly over the 0.018-inch measuring wire. The 4 French double lumen catheter is placed over the wire through the included 4.5 French peel-away sheath. Available 2.6 French double-lumen catheters are typically placed via included introducer needles which are of insufficient length for the described tunneling technique; the authors access in the described technique and then place this particular line through a separately packaged 3 French peel-away sheath.

Transabdominal imaging is used to confirm catheter tip placement, obviating post-procedure radiography in most cases (Figure 2(h)). Careful panning in the longitudinal view helps distinguish true catheter tip from a cross-section of the catheter producing a false tip appearance. Orthogonal, transverse plane imaging is useful to confirm the tip position as well as IVC, rather than aortic, catheterization (Figure 2(i)). The catheter is then secured with either 3-0 monofilament sutures or an adhesive retention device on the basis of unit preference.

**Pitfalls and troubleshooting**

**Anatomic variation.** While thorough pre-procedure review of the related imaging helps in prospective identification of anomalies, others will be discovered on planning US (Figure 3). Situs inversus will necessitate midline or left-sided transabdominal imaging during line placement. While a left-sided IVC will typically drain to the left-renal vein and then orthotopic suprahepatic IVC, relative tortuosity of the access course may create procedural challenges.3 Azygous continuation of the IVC will display absence of the abdominal IVC, atrial drainage of the hepatic veins and a large ascending vein in the retrocrural space (Figure 3).

**Difficult advancement.** Blood return cannot always be relied upon for confirmation of vessel entry; uninhibited advancement of wire with US visualization confirms appropriate passage. Early resistance and wire buckling (<2 cm from needle tip) typically indicate a subluminal or extravascular position. Initially smooth entry followed by resistance (depth 2-8 cm) generally indicates an intravascular position with venous tributary wire entry. Commonly encountered non-target wire positions include inferior epigastric vein (Figure 4), pelvic tributaries and paravertebral/lumbar veins. Careful wire repositioning through the needle may suffice. In other cases, the authors will exchange the needle for the 3 French dilator of the Micropuncture Introducer Set and redirect the wire under US guidance. A pre-shaped, hydrophilic 0.018-inch Glidewire (Terumo, Somerset, New Jersey) may be useful to negotiate past tributaries. Once IVC access has been achieved, the dilator is advanced into the IVC and the Glidewire is exchanged for the measuring wire.

**Wire loops.** Loops forming along the distal wire will occasionally form as the wire is advanced. The leading edge of the loop may resemble the wire tip, resulting in falsely long wire measurements if not recognized. Gentle panning of the US on longitudinal view help distinguish a looped wire from the wire tip. The loop itself may be visualized (Figure 5) or, more commonly, parallel segments of the wire as it doubles back in the IVC. Transverse views of the closed aspects of the wire will demonstrate two sections of wire loop. Maneuvers to reduce wire loops include external rotation of the wire, wire translation across the ostia of large tributaries (eg hepatic, renal veins) and transient advancement of the wire into the atrium.

**Non-visualized wire.** Wires passed to an appropriate depth (12–20 cm) must be confirmed within the IVC prior to line placement. Potential etiologies of a nonvisualized wire include extravascular position, lumbar, or epidural venous plexus, and arterial access. Portable radiography to assess wire position should be performed rather than “blind” line placement.
Discussion

Central venous catheter (CVC) insertion is performed millions of times per year with a majority of CVCs being peripherally inserted central catheters (PICC).4 In pediatrics, tunneled CVCs make up 6.3% of all central venous access lines.5 There are multiple potential access sites (internal and external jugular, subclavian, axillary, and femoral); however, femoral vein access is reported as the most common site for central venous access in children with benefits including
readily identifiable anatomic landmarks, lower risk profile and a higher prevalence of operator experience at this site.6

Aside from totally implanted CVCs, access can be with a tunneled or non-tunneled technique. The latter is typically reserved for urgent or short-term situations and is most commonly used by ICU providers. Femoral venous catheterization can be performed at the bedside with either anatomic landmarks alone or with US guidance, or in the surgical operating room/IR suite. Creating a skin entry site remote from the inguinal diaper area theoretically reduces the rate of central line–associated blood stream infections. Despite the previously proposed benefits of tunneling the device, placement of tunneled catheters has classically been considered a more invasive procedure requiring surgical or interventionalist expertise. The single-access tunneling technique, however, may be easily adopted by an intensivist experienced with US.

Recent studies have demonstrated no statistical difference between complication rate of placement at the bedside compared to the IR suite.7-11 Another study showed a bedside PICC program could be implemented with pediatric critical providers providing PICC placement at bedside after completing 10 observed PICC line placements under IR supervision12. And in regards to bedside performance, Lau and Chamberlain performed a meta-analysis of published pediatric randomized clinical trials concerning central venous access, which found a 31.8% increased success rate with US guidance and significantly less puncture attempts.9,13,14 IR services traveling to the bedside may realize service-line efficiencies as an added benefit.15 The use of US would also be consistent with the principles of keeping radiation dose as low as reasonably achievable (ALARA) and the imaging gentle alliance.16,17

Conclusion

The use of US guidance for central venous access is a readily learnable skillset with studies demonstrating short learning curve in trainees or less-experienced operators. Critical care providers and IR physicians can use this technique at the bedside to quickly and efficiently place tunneled central lines, potentially improving patient care from decreased resource utilization in the IR suite and decreased need for patient transportation, while still providing safe reliable central venous access.

Declaration of conflicting interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

Statement of ethics

All authors have read and contributed to this manuscript. All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Informed consent was waived from all individual participants included in the study.

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The Journal of Vascular Access 00(0)

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