Vascular Access in the Pediatric Population

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KEYWORDS

• Vascular access • Central venous catheter • Ultrasound

KEY POINTS

- The selection of the appropriate central venous catheter requires knowledge of the indication for placement and the intended duration and frequency of use. Clear communication between the surgeon and the primary provider requesting the catheter is essential to performing the correct procedure.
- Seldinger or modified Seldinger technique is preferred for nearly all vascular access procedures. The authors recommend use of a 21-gauge (g) or 22-g access needle and thin (0.018-in) flexible-tip wire to establish access.
- Ultrasound guidance improves the safety and ease of most vascular access procedures. Transverse or in-line transducer orientations can be used depending on the anatomy and approach.
- Most central line–associated blood stream infections (CLABSIs) require catheter removal. Blood cultures should be negative for at least 48 hours before placing a new line except in rare circumstances.

INTRODUCTION

Vascular access procedures are a common and important part of pediatric surgical practice. Children require vascular access for numerous indications, including hydration, infusion of parental nutrition, administration of medications, and obtaining blood for laboratory analysis. Advances in vascular access have made many disease processes, such as intestinal atresia, short bowel syndrome, and various malignancies survivable.

Pediatric vascular access presents numerous challenges to the pediatric surgeon. In obtaining access, the pediatric surgeon must make several important preoperative

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decisions – what type of access to obtain, the size and number of lumens required, and where to place the catheter. Therefore, sound knowledge of the indications, contraindications, advantages, and disadvantages of different types of access is required to provide the best care for the patient. This article addresses these questions in decision making and presents the basic tenets of vascular access in children and how to manage this access postprocedurally. The majority of the article focuses on central venous access, but arterial access, peripheral venous access, and peripherally inserted central catheters (PICCs) are addressed as well.

SURGICAL TECHNIQUE

Preoperative Planning

Peripheral venous access

Peripheral venous access could be considered the mainstay of vascular access during hospital admission, because it is nearly ubiquitous in inpatients. Peripheral access is adequate for intravenous (IV) hydration, most medication administration, and often blood sampling. It is usually more technically straightforward and safer than central access and can be performed at the bedside without anesthesia, although topical analgesics are often helpful.

Peripheral access is often obtained by other skilled members of the patient care team, such as nurses and anesthesia staff. Peripheral venous access can be challenging, however, in children, and a pediatric surgeon may be called on if others are unsuccessful in obtaining access. Pediatric veins are small in caliber and often difficult to see and feel, especially in a patient who may be dehydrated. It is, therefore, helpful to be familiar with the anatomic locations amenable to peripheral IV insertions as well as the technology available to assist with access.

The anatomic options for peripheral IV insertion are summarized:

- Scalp: generally limited to neonates.
- External jugular vein: of adequate size and visibility but frequently difficult to access due to excessive mobility, difficult location, and ease of compression, even with the access needle
- Superficial veins of the arm and dorsal hand/wrist: good targets for peripheral venous access; however, the antecubital fossa must not be crossed with the catheter unless the arm is immobilized
- Greater saphenous vein: often a good target, especially anterior to the medial malleolus. This is best visualized with the foot held in plantar flexion. In an emergency when no other peripheral access can be acquired, the distal saphenous vein also represents a good target for peripheral cut-down. This is performed via a small transverse incision medial and superior to the medical malleolus, with suture ligature and direct venipuncture.[1]

Technology can be used to aid in peripheral venous access. Ultrasound offers good delineation of vascular anatomy (**Fig. 1**). It can distinguish arterial from venous structures based on compressibility and pulsatility and with use of color flow Doppler. Recent studies have demonstrated that ultrasound use in peripheral vascular access increases accuracy and decreases attempts required.[2,3] More recent technological advancements have included infrared-based vein finders. This modality improves vein visibility, thereby increasing accuracy and decreasing the pain associated with access.[4,5]

Central venous access

Central venous access is required for the administration of several medications and fluids, including many vasoactive medications; hyperosmolar fluid, including total

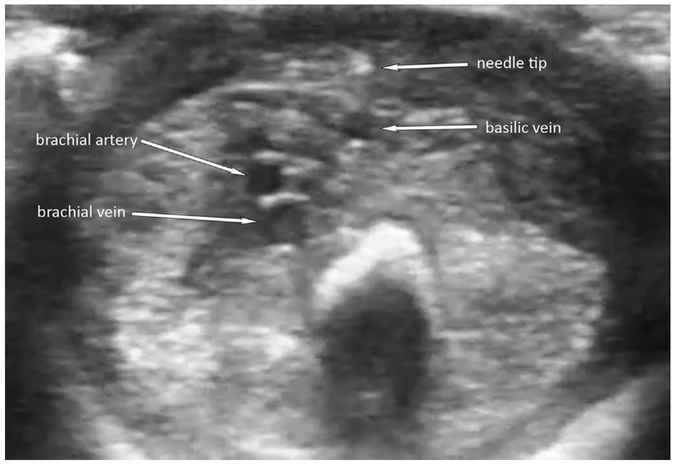

Fig. 1. Ultrasound image of upper arm anatomy. Note that in cross-section, vessels appear as anechoic circles. Arteries and veins can be differentiated by compressibility, pulsatility, and use of color flow Doppler. This particular image represented needle access to the basilic vein in a 460g premature neonate for PICC placement.

parenteral nutrition (TPN); and cytotoxic medications (most chemotherapy). Central access is also indicated any time venous access is required and peripheral access is unable to be obtained, which is a frequent challenge in the pediatric population. Central venous access can be approached in many different ways, however, depending on the medical therapy required. If a pediatric surgeon is not the primary provider using the catheter, clear communication between the primary provider and surgeon is essential to ensure the patient undergoes the correct procedure, with the correct catheter and number of lumens.

The types of central venous access are summarized in Table 1. The primary determinants in central venous catheter selection are intended duration and frequency of use. Central venous lines (CVLs) intended for long-term use, continuing after hospital discharge, are often tunneled under the skin to provide added stability. Cuffed CVLs, such as Broviac and Hickman catheters, exit the skin so they can be easily accessed, making them ideal for continuous use, such as for TPN. Ports, on the other hand, remain completely subcutaneous. This means needle puncture of the skin is required for use, but risks of infection and line damage are decreased. These ports are for long-term intermittent use, such as administration of chemotherapeutic drugs. Both these tunneled CVLs allow for more than 1 lumen if desired, depending on the intended medication administration plan.

Percutaneous, nontunneled CVLs are intended for acute use, generally during hospital admission. Similarly, acute hemodialysis lines allow for hemodialysis or plasmapheresis in the hospital setting in the absence of more durable access, such as an arteriovenous fistula or graft, but are not intended for long-term outpatient use. PICCs are more versatile. As the name implies, they are long, thin catheters inserted into a peripheral vein, with the tip in the central venous compartment. Their length and small diameter limit the flow they can tolerate, but they provide more stability and comfort than most percutaneous CVLs and, therefore, can be used in the outpatient setting for prolonged periods of time, such as during a weeks-long course of IV antibiotics.

Table 1
Types of central access

	Line	Duration of Use	Requires Operating Room?	Example Uses
Nontunneled	PICC	Intermediate to long term	No	Prolonged antibiotic administration (eg, after perforated appendicitis)
	Percutaneous CVL	Short term	No	Vasopressor or hyperosmolar fluid/medication administration as inpatient
	Acute hemodialysis line	Short term	No	Acute hemodialysis (no arteriovenous fistula/graft used)
Tunneled	Cuffed CVL	Long-term, regular use	No, but lower infection rate in operating rooms[6]	Prolonged/ outpatient parenteral nutrition
	Port	Long-term, intermittent use	Yes	Chemotherapy administration

Preoperatively, the surgeon must also decide where to place the CVL. Central access may be obtained via the external jugular or internal jugular (IJ) vein, facial vein, subclavian vein, saphenous vein or femoral vein, with the IJ, subclavian, and femoral the most common and well defined.[1] The advantages and disadvantages of each location are outlined in **Table 2**.

Table 2
Central venous line locations

Site	Advantages	Disadvantages
IJ vein	• Shortest distance to right atrium • Straightest route to right atrium • Decreased incidence of stenosis • Aided by use of ultrasound[7]	• Neck access, therefore potential discomfort • Line position may change with head movement (if placed high in neck)
Subclavian vein	• Short distance to right atrium • Relatively fixed position → comfort and line stability	• Ultrasound guidance precluded in subclavicular approach (must use landmarks unless approach from above clavicle) • Poor choice for dialysis access (higher stenosis incidence, difficulty with future AV fistula creation)
Femoral vein	• Relative ease of placement using landmarks • Aided by use of ultrasound[8]	Position in groin crease → limits comfort and mobility, decreases stability

Equipment

Access

Most venous access in children can be obtained with a 21-g or 22-g needle. Smaller needles preclude passage of all but the smallest guide wires and also risk bending on insertion. Larger needles present unnecessary risk of damage to nearby structure and the target vein itself. A 22-g needle allows passage of a 0.018-in coaxial wire. In the authors' practice, the 0.018-in Cope nitinol Mandril Wire Guide (Cook Medical, Bloomington, Indiana) is preferred. This wire has a flexible tip, which reduces risk of vascular damage from wire passage, but also a stiff shaft, which increases ease of dilator and catheter threading.

In general, J-wires or C-wires should be avoided in pediatric patients. Although the intention of these wires is to curl to form a blunt end while advancing the wire in adult patients, the radius of curvature is often too large for the size of a child's vein. This risks loss of access to the vascular lumen by the wire and needle.

Dilators and catheters

Once the target vein has been accessed by a 0.018-in wire, this can be exchanged for a larger, 0.035-in guide wire using a 3F to 4F dilator (3F dilator seated within a 4F dilator). These dilators are standardly included with the micropuncture vascular access kit. A 0.035-in wire allows for the passage of larger dilators. Depending on the catheter selected, the surgeon can then place the catheter directly over the wire (Seldinger technique) or place an introducer through which the catheter can be placed (modified Seldinger technique). In the very small vessels of the neonate, the catheters are made to go over smaller wires, such as 0.018-in and 0.010-in wires. In these cases, changing wire to 0.035 in is not helpful or necessary.

Ultrasound

Historically, central venous access was obtained using anatomic landmarks. The introduction of ultrasound guidance into the technique, however, has made the procedures safer and easier, particularly in children.[7,9,10] A high-frequency (7.5–20 MHz), linear array transducer is used because it gives best resolution without the need for significant tissue penetration.

It is important to clearly establish left-right orientation on ultrasound prior to attempting access (left side of the probe should be seen on the left side of the screen). Access is also aided by orienting the probe in such a way that the handle does not impede manipulation of the needle and wire. This is especially true of the hockey-stick probe, which has a handle that can be angled away from the working anatomy.

Fluoroscopy

Fluoroscopy is an essential tool for CVL placement in the operating room. It can be used to identify key landmarks before attempting access (eg, the carina in cases of IJ or subclavian access). It also guides wire advancement and dilator/peel-away sheath placement and ensures appropriate catheter position at the end of the procedure.

Preparation and Patient Positioning

Positioning

When ultrasound is used, the ultrasound machine should be placed across the table from the operating surgeon. The patient is placed supine on a radiolucent table for nearly all vascular access procedures in the operating room. The extremities are extended to optimize exposure if they contain the target vessel; otherwise, the arms are tucked. For jugular and subclavian access, the patient is placed in Trendelenburg position to distend target veins and prevent air embolism. A shoulder roll can be used to extend the neck and improve ease of access to the IJ; contrarily, the authors do not recommend use of a shoulder roll in subclavian access because it decreases the cross-sectional area of the subclavian vein.[11] Turning the head to the contralateral side is also helpful in IJ and subclavian access. Femoral vein exposure is aided by abduction and external rotation of the leg.

Sterile preparation

Standard skin preparation is used, in most cases consisting of chlorhexidine solution. Hats, masks, and sterile gloves and gowns are worn. If fluoroscopy is to be used, lead should be worn by all those in the operating room. Ultrasound requires a sterile probe cover, with nonsterile ultrasound gel directly on the transducer within the cover and sterile ultrasound gel available for use directly on the patient. Avoiding any air bubbles in the gel layer between the probe and the probe cover is extremely important because air causes shadowing and thus large areas of nonvisualization in the ultrasound field of view.

Procedural Approach

Cut-down technique

Historically, central venous access was obtained by surgical exposure of the target vessel. In this technique, a venotomy is performed, with or without proximal ligation of the vein, and the CVL placed. If the distal vein is not to be ligated, a lateral venotomy with a purse-string suture of 7-0 Prolene is used to secure the catheter. Anatomic targets of such cut-downs are the external jugular vein, facial vein, IJ vein just above the clavicle, and the proximal greater saphenous vein, with advancement of the catheter into the femoral vein. The greater saphenous vein still has some utility in critically ill infants requiring emergent access, but overall the cut-down technique has been largely replaced by percutaneous access.[1] Despite this, it remains an important technique that is indispensable in many circumstances.

Percutaneous technique – Seldinger and modified Seldinger

In 1953, Swedish radiologist Sven-Ivar Seldinger published a novel technique for vascular access involving a needle, a wire, and a catheter.[12] This technique, which now bears his name, has become the standard approach not only for vascular access but also for other percutaneous techniques, such as chest tube placement and biliary tract access.

The first step in Seldinger technique is access to the vascular lumen via needle venipuncture. As discussed previously, in children this can generally be performed with a 21-g or 22-g micropuncture needle. The bevel of the needle is oriented upwards. When using landmarks alone, a syringe is used and gentle suction applied so that successful luminal access is confirmed by the return of blood. When using ultrasound in the pediatric population, however, the authors recommend not using a syringe, because this hinders fine touch of the needle, and the suction applied by the syringe can cause vascular collapse and vasospasm. With the landmark technique, once blood is seen coming into the syringe, the syringe is taken off carefully without needle movement and a wire is advanced through the needle and into the lumen of the vessel.

When using ultrasound, needle tip entry into the vessel is visualized with the ultrasound. Once the needle tip is seen in the lumen of the vessel and the vessel wall is no longer tented (the needle has clearly pierced the wall as opposed to deforming it), the wire is advanced through the needle and into the vessel. For peripheral access, once the needle is noted to be in the lumen of the vessel, the needle is advanced some distances further (approximately 1 cm) down the barrel of the vessel lumen under ultrasound guidance. This prevents ejection of the needle and/or wire if the vessel spasms, a common phenomenon in children, especially newborns. It also ensures that the needle has not tented the vessel wall and ensures intraluminal location of the needle and/or catheter tip. This strategy has been shown to reduce the risk of extravasation during peripheral venous access.[13]

With the needle well into the vessel lumen, the wire is advanced. Care should be taken not to attempt to force the wire past any resistance. If resistance is met, ultrasound or fluoroscopy should be used to confirm proper wire placement and to guide advancement.

Once the wire is in place, maintaining control of its position becomes the surgeon's top priority. A small skin nick is made with an 11 blade adjacent to the wire, avoiding any skin bridge between the two. Dilators are passed over the wire to expand the tract to the necessary size. Preferably, serial dilation should be performed under fluoroscopy. Once the tract is appropriately dilated, the catheter is advanced over the wire. Proper position is confirmed with ultrasound and/or fluoroscopy, and the catheter is secured at the skin.

A modification to the Seldinger technique can be applied with silastic catheters, which are sometimes difficult to place bareback over a wire. In this situation, a combination introducer sheath and dilator is placed over the wire into the vein lumen. The wire and dilator are removed simultaneously, leaving the introducer in place. A finger is quickly placed over the opening of the introducer to prevent back-bleeding. The silastic catheter can then be advanced through the introducer into the vein lumen. Most introducers can then be split and peeled down their length to be removed around the catheter.

Anatomy

Prior to the widespread use of ultrasound, anatomic landmarks were the primary guides to central venous access. Although ultrasound has improved the accuracy, ease, and safety of these procedures, knowing the anatomic landmarks is still important to performing these procedures safely. The landmarks for the common sites of access are as follows:

- IJ vein: the right side provides a more direct route to the heart. The needle is inserted into the skin at just below the confluence of the sternal and clavicular heads of the sternocleidomastoid, directed inferiorly toward the ipsilateral nipple at a 30° angle to the skin.
- Subclavian vein: the skin is punctured just below the clavicle, approximately two-thirds of the distance from the manubrium to lateral clavicular head. The needle is directed medially toward just above the sternal notch, also at a 30° angle from the skin. Pushing down on the needle and taking a shallower approach may help avoid lung injury. Ultrasound is not as useful when using this subclavicular approach but does have utility if the subclavian vein is to be accessed from a supraclavicular approach. The subclavian vein can also be accessed with ultrasound guidance in larger patients near the deltopectoral groove.
- Femoral vein: the femoral artery is palpated just below the inguinal ligament approximately one-third of the way from the pubic tubercle to the anterior superior iliac spine (ASIS). The femoral vein lies just medial to this. The skin is punctured well below the inguinal ligament, with the needle directed toward the umbilicus at a 30° angle to the skin In neonates, the femoral vein tends to lie more posterior than medial to the femoral artery (**Fig. 2**A, B). In this situation, the needle can be inserted medial to the artery, then pushed laterally and advanced further into the vein. This technique, however, requires ultrasound guidance, as seen in **Fig. 2**C.

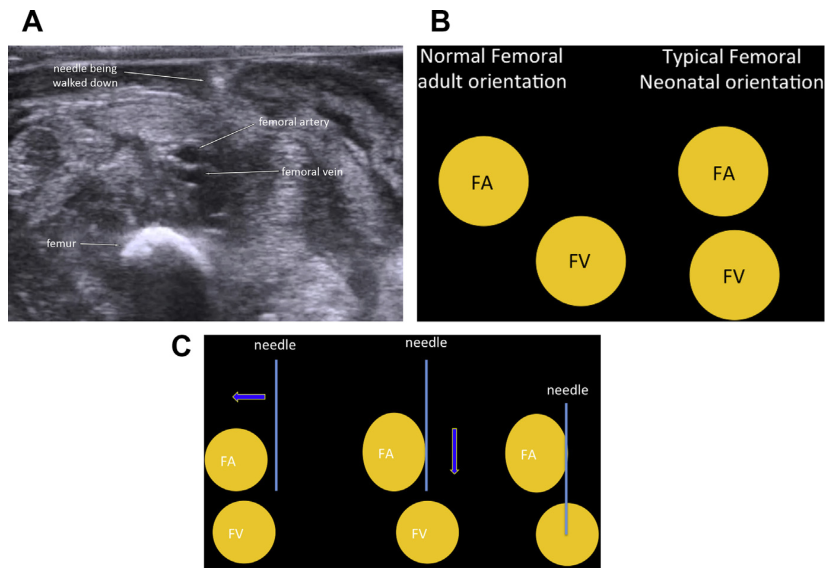

Fig. 2. Femoral access. (*A*) Ultrasound view of femoral vessels in a neonate. (*B*) Unlike in adults in whom the femoral vein (FV) lies medial to the femoral artery (FA), the femoral vein in the neonate tends to lie directly deep to the artery. (*C*) The femoral vein can be accessed in neonates by inserting the needle just medial to the femoral artery under ultrasound guidance. Once the tip of the needle is just deep to the artery, the needle can be moved laterally to push the artery aside and align the tip over the femoral vein.

Ultrasound use

Ultrasound can be immensely helpful in accurate vascular access, and the American College of Surgeons recommends use of real-time ultrasound for central venous catheter placement.[14] Like any technical skill, however, ultrasound-guided line placement requires training and practice. With enough experience, ultrasound increases the safety, accuracy, and success of central venous catheter placement.

Ultrasound displays 3-D structures in 2 dimensions. Therefore, when trying to access a vessel, the operator must choose to view the vessel transversely (as a cross-section or circle) or longitudinally (as a line). The third dimension can be obtained by moving the transducer perpendicular to its linear axis. This requires constant spatial reconstruction, however, within an operator's mind and complicates needle placement for anyone but an experienced surgeon. The procedure is simplified by using ultrasound in 1 of 2 orientations: transverse or in-line.

Transverse orientation The transducer head is oriented perpendicular to the vessel and needle axis, producing a cross-sectional view of both. The needle is inserted at a 45° angle at the midpoint of the transducer, producing excellent left-right resolution. Because the needle is seen in cross-section, however, it appears as only a small point on the display, with the location/depth of the needle tip unknown. This can be remedied by regularly sliding the transducer down the trajectory of the needle past the tip until it disappears and then back until it reappears, so that the tip location is known as the needle is walked down into the vessel. Use of the transverse orientation for IJ access is seen in Fig. 3A, B and for PICC placement in a neonate in Fig. 3C.

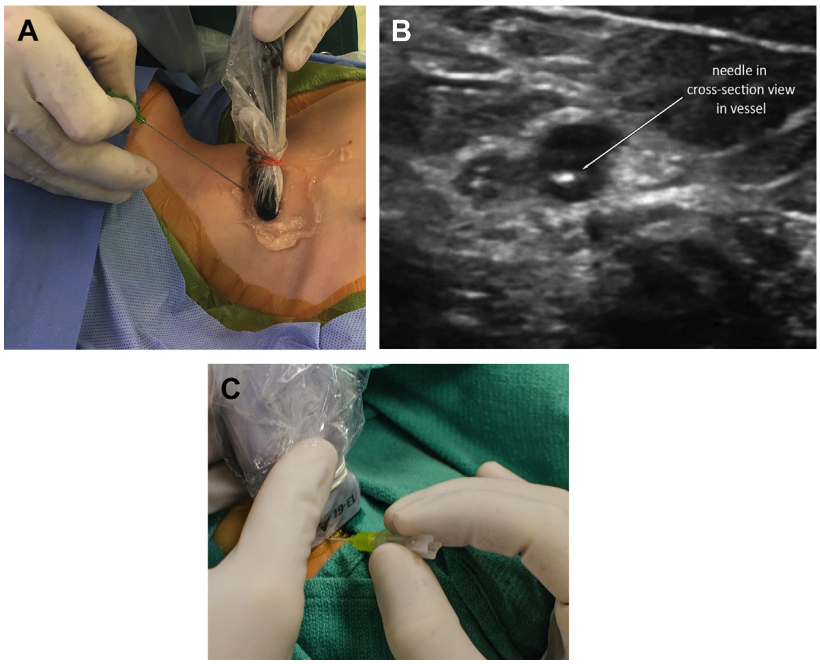

Fig. 3. Transverse transducer orientation. (*A*) The ultrasound transducer is oriented perpendicular to the vessel (here the IJ) and the needle placed under the center of the probe. (*B*) The needle is seen in cross-section within the vessel lumen. Therefore the full length is not visualized. (*C*) The needle is inserted at 45° to the skin at the midpoint of the transducer. The transducer is walked down the needle to identify the tip.

In-line orientation The ultrasound probe is oriented parallel to the needle axis. This enables visualization of the entire length of the needle. The needle can then be advanced with the tip's location known relative to nearby major structures. This orientation is ideal for IJ access, because inadvertent puncture of the carotid artery or lung can be avoided (**Fig. 4**). A common mistake using this approach is to lose sight of the needle itself and to instead view the movement of the surrounding tissue. Losing clear visualization of the needle tip defeats the purpose of in-line orientation yet is easy to do with subtle movement of the transducer. This approach requires patience, because fine adjustments of the transducer head keep it aligned directly over the needle trajectory.

Tunneling technique

When durable, long-term central access is required, tunneled IJ venous catheter placement is the procedure of choice. A subcutaneous tunnel is created from the point of access (the lateral IJ just superior to the clavicle) laterally over the clavicle and inferiorly to the anterior chest to either an external hub or to a subcutaneous port. The course of the tunnel is important, because an acute bend can lead to kinking and occlusion of the catheter, whereas tracking too high in the neck can lead to catheter malposition with head movement.

Access to the IJ is obtained using the in-line probe orientation to allow full visualization of the needle (see **Fig. 4**). The linear array, hockey-stick probe is placed just superior to the clavicle, revealing the distal IJ, subclavian vessels, the carotid artery, and

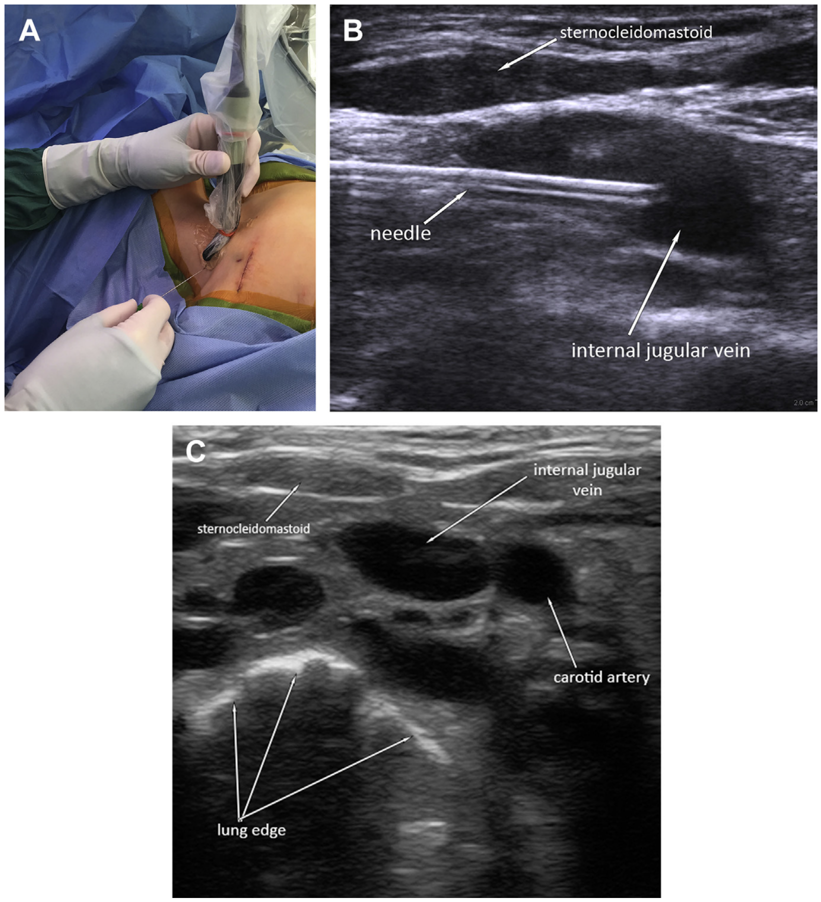

Fig. 4. In-line transducer orientation. (*A*) The needle is inserted parallel to the transducer head, starting from the end opposite the hand when using a hockey stick probe. In this case, the target vessel is the IJ. (*B*) In-line orientation allows visualization of the length of the needle. For IJ access, the needle is inserted lateral to the sternocleidomastoid muscle and advanced deep to the muscle into the vein. (*C*) Ultrasound can be used in in-line orientation to identify and avoid damage to surrounding structures. The IJ lies anterolateral to the carotid artery. The apex of the lung is seen as a bright interface between soft tissue and air.

often the brachiocephalic vessels. The needle is advanced in-line, taking care to avoid damage to the lung, carotid, or external jugular vein. Once the needle is intraluminal, the wire is advanced. With the lateral approach, occasionally the wire is advanced cephalad up the IJ, which can be seen on fluoroscopy. If this occurs, the needle tip should be confirmed to remain intraluminal with ultrasound, and, if so, the wire can be withdrawn and the needle angled inferiorly down the IJ. The needle then guides the wire in the proper direction with readvancement, again confirmed with fluoroscopy.

With the wire in place, the subcutaneous tunnel is created from the chest wall incision to the neck incision. Care is taken to avoid any sharp angles in the tunnel course, instead taking a gentle curve (Fig. 5A, B). Using a low, lateral neck access incision facilitates this.

Ideal catheter position is with the tip at the cavoatrial junction. This can be approximated on fluoroscopy as 1.5 to 2 vertebral bodies inferior to the carina (Fig. 5C). Therefore, before placement through the introducer into the IJ, the catheter is placed through the subcutaneous tunnel, and the appropriate length assessed by laying the catheter on the patient's chest while using fluoroscopy. The catheter is then cut to length and advanced through the introducer. The introducer is removed, and proper position is confirmed with fluoroscopy.

Peripheral vascular access

A similar technique can be used for both peripheral venous and arterial access. In general, the transverse ultrasound orientation is used. A helpful technique in aligning the needle is to generously apply gel to the skin overlying the vessel and then place the needle flat against the skin directly under the transducer. This creates a shadow under the needle that can be aligned directly over the vessel (Fig. 6). Once this appropriate

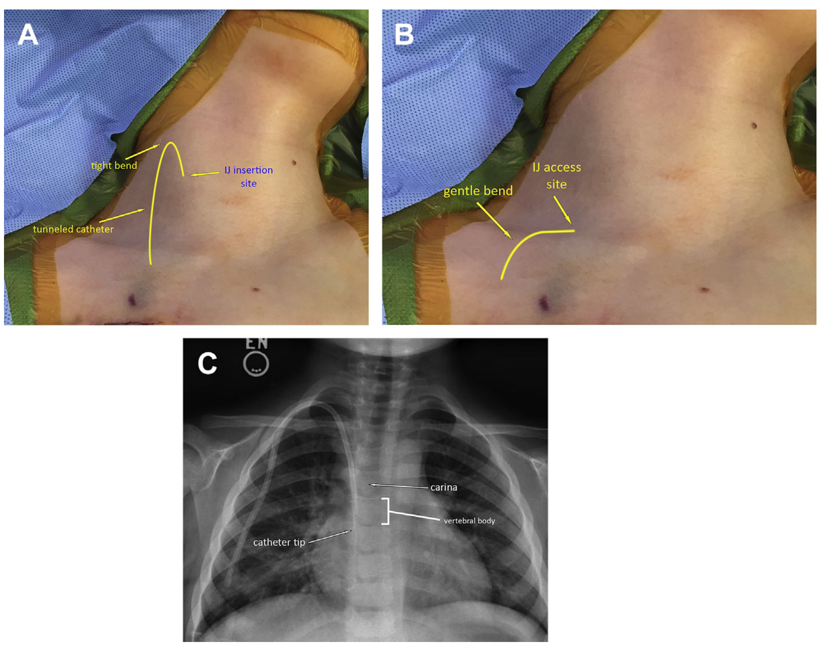

Fig. 5. Tunneled IJ catheter placement. (*A*) The standard IJ approach uses transverse probe orientation and a craniocaudal needle approach. This results in an acute angle of the tunneled catheter high in the neck and risks kinking of the catheter. (*B*) Using a lateral IJ approach with in-line transducer orientation allows for a low insertion, just above the clavicle, and a gentle curve of the tunneled catheter. (*C*) The postprocedure chest radiograph using this low lateral approach to the IJ confirms a gentle curve to the tunneled catheter without kinking. The tip of the catheter is seen at the cavoatrial junction, 1.5 to 2 vertebral bodies below the carina.

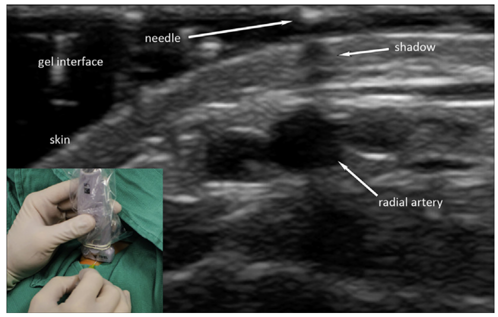

Fig. 6. Peripheral access. Using transverse transducer orientation, the needle can be placed flat against the skin directly against the skin under the midpoint (inset) of the probe. This creates a shadow, which, once aligned over the target vessel, increases the accuracy of insertion when the needle is advanced through the skin.

needle orientation is established, the needle can be angled down 45° into the skin and advanced. The tip of the needle can then be walked down to and into the target vessel with the transducer, as described previously.

Peripherally inserted central catheter

PICCs are long, thin, flexible catheters that provide added versatility because they are functionally central venous catheters but are inserted peripherally. They are made in a variety of sizes, as small as 1.9F (26 g) and can be placed through a peel-away sheath introduced with a 23-g needle in modified Seldinger fashion. They can be placed into essentially any vein into which a peripheral IV can be inserted, provided the catheter is long enough to reach the central venous compartment from that location. The basilic vein is a common target for PICC placement, because it empties directly into the axillary vein without any acute angles, allowing ease of catheter passage (see Fig. 1).

Immediate Postprocedural Care

In the immediate postprocedure period, any early complications must be assessed for. For vascular access procedures performed in the operating room, a brief period in the postanesthesia care unit enables close observation to rule out complications related to bleeding or anesthesia. In cases of IJ and subclavian access, regardless of where the procedure was performed, a potential early complication is pneumothorax. Therefore, routine chest radiograph should be obtained after these procedures. The chest radiograph also provides confirmation that the tip of the catheter remains in the appropriate location. In general, the line can be used immediately after placement.

REHABILITATION AND RECOVERY

Recovery

Perhaps with the exception of cut-down procedures, vascular access is minimally invasive and well tolerated. Pain is generally mild, and there are few or no limitations on routine activity. If a patient is going to be discharged with the line, the family should be educated well about care of the site as well as how to handle common issues, such as catheter damage or occlusion. These complications are discussed later.

Removal

Indications for catheter removal depend on the type of catheter and its intended use. Line infection or damage may require removal and are discussed later. Peripheral IVs and CVLs should be removed prior to hospital discharge. In general, other lines may be removed when they are no longer needed.

The complexity of catheter removal also depends on the type. Percutaneous CVLs and PICCs can generally be removed simply by pulling them out with the patient bearing down and then holding gentle pressure to ensure hemostasis. Cuffed CVLs require local anesthesia at the insertion site (children often also require sedation or general anesthesia), because the cuff induces scar formation and must be dissected free from the catheter, which can cause pain. Ports often require general anesthesia in children because removal is more invasive, requiring surgical excision of the subcutaneous port, which is sutured to the pectoralis fascia.

Occasionally, a long-standing catheter is unable to be extracted. This indicates that the catheter has adhered to the venous endothelium. If the catheter cannot be removed by gentle, constant pulling, the surgeon should immediately place a wire down the catheter, ideally with the tip of the wire well into the inferior vena cava, before using any aggressive moves to remove it. If the catheter breaks, the wire maintains vessel access and can aid in retrieval with snare in interventional radiology. Although there is some suggestion that catheters that break on removal are secured and do not embolize to the lung, the authors' experience has shown the contrary on multiple occasions and, therefore, these catheters should be retrieved when possible.

POTENTIAL COMPLICATIONS/MANAGEMENT

Early Complications

Early complications of vascular access procedures generally involve damage to nearby structures. Because the IJ, subclavian, and femoral veins are all accompanied by major arteries, arterial injury may result from central venous access. The risk of such complications can be reduced by using ultrasound guidance and a small access needle. If access is performed without ultrasound guidance, needle advancement should always be straight without lateral sliding or torque, and, if adjustment is needed, the needle should be withdrawn straight out. With ultrasound guidance, however, the needle can be directed at will if needle and surrounding structures are clearly visualized.

If arterial injury is suspected, management depends on the size of the needle used. A micropuncture needle can be withdrawn with subsequent pressure, which is usually adequate to obtain hemostasis. If the needle is large bore, it should be left in place, because it is likely plugging the hole and preventing more dramatic hemorrhage. Imaging should then be obtained (radiograph or fluoroscopy). If this supports arterial injury, surgical removal may be indicated to allow repair of the arteriotomy. Femoral arterial injury is more easily controlled than carotid or subclavian artery injury, so in this case the catheter may be removed and firm pressure held.

With IJ and subclavian access, the pleura may be damaged by the access needle as well. This risk is elevated in patients undergoing positive pressure ventilation, because the apex of the lung reaches the lower neck. Chest radiographs should be obtained routinely after these procedures to rule out this complication.

Late Complications

Line malfunction/damage

Damage to cuffed CVLs is common, given the exposed portion of the catheter and activity level of young children. Silastic catheters can usually be repaired using available kits, provided the damage is at least 5 cm from the skin. A study in intestinal failure patients showed that there is no increased risk of infection with line repair.[15] If a catheter cannot be repaired, replacement may be necessary. In this case, as long as the catheter is not infected, it may be exchanged over a wire.

Line thrombosis/occlusion

Line thrombosis occurs more commonly in children with cancer. Tissue plasminogen activator may be successful in cases of catheter thrombosis. Occlusion due to lipid or mineral deposits may be cleared with 70% ethanol and hydrochloric acid, 0.1 N, respectively, with varying success. If medical therapy is ineffective, catheter removal and replacement may be necessary.

Perforation

Perforation of the superior vena cava or right atrium by a central venous catheter is extremely rare. Incidence in the literature ranges from 0.0001% to 1.4% but is likely under-reported.[16] The choice of catheter material (silastic vs polyurethane) does not seem to affect perforation risk.[17] The risk of perforation, however, is slightly higher with PICCs than with CVLs inserted via the IJ or subclavian.[18] Placement in the right IJ provides least risk of this terrible complication due to its straight course, because the side of the catheter tends to contact the vessel wall as opposed to the tip. Perforation below the pericardial reflection can cause tamponade but above the reflection can cause exsanguination into the pleural space. It is likely the whipping of the catheter during systole that causes erosion and perforation, so the tip should be placed near the cavoatrial junction.

Vessel thrombosis/stenosis

Vessel thrombosis due to central venous catheters can occur, especially in children with cancer. When possible, treatment involves removal of the offending line. Venous stenosis is uncommon, but more likely to occur with subclavian than IJ access.

Infection

There are 3 types of infection associated with central venous catheters: exit-site infection, tunnel or pocket infection, and CLABSI.[1]

- Exit-site infection: involves skin at the exit site of the catheter. Generally the causative organism is a skin pathogen. This usually can be treated with antibiotics and local wound care.
- Tunnel/pocket infection: more serious than an exit-site infection, this involves infection of the subcutaneous tunnel. Signs include erythema, induration, and excessive tenderness along the tract as well as expression of pus from the exit site. Antibiotic penetration is generally poor and lack of treatment can progress to systemic sepsis, so line removal is usually indicated.
- CLABSI: the most serious of the catheter-related infections, CLABSI can lead to systemic sepsis. External signs may be absent, and cultures from both the central line and peripheral site(s) are necessary.

CLABSI represents a major concern in patients with indwelling central access. Risk factors include neutropenia and TPN.[19] It was previously thought that femoral lines bore a higher risk of CVL infection. Recent studies, however, including a Cochrane review in adult patients, do not support this claim.[6,20] A 2011 systematic review identified the following strategies for preventing CLABSI in children:

- Chlorhexidine skin preparation and chlorhexidine-impregnated dressing
- Use of heparin and antibiotic-impregnated central venous catheters

- Use of ethanol lock or vancomycin lock therapy[21]

In cases of a suspected infected catheter, peripheral and central blood cultures should be drawn prior to initiating empiric antibiotics. Antibiotics are sometimes sufficient treatment. If bacteremia has not cleared after 72 hours of therapy, however, the catheter should be removed. Catheter removal is also required if the causative organism is *Staphylococcus aureus, Bacillus cereus,* fungus, or other resistant organisms.

If a catheter is removed due to infection, a new line should not be placed until at least 48 hours after the first negative blood culture and should be placed at a new site. In rare cases, if preservation of the catheter is critical and bacteremia has responded to antibiotics, the line may be exchanged over a wire. This practice, however, remains controversial.

SUMMARY

Vascular access procedures in children are a mainstay of the pediatric surgeons practice. Most procedures can be performed percutaneously by the Seldinger or modified Seldinger approaches. Although vascular access can be challenging, the use of imaging technology, such as ultrasound and fluoroscopy, increases the safety and ease of these procedures. Ultrasound, in particular, decreases complications associated with vascular access but requires patience and experience. Today's pediatric surgeon should be comfortable performing these procedures using this technology and should be able to diagnose and treat the common complications.

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