Special Populations: Pediatrics

8

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Introduction

Obtaining emergent vascular access for pediatric patients poses additional challenges beyond those routinely encountered with adult patients, including anatomical differences, difficulties restraining patient movement during cannulation procedures, and parental anxiety [1]. Anatomical considerations for pediatric subjects include greater head-to-body size ratio, excess superficial soft tissue, increased tissue softness, and smaller, more compressible vasculature. These differences impact both landmark identification and cannulation success rates for pediatric patients [1, 2]. Practical concerns relating to these anatomical differences will lead providers to consider the benefits and risks of vascular access differently for pediatric subjects. This chapter summarizes the key considerations when attempting emergent vascular access for pediatric patients, with a special focus on how pediatric venous access techniques differ from those used with adult subjects.

The type and gauge of vascular access device (VAD) recommended for pediatric subjects differs according to the age of the patient. It is important to remember that pediatric patients have smaller blood vessels than adults, which influences the gauge of catheter recommended. A balance should be sought between providing adequate

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capacity for flow and avoiding complications related to an excessively large cannula. In general, a cross-sectional *catheter-to-vein ratio (CVR)* of <50% is recommended for pediatric patients and <33% for neonates [3–5]. Larger CVRs may predispose to venous thrombosis and phlebitis [3, 4], while exceedingly small-caliber catheters are predisposed to catheter occlusion [5].

Certain definitions for the various classifications of pediatric subjects must be familiar to the emergent access provider. *Neonates* are generally defined as pediatric subjects within the first 28 days of extrauterine life, while *infants* are those subjects less than 1 year of age [6]. Children born prematurely (<37 weeks' gestation) or with low birth weight (<2500 grams) generally have decreased whole-body energy stores, despite greater metabolic needs when compared to full-term, average-weight newborns. Additionally, extracellular water makes up a larger proportion of body weight in infants (70–80%) compared to adults (60%) [7]. Circulating blood volume is approximately 89–105 mL/kg in premature newborns, drops to 82–86 mL/kg in term births, and declines to 70 mL/kg in adults [8]. Although infants have more circulating blood volume per unit of body weight than adults, their absolute blood volume remains quite small. These factors combine to make neonates and infants more vulnerable to hypovolemia than older children and adults [9]. Although the absolute volumes of fluid required to restore euvolemia may be less in pediatric subjects, they remain more sensitive to fluid loss than adults, underscoring the need for rapid vascular access to meet their infusion needs.

Pediatric Vascular Access Devices

Many options are available to providers when attempting emergent vascular access for pediatric subjects, including intraosseous (IO), peripheral intravenous (PIV), midline (MLC), peripherally inserted central catheter (PICC), and central venous catheter (CVC) devices. These approaches to vascular access are discussed in greater depth in the corresponding chapters of this text. Table 8.1 compares the types of vascular access device (VAD) most commonly utilized for pediatric subjects, including the relative advantages and disadvantages of each technique.

Intraosseous (IO) Catheter

The intraosseous route is ideal for critically-ill children, as the medullary space of long bones provides a non-collapsible vascular access route, even in the presence of severe hypovolemia and hypotension. This starkly contrasts with the peripheral venous system, which typically collapses in shock states, complicating peripheral (or even central) venous cannulation. As mentioned in Chap. 7, a wide range of IO access systems exist, including manual and mechanically powered devices.

Most designated IO catheters are 20-gauge in diameter, but the length of IO catheter required for individual patients will vary according to the patient's body weight and the anatomic site selected for cannulation. In general, a 15-mm IO needle is

Table 8.1 Comparison of different vascular access devices used for pediatric resuscitation

Type of access	Common sites	Advantages	Disadvantages
Intraosseous (IO) catheter	Femur, proximal tibia, distal tibia	Easily and rapidly placed, accesses a non-collapsible space	Short-term use, can only infuse PIV-compatible solutions, risk of extravasation and related complications
Peripheral intravenous (PIV) catheter	Dorsal plexus of hand or foot, saphenous vein, antecubital veins, external jugular vein, scalp veins	Simple, cost-efficient, minimal complications, may be placed rapidly	Short-term use, infiltration risk, can be difficult to place in some patients, blood draws can be difficult
Midline catheter (MLC)	Deep peripheral veins of the upper extremity	Longer dwell times than IO/PIV, more easily inserted than CVC, no radiographic confirmation required	Blood draws can be difficult, can only infuse PIV-compatible solutions
Peripherally inserted central catheter (PICC)	Cephalic vein, brachial vein, basilic vein	Blood sampling possible, patient can be sent home with PICC, central-only solutions can be given, can monitor CVP and mixed venous oxygen saturation	Need specialized training to place, radiographic confirmation needed, patient care education required if going home with PICC
Central venous catheter (CVC)	Internal jugular vein, femoral vein, subclavian vein	Multiple lumens, easy blood sampling, can monitor CVP and mixed venous oxygen saturation, central-only solutions can be given, can be placed faster than PICC	Need specialized training to place, cannot be sent home, limited dwell times due to infection risk, highest risk of life-threatening complications

utilized at all body sites for patients weighing 3 to 39 kg, regardless of age. Manufacturers do not generally endorse the use of IO for patients with body weight <3 kg, although the use of IO catheters in neonatal subjects has been well-described in the medical literature [10]. The long bones of pediatric patients are softer and less calcified than those of adults, which may allow alternate IO infusion devices (e.g., butterfly needle, short spinal tap needle) to penetrate the bony cortex and cannulate the IO space for purposes of IO infusion [10, 11]. Pediatric patients with excessive soft tissue thickness at the selected insertion site may require the use of a 25-mm-long IO catheter, although care should be taken to avoid excessive insertion depths to reduce the risk of extravasation. The use of excessive force with IO insertion must be avoided in pediatric subjects, as pediatric long bones are poorly calcified and prone to fracture when excessive force is applied. In addition, the smaller size of the intramedullary space inherently reduces the volume-accepting capacity of the IO space, and the veins that drain this space are of smaller caliber and therefore less able to accommodate large volumes of infusion.

These differences would seem to increase the risk that excessive infusion pressure and volume could lead to extravasation of fluid into the soft tissues surrounding the IO insertion site. Given the smaller size of extremity soft tissue compartments relative to the volume infused, it follows that excessive volume infusion through an

Table 8.2 Comparison of anatomic sites for intraosseous catheter insertion in children and adults

Location	Adult (≥40 kg)	Child (3–39 kg)
Proximal humerus	Yes	Not recommended
Sternum	Yes	Not recommended
Iliac crest	Yes	Not recommended
Distal femur	Yes	Yes
Proximal tibia	Yes	Yes
Distal tibia	Yes	Yes

IO catheter may be more likely to lead to increased compartmental pressures and produce compartment syndrome. The risk of simultaneous iatrogenic *cis* and *trans* penetration of the target bone (i.e., penetration through both sides of the bone) would also seem to be increased with pediatric IO placement due to small medullary size, further increasing the risk of extravasation with IO infusion. While monitoring IO insertion sites for signs of extravasation is important for any patient of any age, the risk of compartment syndrome due to IO extravasation in the pediatric population may be greater than that for adult subjects. Thus, a heightened awareness of this risk is paramount when placing IO catheters in children.

The anatomic locations recommended for IO catheter placement in children are more restrictive than those endorsed for adults. Recommended sites for IO placement in infants and children with body weight <40 kg include the proximal tibia, distal tibia, and distal femur [11]. Chapter 7 of this book describes IO placement, including the wide range of devices available to the emergency care provider. A comparison of recommended IO catheter insertion sites for adult and pediatric subjects is provided in Table 8.2.

Landmark-Based Peripheral Intravenous (PIV) Catheter

Peripheral intravenous (PIV) access has traditionally been considered the preferred approach for rapid delivery of isotonic solutions in pediatric patients with undifferentiated hypotension and shock. Large-bore PIV catheters are preferred to central venous catheter (CVC) placement, due to more rapid placement times, shorter cannula lengths, and lower rates of complications [12, 13]. The shorter length characteristic of PIV catheters allows for less resistance to forward flow, facilitating higher fluid infusion rates [14]. Peripheral veins in the scalp, hands, feet, and antecubital region may be the only accessible PIV insertion sites in infants, due to increased body fat relative to older children and adults. The gauge of catheter selected depends upon the age of the patient and the site selected. Among neonates, 24- or 26-gauge catheters are most often used, although any catheter in the 20- to 28-gauge range may be considered [5, 9]. The 22- to 24-gauge over-the-needle-type PIV catheters are most commonly used in children [9].

Placement of PIV devices in pediatric subjects differs from that in adults, although some similarities are found. As with adults, the nondominant hand is preferred for cannulation, although younger children may not have a dominant hand.

Areas of flexion (e.g., wrist) should be avoided [4]. Distal veins in the upper extremities should be considered before more proximal or lower extremity venous targets. In contrast to adult patients, lower extremity veins are often considered in pediatric subjects. Due to decreased compliance with vascular access attempts, it is generally recommended to consider the use of arm boards when the hand veins are targeted in pediatric subjects, to minimize movement of the extremity after venous access has been established.

The *dorsal arch veins* of the hand are often the first area targeted in pediatric patients, although care must be taken to avoid the dorsal digital arteries. Collateral circulation exists between the deep and superficial arterial arches of the hand at most digits, which appears to minimize the risk of ischemia when the dorsal digital arteries are injured during vascular access attempts. However, the thumb may be at a higher risk of VAD-related ischemia, as both the dorsal and palmar arteries may arise from the *princeps pollicis artery* of the thumb (a branch of the radial artery), which is dorsal and superficial to the first web space muscles in 10–15% of infants [15]. The *cephalic vein* at the anatomic snuffbox of the wrist is a common target for pediatric patients. This vein is often quite large and generally available. Veins at the volar (palmar) aspect of the wrist are small in pediatric patients and not as durable as dorsal hand or antecubital veins. Since central venous access is often attempted in pediatric subjects at the antecubital fossa, this site is not recommended for first consideration in pediatric PIV access attempts.

When treating a conscious pediatric inpatient, vascular access attempts should be conducted outside of the child's room whenever possible, leaving the child's room their "safe space." Regardless of where the attempt is made, providers should ensure that additional staff are on hand to help in distracting the patient or otherwise facilitating the attempt. Providers should use developmentally supportive measures to minimize stress, such as a pacifier, talking softly, swaddling with the parent [16], or avoiding sudden moves [7]. When parents are available to assist the provider, it is recommended to have the child face the parent [16].

Infants should be covered with a blanket to minimize cold stress during the attempt. Providers should consider placing the extremity on an arm board before venipuncture attempts on the dorsal hand. Transillumination devices (as mentioned in Chap. 10) placed beneath the extremity can help to improve vein visualization. The oral administration of 2 mL of a 25% sucrose solution by syringe or on a pacifier immediately prior to the procedure may help to decrease pain perception [16]. Providers should also consider use of a topical anesthetic cream at the planned insertion site, although this application should occur up to 1 hour before venipuncture to maximize the effect. Providers should use only hypoallergenic or paper tape to secure the catheter and should apply warm water to the catheter during the removal attempt to facilitate easy removal.

The major superficial *scalp veins* can be used for vascular access in children up to age 18 months of age, after which time this route becomes more challenging due to the maturation of the hair follicles and toughening of the epidermis [9]. The four scalp veins most commonly used for PIV access are the *temporal, frontal, posterior* *auricular*, and *occipital veins*. Unlike most peripheral veins, scalp veins do not contain valves [7]. The patient's head is maintained in a dependent position during the attempt to promote venous distension. The four most common scalp veins used for venous access are illustrated in Fig. 8.1. Image also shows a rubber band across the forehead to engorge the veins, as well as a common technique for securing the butterfly needle to the scalp with adhesive tape.

The use of scalp veins for venous access may be foreign to those providers who are accustomed to treating adult patients, as this is not a recommended access site for adults. However, scalp veins are frequently accessible in infant subjects due to their larger relative head size in comparison with body size. In general, this access site is considered when other access sites for peripheral IV cannulation have been exhausted or determined to be inaccessible. When considering the scalp veins for cannulation, the provider should locate the commonly accessed scalp veins (as above), with preference for a vein behind the hairline to avoid visible scarring due to PIV placement. It may be necessary to shave the area of interest to increase visualization of the target vein and facilitate dressing adherence to the scalp. Elastic band placement around the head above the level of the ears and eyes may help to engorge the target veins prior to cannulation. A butterfly needle (23-, 25-, or 27-gauge) or 22- or 24-gauge over-the-needle PIV catheter is typically used for this procedure.

When placing a scalp PIV, the patient should be restrained in the supine position, with an assistant available to stabilize the patient's head during the

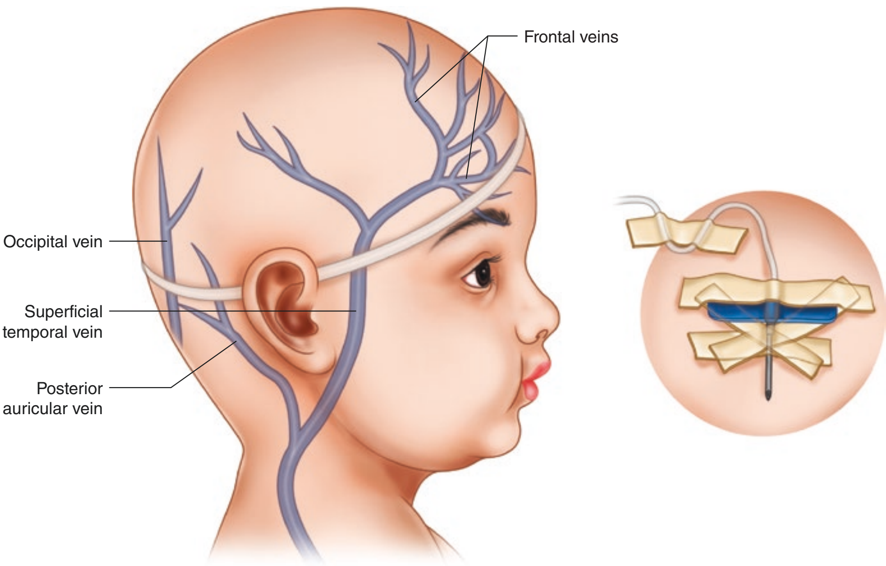

Fig. 8.1 Scalp veins commonly available for peripheral intravenous cannulation in infants

procedure to prevent patient movement during placement. The optimal vein selected will have a straight segment long enough to accommodate the length of PIV catheter intended to dwell within the vein. It is important to assess target vessels for the presence of pulsation, which would suggest that the vessel is arterial and not appropriate for cannulation. An elastic band (e.g., rubber band) may be placed around the head above the level of the eyes and ears to enhance engorgement of the vessel. This will increase the diameter of the vessel and enhance visualization. It may be helpful to place a piece of tape around the rubber band to provide a tab to grasp and lift when removal of the elastic band is desired after cannulation.

Topical antiseptic solution should be applied to the insertion site and allowed to dry prior to cannulation. The needle should penetrate the scalp 5 mm from the desired venous cannulation site, with an angle of insertion of about 30 degrees. The needle should be inserted in the direction of blood flow. Once the needle has penetrated the target vein, the elastic band should be released and the catheter flushed with 0.5 mL of saline to confirm intravascular placement. If the fluid extravasates with formation of a wheal at the site, this is evidence of extravasation and suboptimal cannulation, and the insertion should be attempted at a different site. Once the catheter has been appropriately placed, the device should be anchored to the scalp with tape and measures taken to avoid accidental dislodgement. Complications include accidental arterial cannulation, ecchymosis and hematoma at the insertion site, and infection.

Additional peripheral venous cannulation sites should also be considered. The *external jugular (EJ)* vein is generally visible in pediatric subjects and lies superficial to the skin surface, over the sternocleidomastoid muscle [1]. Although this vein drains into the central circulation, the EJ vein turns sharply under the clavicle, preventing central venous cannulation from this site [1]. This vein's superficial depth usually allows for direct compression in the event of iatrogenic hematoma [2]. However, pediatric patients with excessive neck fat or short neck may not have a visible EJ vein. The use of this insertion site is *not recommended in pediatric subjects if the vein is not superficially visible* [1].

Cannulation of the pedal (foot) veins is often attempted in pediatric subjects, although pedal vein cannulation is not recommended in adult patients. Peripheral venous cannulation of the foot is targeted at the *dorsal venous arch* and *venous plexus*, including the long saphenous vein, short saphenous vein, and lateral/medial marginal veins. These pedal veins, along with the other common pediatric peripheral venous targets of the hands and feet, are illustrated in Fig. 8.2.

In an undifferentiated pediatric population, PIV catheter insertion appears to be most often successful when performed at the cephalic vein in the proximal forearm using US guidance, or at the antecubital fossa [17, 18]. Peripheral IV cannulae placed in the forearm also appear to be more durable than those placed in the scalp, hand, or leg [19]. Catheters inserted at the bend of the arm or the lower extremity appear to be more likely to infiltrate or fail to infuse [20].

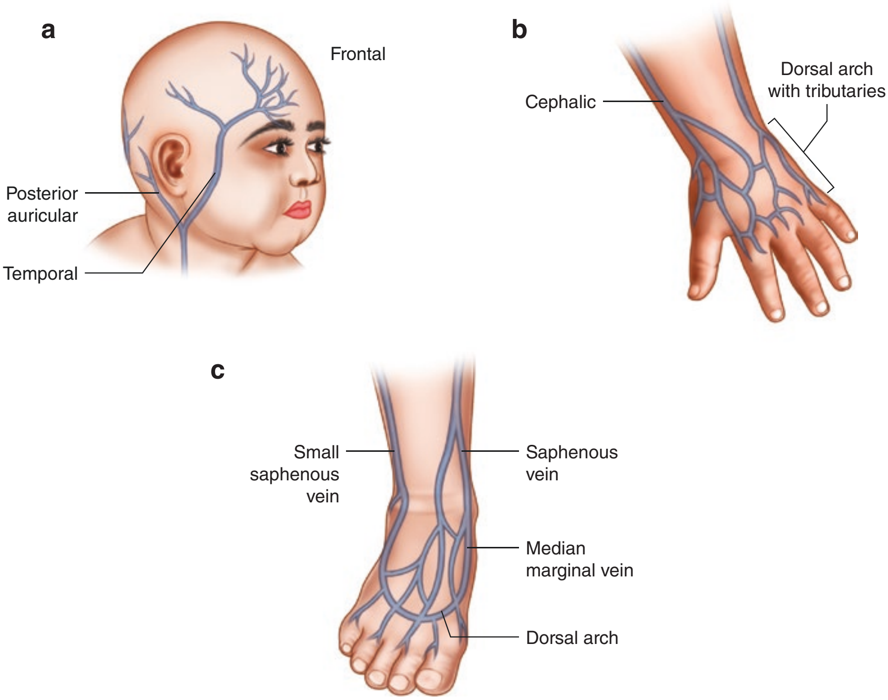

Fig. 8.2 Common sites for landmark-based PIV cannulation in infants and children

Ultrasound-Guided Peripheral Intravenous (US-PIV) Catheter

The success rate for ultrasound-guided PIV (US-PIV) placement is highly variable in children, and the use of US guidance *does not improve first-attempt success rates* for PIV catheterization in a general pediatric population [21]. However, US-PIV placement may be of special value in pediatric patients with difficult venous access, including those who have already failed multiple previous landmark-based PIV attempts [22], obese subjects, and chronically ill patients with a history of frequent hospitalizations requiring IV insertion [23]. Among pediatric patients (including infants) with difficult vascular access, the use of US guidance is associated with faster peripheral venous cannulation, with fewer attempts and needle redirections [24–27]. These benefits have been demonstrated with both emergency nurse and emergency physician providers [25]. Considering the additional challenges inherent to the pediatric population, US visualization of anatomy may be of use by allowing providers to better evaluate and identify the most appropriate venous access points, to more safely insert peripheral and central venous catheters, and to immediately identify complications [13, 28–31]. The complication rate for PIV access has been shown to positively correlate with the number of vascular access attempts made;

thus, the use of ultrasound to decrease the number of required attempts may reasonably be expected to reduce complication rates for pediatric patients [28].

The *brachial vein*, *cephalic vein*, and *basilic vein* of the upper arm are the vessels most commonly targeted with US-PIV placement in pediatric subjects [2]. Ultrasound guidance is most useful for pediatric patients with small-caliber veins or excessive peripheral fat, especially at the antecubital veins [2, 32]. The use of ultrasound-guided peripheral venous catheters may be especially valuable to pediatric subjects requiring infusions lasting longer than 5 days [33, 34].

The IV catheters used for US-PIV placement are generally longer than standard PIV catheters; as with adults, short PIV catheters may not be long enough to cannulate deeper arm veins [2]. However, the use of longer PIV catheters, especially those with small internal diameters, is associated with greater resistance to flow [14]. Pressure-assisted flow and/or micropuncture catheters may be required if rapid fluid administration is needed, to compensate for this additional vascular resistance [14].

The degree of venous and arterial compression may be different during US-PIV insertion in pediatric patients when compared to adult subjects, as the vasculature of pediatric subjects is more easily collapsed with soft tissue compression [2]. Generous use of ultrasound gel appears to help mitigate excessive probe pressures [35].

Central Venous Catheter (CVC)

The approach to CVC placement for pediatric patients mirrors that of adult patients, which is already described in Chaps. 5 and 6 of this text. It should be noted that PIV or intraosseous (IO) access is generally preferred to central venous access during initial pediatric resuscitative efforts, although the decision to place a CVC should be guided by the patient's specific medical condition and therapeutic needs. The common indications for the use of CVC are listed as follows [36]:

- Short-term administration of intravenous medications requiring continuous administration or frequent blood collection
- Prolonged administration of intravenous medications
- Administration of parenteral nutrition or hyperosmolar solutions
- Administration of total plasma exchanges, red blood cell exchanges, erythrocytapheresis, and clotting factors
- Administration of cyclical chemotherapy

Ultrasound guidance is recommended for central venous catheter (CVC) placement in all pediatric patients [2]. Existing evidence suggests that ultrasound-guided central venous catheter (US-CVC) placement in pediatric populations has a success rate of up to 98% [29]. The complication rate for pediatric US-CVC placement in a general pediatric population is quite low, reported to be around 5% [29]. However, complications rates have been shown to be higher in infants than in older children, especially among infants less than 2.5 kg in body weight, at around 28% [30].

Locations for CVC placement in the pediatric population include the *femoral (FEM) vein, internal jugular (IJ) vein, subclavian (SC) vein*, and *peripherally inserted central catheters (PICC)* in the *basilic vein* or *brachial vein* of the upper extremity. While the preferred insertion sites for CVC lines are the IJ and SC veins in adults, these veins may be prohibitively difficult to cannulate in pediatric subjects. Consequently, the FEM vein is often considered first-line for CVC cannulation in pediatric subjects [2, 37]. This vein is easily accessed under emergent conditions and is less prone to difficulties in line placement with pediatric subjects.

Many factors should be taken into consideration during selection of a CVC insertion site, including the patient's preexisting medical conditions, venous anatomy, the indication and urgency of the need for venous access, provider experience, and available devices [2]. Patient age, weight, and height are important determinants of catheter length and caliber among pediatric patients [38–43]. Table 8.3 provides a comparison of the mean IJ, SC, and FEM central vein diameters associated with different age categories.

Previous studies have shown that the internal diameter of the IJ vein in neonates and infants may be smaller than the diameter of the standard "big-radius" curved J-tip Seldinger guidewire, leading to difficulties in cannulating the IJ and SC veins with a standard guidewire [46]. Furthermore, the use of Trendelenburg positioning does not appear to increase IJ diameter in children less than 6 years old [46]. The diameter of CVC device recommended depends greatly upon the age of the patient. For example, 3-Fr catheters are recommended for FEM CVC placement in patients <1 year old, with 4- or 5-Fr catheters used in young children [42].

Although the extrapolation of evidence from studies of adult populations to pediatric subjects is controversial, pediatric-specific studies have confirmed that the carina remains an appropriate anatomical and radiological landmark for determining whether the tip of an IJ or SC catheter is placed properly in infants and small children [48].

In general, complications of CVC placement in children mirror those encountered in the adult population. Early complications include pneumothorax, hemothorax, cardiac tamponade, arterial puncture, hematoma formation, air embolism, and cardiac arrhythmia [1]. Late complications include erosion of the vessel wall, vein thrombosis (including potential occlusion of the lumen), catheter rupture, dislodgement or migration of the catheter, and catheter-associated infections of the soft tissues or bloodstream [1]. These risks may be further increased in infants and other

Table 8.3 Mean central vein diameter (mm), according to age [38–47]

Central vein	Neonates	Infant	Child (<6 yo)	Adolescent	Adult
Internal jugular (IJ) vein	5.5	8.9	10.5	11.9	11.3
Subclavian (SC) vein	5.6	5.5	6.9	8.5	11
Femoral (FEM) vein	3.8	4.5	7.3	7.8	8.9

pediatric patients with extremity or vascular abnormalities [1]. The risk of catheter-associated infection appears to be increased with increased proximity of the insertion site, as well as the use of a polyurethane catheter in infants [49]. Younger pediatric subjects appear to have a higher risk of iatrogenic vertebral artery puncture with IJ attempts due to the relative proximity of this artery to the IJ vein [50].

The *femoral (FEM) vein* is often the first choice of insertion site for emergent CVC access in pediatric subjects, as it is associated with easily recognizable landmarks [49] and can be cannulated quickly during emergent resuscitation [1]. Contraindications to FEM CVC placement include vascular malformation of the lower extremity, congenital malformation of the lower extremity, femoral hernia, abdominal tumor, trauma, or abdominal ascites [1]. Ultrasound-guided CVC placement at the FEM site is associated with a higher first-attempt success rate and fewer needle passes in pediatric patients when compared to other CVC sites [49]. Reported disadvantages of the FEM site include a high risk of contamination, difficulty securing the catheter, and patient discomfort [1]. However, the complication rate associated with FEM CVC insertion is similar to that for other central venous sites in the pediatric population (including infants) [51, 52]. Although the FEM insertion site is generally discouraged for adult patients due to concerns of increased infection risk, the rate of bloodstream infection associated with FEM CVCs in children is approximately 3.7%, lower than that for other CVC insertion sites (7.3%) [52].

The *internal jugular (IJ) vein* is associated with the highest procedural success rate for CVC placement among pediatric patients (86% vs. 65% at other CVC sites), but this site may also be associated with a higher risk of complications in children [33]. Like the FEM insertion site, placement of an IJ CVC does not interfere with cardiopulmonary resuscitation efforts in pediatric patients [2]. Unlike subclavian insertions, the insertion site for IJ cannulation is well-exposed and allows for direct compression of the site to avoid hematoma formation or excessive bleeding following a failed attempt [2]. Despite the relative safety of IJ placement, ultrasound guidance is recommended for placement of IJ CVCs in pediatric patients [2]. Certain characteristics common to pediatric subjects, including excessive neck fat and short neck size, may complicate use of the IJ insertion site [33]. Reported complications following IJ CVC placement include carotid artery puncture, pneumothorax, thoracic duct injury (especially if performed on the left side), sympathetic nerve injury, neuropathy, venous thrombosis, and infection [53]. As with adults, the IJ vein is typically easier to cannulate on the patient's right side, since the IJ vein usually joins with the SC vein at a straighter angle on this side [54]. The pleural dome is also lower on the right, theoretically decreasing the risk of pneumothorax [1]. In addition, the thoracic duct is significantly larger on the left side; on the right, it is generally smaller and often congenitally absent [1].

The *subclavian (SC) vein* is not a common choice of site for emergent central vascular access in pediatric patients [2, 49]. The SC vein is generally smaller and arches more superiorly in infants than in adults, and the percutaneous entry site for this venous access point may be more difficult to identify [1, 49]. Additionally, while subclavian vein catheters are associated with a low risk for infectious complications in adults, this has not been definitively established in children [55].

Successful placement of a subclavian CVC for pediatric patients, especially infants, requires an advanced skill set, due to the presence of increased subcutaneous fat obscuring external landmarks and obstructed views of the target vessel due to shadowing from the clavicle [1]. Proper positioning of the patient during the access attempt is essential. Placement of a towel roll between the shoulders may help to elevate the chest and expose the relevant anatomy [55]. Malpositioning is a common problem with pediatric SC lines, including catheter migration [55]. Complications known to be associated with SC CVC placement include pneumothorax, bleeding, cardiac tamponade, dysrhythmia, thoracic duct injuries, air embolism, and neuropathy [1]. In children, the SC CVC insertion site is associated with the highest rate of fatal complications, when compared to the FEM or IJ insertion sites [53, 56, 57].

Axillary (AX) vein CVC placement can be performed using US guidance and appears to be associated with higher first-attempt placement success rate (46% vs. 40%) and shorter median time to placement (156 sec vs. 180 sec) than landmark-based SC CVC placement [58]. Ultrasound-guided supraclavicular *brachiocephalic (BC) vein* CVC placement appears to be more successful on the first attempt than IJ CVC, with reduced puncture attempts and cannulation time in critically ill children [59].

A comparison of the three most common CVC insertion sites, including their relative advantages, disadvantages, and characteristic complications, are provided in Table 8.4.

Table 8.4 Comparison of CVC insertion sites for pediatric patients

Central vein	Advantages	Disadvantages	Complications
Internal jugular (IJ)	Direct route to SVC (RIJ), larger lumen diameter, removed from the resuscitation field, directly compressible	Takes longer, requires more operator experience, more difficult in pts. <1 year with short, fat necks; more difficult in patients with tracheostomies or who are not intubated	Carotid artery puncture, pneumothorax, thoracic duct injury, infection, bleeding, thrombosis
Subclavian (SC)	Less collapsible, easier to secure, lower infection rates (in older children)	Requires operator experience, no access to control bleeding, higher risk of pneumothorax/hemothorax during placement, not commonly placed under US guidance	Pneumothorax, hemothorax, thoracic duct injury, tamponade, catheter malposition, infection, bleeding, thrombosis
Femoral (FEM)	Requires the least operator experience, fastest, remote from the resuscitation field, available for direct compression	Risk of contamination, may be more uncomfortable for patients	Femoral artery puncture, intraperitoneal/retroperitoneal catheter malposition, infection, bleeding, thrombosis

Peripherally Inserted Central Catheter (PICC)

A peripherally inserted central catheter (PICC) is an intermediate-term vascular access inserted in a vein of the deep arm (e.g., basilic, brachial, or cephalic), with the tip positioned at the junction of superior vena cava and right atrium. Insertion of a PICC line is typically not a viable option for emergent vascular access in children or adults. Placement of these lines requires specific resources (e.g., equipment, expertise, time, and patient compliance) that may not be available to the unstable patient. When they are placed in children, the *basilic vein* appears to be the preferred insertion site, although many other options are available [3, 4].

In older children, ultrasound-guided Seldinger technique is used [60]. In neonates, cubital or saphenous veins are cannulated utilizing a sheath-over-needle apparatus. Fluoroscopy is typically used to confirm proper placement [61]. Complications of forearm venous cannulations in pediatric patients include infection, hematoma, infiltration, and superficial and deep vein thrombosis [62–64]. Placement of PICC lines in the lower extremity is suggested in patients with congenital cardiac conditions, due to lower associated risk of complications [5]. The rate of complications associated with PICC line insertion has been shown to decrease with advancing age in children [20].

Umbilical Vein/Artery Catheterization (UVC/UAC)

Although most commonly performed in the delivery room, *umbilical vein catheterization (UVC)* and *umbilical artery catheterization (UAC)* remain a viable option for emergent vascular access in newborns within the first 7–14 days of life [65–67]. It should be reserved for cases in which alternate access is impossible or inadequate, as UVC is associated with a high rate of complications, including infection and thrombosis [65–68].

Although direct peripheral intravenous access remains the preferred vascular access route for neonates, UVC is associated with greater placement success rates than peripheral venous access techniques in the setting of emergent neonatal resuscitation [66]. The umbilical vein can be used for exchange transfusions, central venous pressure monitoring, fluid infusion, and medication administration [66]. However, both UVC and UAC are contraindicated in patients with gastroschisis, omphalitis, omphalocele, peritonitis, necrotizing enterocolitis, or compromised lower extremity blood flow.

At term birth, the umbilical cord is approximately 1.8 cm in diameter, containing two umbilical arteries and one umbilical vein [69]. The umbilical arteries are distinguished from the veins by their smaller (4 mm vs. 8 mm) internal diameter and thicker vessel walls. As illustrated in Fig. 8.3, the umbilical vein is usually situated at the 12 o'clock position on the stump, with the paired umbilical arteries on the opposite side of the cord. The three umbilical vessels are surrounded within the cord by Wharton's jelly, a mucoid connective tissue that performs the role of the *tunica adventitia*, which is not present in umbilical vessels [70]. Thus, this substance

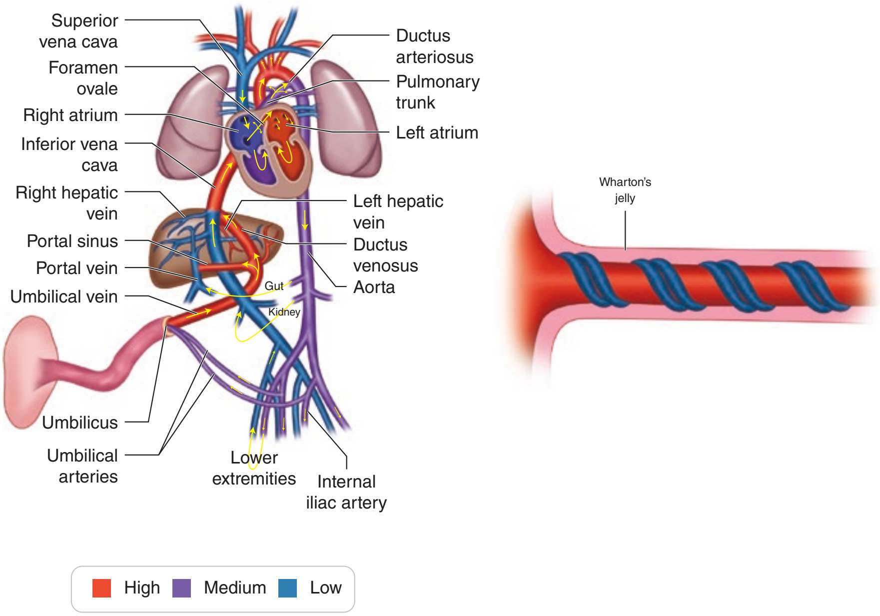

Fig. 8.3 Neonatal vascular anatomy, including oxygenation levels of blood in the umbilical cord and associated vessels

provides structural support for the vessels and aids in their contraction, to prevent kinking of the vessels in utero.

Prior to birth, the uterine placenta provides the fetus with oxygen, so the blood coming from the fetus into the placenta is moderately deoxygenated, and the blood coming from the placenta to the fetus via the umbilical veins is oxygen-rich. The umbilical vein anastomoses with the fetal venous system via the *ductus venosus*, which bypasses the hepatic vasculature to drain directly into the inferior vena cava (IVC). The ductus venosus begins to close within days of birth and is functionally closed in most newborns by age 1 week [71]. This limits the use of the umbilical vein for direct infusion into the IVC to the first 1–2 weeks after birth. The two umbilical arteries anastomose with the corresponding internal iliac arteries, which derive from the common iliac arteries arising from the terminal aorta [72]. Figure 8.3 shows the normal fetal anatomy, including major blood vessels of the fetus and neonate. As this figure shows, blood entering the fetus from the placenta is highly oxygenated, while blood leaving the fetus via the umbilical arteries has a mid-level oxygen saturation.

Cannulation of the UVC is performed as follows [73]. The umbilical stump is first scrubbed with a bactericidal solution, and a loop of umbilical tape (or purse-string suture) is placed around the cord at its junction with the skin surface. Povidone-iodine solution is recommended for UVC and UAC, as the use of chlorhexidine solution is associated with increased risk of chemical burns to the skin, especially in preterm neonates [4].

The cord is then transected with a No. 11 blade scalpel approximately 1 cm above the skin surface, and the vessels are identified. The umbilical vein may continue to bleed after cutting, although the arteries tend not to bleed. The umbilical vein can be dilated gently with non-teethed curved Iris forceps, as needed. The catheter is then inserted to a depth of 1–2 cm beyond the point at which good blood flow is detected. The standard umbilical vein catheter sizes range from 3.5 Fr (for preterm neonates, <3500 grams) to 5 Fr (for term neonates, >3500 grams) [73]. The usual depth of insertion for a term newborn is 4–5 cm [73]. Once free backflow of blood is verified, the catheter is anchored to the umbilical cord with the umbilical tape or purse-string suture. If resistance is met, the stump can be pulled inferiorly (i.e., toward the patient's feet) so that the catheter is being directed more superiorly (i.e., toward the patient's head). This may reduce the angle of insertion and alleviate obstruction from the surrounding soft tissues. An overly tight umbilical tape (or purse-strong suture) may also be suspected if difficulty is encountered when attempting to advance the catheter.

If central venous monitoring is desired, the catheter should be inserted further (usually 10–12 cm) until it reaches the IVC. Proper tip position (within the IVC, just distal to the right atrium) is confirmed radiologically but usually corresponds to an insertion depth equal to two-thirds of the distance from the patient's shoulder to the umbilicus. Visualization of injected saline through the UVC with ultrasound can be used to confirm proper UVC tip position and identify inadvertent malpositioning within the hepatic portal circulation [4, 74]. A tape bridge may be used to secure the catheter to the patient's abdomen after placement. Figure 8.4 shows the three stages of UVC placement, including cord transection (a), catheter insertion (b), and subsequent stabilization of the line with a tape bridge (c).

Umbilical artery catheterization (UAC) can be used to facilitate continuous arterial blood pressure monitoring, blood gas sampling, and exchange transfusions in neonates. The placement technique mirrors that of umbilical vein catheterization, although curved Iris forceps may be needed to dilate the arteries as they are usually smaller and more muscular than the vein. After cannulation of the umbilical artery, the catheter is flushed with heparinized saline to avoid inadvertent introduction of

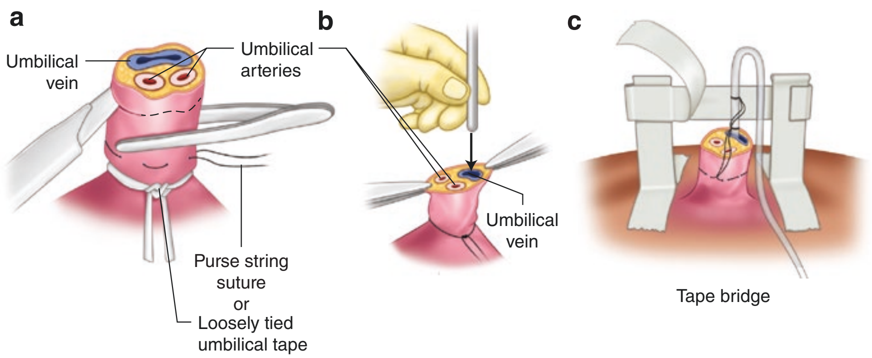

Fig. 8.4 Three stages of umbilical vein catheterization

air bubbles. Lidocaine 2% for intravascular use may be trickled on the artery to prevent arterial spasm. The radiological position of the catheter tip on post-placement chest X-ray should be between the sixth and ninth thoracic vertebrae. This "high position" of umbilical artery catheter (i.e., between T6 and T9 vertebral levels) is preferred over the "low position" (L3 to L4 level), as it is associated with fewer complications [4]. The formula used to calculate the required insertion depth for umbilical artery catheters is *depth (cm)* = *9* + *(3* × *weight in kg)* [61].

Umbilical venous catheters should be removed as soon as they no longer needed (ideally within 7–10 days) but can be used for up to 14 days if managed appropriately [4]. Umbilical artery catheters should be removed as soon as no longer needed or when providers note any sign of vascular insufficiency to the lower extremities. An umbilical artery catheter should not be left in place for more than 5 days [75]. Removal of umbilical catheters should be done over several minutes, to reduce the risk of bleeding and to allow vasospasm (in the case of UACs) [4].

Arterial Catheters

Arterial catheters are generally used for invasive continuous blood pressure monitoring or when frequent arterial blood gas analysis is required. In newborns <2 weeks of age, the umbilical artery can be used, as described above. In infants and children, the *radial artery, femoral artery*, and *posterior tibial artery* are commonly used. The technique is like that used for adults, as described in Chap. 13. However, US guidance for radial artery cannulation has been shown to improve first-attempt success rates and reduce complications when compared to the palpation or Doppler US methods traditionally used with adults [61].

Methods to Enhance Placement Success

Establishing emergent vascular access in unstable (or merely uncooperative) pediatric patients offers many unique challenges to the care provider. These challenges include the need to engage the child's cooperation with VAD placement, increased potential for psychological trauma, smaller veins, and increased subcutaneous fat, making both palpation and visualization of veins more difficult [76]. Earlier in this chapter, several methods were described to help minimize the anxiety and psychological trauma associated with vascular access device placement in children. Many of the techniques described for vein identification and cannulation among patients with difficult vascular access described Chap. 10 may also be applied to pediatric patients.

Techniques used to facilitate PIV placement through improved visualization of the veins include local warming, transillumination, the application of epidermal nitroglycerin, and the use of ultrasound guidance. Pain perception can also be mitigated in pediatric and adult subjects through topical medications. Moderate-quality evidence suggests that the use of a *vapocoolant* (e.g., topical anesthetic skin refrigerants, PainEase®) immediately before intravenous cannulation reduces pain during the procedure and does not increase the difficulty of cannulation or cause serious adverse effects but is associated with mild discomfort during application [77]. Local anesthetic techniques, including the application of a *eutectic mixture of lidocaine and prilocaine (EMLA)* to the insertion site, may help alleviate patient discomfort but must be placed at the insertion site well in advance, as this topical anesthetic requires 20–30 minutes to achieve its full effect [78].

Providers may need to briefly restrain pediatric subjects during the access attempt or immobilize the target extremity during and after line placement. Shielding of the VAD insertion site may be helpful in preventing the child from pulling on the infusion tubing and dislodging the VAD after placement. Traditional examples of protective devices for VAD insertion sites include taping the tubing to the skin, wrapping the extremity loosely with gauze, taping a small paper cup over the insertion site, or taping the extremity to an arm board or sandbag to reduce movement of the extremity. Although these techniques and devices may protect the VAD, patient safety remains a chief concern and care should be taken to avoid injury to the patient with their use. When using gauze or other wrappings, it is important to ensure that the VAD and insertion site remain accessible to care providers and that the dressings allow for adequate visualization of the extremity to identify complications of intravenous infusion such as extravasation and compartment syndrome.

Decision-Making for Pediatric Subjects

Decision-making regarding VAD selection in children mirrors that of adults, although differences exist. As with adults, *landmark-based PIV catheterization should be considered first* in pediatric subjects, if it is deemed both possible and adequate to treat the patient's condition [21, 24, 27, 32, 79, 80]. Target veins should be visible or palpable to the provider, and "blind" attempts should not be made. *US-PIV placement should be considered after two failed landmark-based PIV insertion attempts* in stable patients, as the US-guided approach appears to be associated with higher rates of cannulation success when compared to additional landmark-based attempts past this milestone [24].

Acceptable PIV insertion sites among pediatric trauma patients should be those in uninjured extremities, with preference for the antecubital, external jugular (in patients without suspected cervical spine injury), and saphenous veins. In the hemodynamically unstable (e.g., hypovolemic) pediatric patient, the size and length of PIV catheter must be optimized for high-volume infusion. That said, the gauge of PIV catheter required may be highly variable within the pediatric population. An adequately gauged "volume line" for an infant may not be adequate for older children [76].

Unstable patients, especially those in extremis or experiencing cardiac arrest may be best served by placement of an intraosseous catheter. Both the Pediatric Advanced Life Support (PALS) and Advanced Trauma Life Support (ATLS) guidelines appear to support consideration of IO line placement if adequate PIV access cannot be established within three attempts or 90 seconds, whichever is sooner [81, 82]. Although IO flow rates may be highly variable in pediatric patients, flow through the catheter can be improved with the application of a pressure bag or the use of syringe injection [76]. Intraosseous catheters should not be placed in extremities with confirmed or suspected fracture or significant soft tissue injury, due to increased risk of extravasation and resulting compartment syndrome.

Conclusions

Pediatric vascular access can be challenging under emergent conditions, especially for infants and newborns. Even providers who are adept at line placement in adults may be intimidated by the prospect of establishing emergent vascular access in a young child. Many important anatomic differences exist between pediatric and adult patients, and these differences must be considered in determining the best techniques for emergent pediatric vascular access. When choosing a vascular access site, the practical and anatomical differences of pediatric patients must be considered in addition to the patient's presenting and preexisting medical conditions, risk of infection, available equipment, and urgency of the need for access.

Key Concepts

- Speed and efficacy are of the utmost importance when establishing venous access, and the well-trained pediatric provider will understand the various devices and approaches that can help to facilitate safe, fast, and effective vascular access.
- Ultrasound can serve as a valuable adjunct to traditional PIV catheter insertion techniques, although this modality may not offer the same advantages as with adult subjects.
- Landmark-based PIV insertion should be attempted first in pediatric patients, although alternative strategies for vascular access should be considered when landmark-based PIV methods fail.
- Ultrasound guidance should be used for pediatric CVC placement, to reduce the risk of line-related complications.
- Umbilical vein catheterization can provide emergent vascular access for newborns up until 2 weeks of age.

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