Central Venous Vascular Access

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Abstract

In children, central venous catheters are most often used for cardiovascular monitoring, emergency vascular access, intermittent blood removal for laboratory analysis, fluid and drug administration, plasmapheresis, hemodialysis, and long-term chemotherapy. This chapter provides an overview of choices in central venous access sites, describes central venous catheterization techniques, and delineates associated risks and complications. Decisions regarding the "best" site for central venous cannulation depend upon patient specific clinical variables, risk of complications, operator experience, future vascular access needs, and projected length of time the catheter will remain in place. In 2011, the Centers for Disease Control (CDC) published updated recommendations regarding the selection, insertion, maintenance, and discontinuation of central lines. This guideline deserves review by practitioners who insert and/or maintain central venous lines in children (see Table 29.1). The femoral vein is the most common site for central venous access in children. This site may have the lowest insertion risk profile and a high degree of operator experience across multiple specialties. In adult patients, IJ and subclavian vessels are preferred sites because the rates of infection and deep venous thrombosis may be less than that found with femoral venous catheterization, however in children these differences are less clear. In children, operator experience and need for minimal sedation when placing femoral catheters, are important drivers in site choice. The subclavian vein is the preferred route for long-term venous access in children because it is easily inserted via the tunneled approach, is well tolerated, and is associated with few complications. Standard landmark insertion techniques

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still apply however the role of ultrasound guided CVC placement is growing in popularity and is recommended by some regulatory groups. Inexperienced operators may benefit most from ultrasound guided insertion. Pediatric providers should use their judgment about when to apply this important adjunct for line placement.

Keywords
Central Line • Percutaneous Venous Access • Central Venous Access • Central Line Placement • Vascular Access

Introduction

Percutaneous central venous access is a common procedure performed in emergency departments (ED) and intensive care units. In adults, in the United States, approximately three million central venous catheters are placed annually, resulting in 15 million central venous catheter (CVC) days in ICUs each year [1, 2]. Like adults, critically ill children often require central venous catheter placement. These catheters are used for cardiovascular monitoring, emergency vascular access during crisis situations, intermittent blood removal for laboratory analysis, fluid and drug administration, plasmapheresis, hemodialysis, and long-term chemotherapy [3–7]. Chiang et al., in a retrospective review of ED admissions over 5 years, reported that among all patients who required placement of a central venous catheter, 20 of 121 patients (17 %) had the catheter placed as a result of a cardiac or respiratory arrest, 78 patients (64 %) had catheters placed for lack of peripheral access, and 23 patients (19 %) had catheters placed for inadequate or unstable peripheral access [5]. Multiple sites using varied techniques have been described for obtaining central venous access in children. Each site and access method has associated risks and benefits. This chapter will provide an overview of choices in central venous access sites, describe standard techniques for central venous catheterization, and delineate associated risks and complications. Other methods of venous access, such as intraosseous access, venous cut down, or peripherally inserted central catheters, will not be part of this review because they are well outlined in other standard references [7]. Catheter related blood stream infections and catheter related thrombosis are the subject of other chapters in this textbook and will be only briefly discussed here.

Choice of Sites and Type of Catheter

There are multiple sites available for central venous catheterization in children. These sites include the femoral, subclavian, internal and external jugular, and axillary veins. Recently peripherally inserted central catheters (PICCs) have been used more frequently to obtain central venous access. PICCs are usually inserted into the basilic or cephalic veins and then advanced into the central circulation. Decisions regarding the "best" site for central venous cannulation depend upon multiple patient specific clinical variables, risk of complications, operator experience, future vascular access needs, and projected length of time the catheter will remain in place [8–11]. Practitioners who insert central lines should be familiar with the existing evidence to minimize untoward complications associated with these invasive devices. In 2011, the Centers for Disease Control (CDC) published updated recommendations regarding the selection, insertion, maintenance, and discontinuation of central lines [12]. The CDC guideline provides exhaustive recommendations pertaining to the maintenance care of catheters and their attachment devices, all focused upon infection prevention. Most of these recommendations pertain to nursing practice and are beyond the scope of this chapter. However, Table 29.1 summarizes the CDC recommendations most relevant to practitioners who insert central venous catheters. Much of this information is not new and some recommendations are derived from adult patients with central lines and therefore may have limited value to the pediatric practitioner. A couple of items deserve specific mention. A category 1A recommendation is to avoid the use of the subclavian vein for percutaneous access in patients with advanced kidney disease or those receiving chronic hemodialysis. This recommendation is intended to prevent subclavian vein stenosis and preserve the use of the subclavian vein for future access needs. Another item pertains to the recommendation to use new sterile gloves when handling the new catheter during guidewire exchange (Category II recommendation) and a 1B recommendation to use guidewire exchange to replace a malfunctioning catheter if there is no evidence of infection.

The femoral vein is the most common site for central venous access in children, especially in the emergency setting [5]. This site may have the lowest insertion risk profile and a high degree of operator experience across multiple specialties, hence its frequent use. In a cohort of 121 ED patients who required central venous access, 101 (83 %) had CVC placement in the femoral vein, 12 (10 %) had the catheter placed in the subclavian vein, and 7 (6 %) in the internal jugular vein [5]. Clinical variables that may impact the choice of site for cannulation include the coagulation status of the patient, whether the patient is breathing spontaneously or via mechanical ventilation, and the severity of the patient's respiratory illness. For example, patients with a significant

Table 29.1 Centers for disease control's recommendations for the selection, insertion, and removal of central lines

Category IA: strongly recommended for implementation and strongly supported by well-designed experimental, clinical or epidemiologic studies
Educate healthcare personnel re central line indications, proper insertion/maintenance practices, and infection control measures to prevent intravascular catheter-related infections
Periodically assess knowledge of and adherence to proper central line practices for all involved personnel
Designate only trained personnel who demonstrate competence for insertion/maintenance of central lines
Achieve skin antisepsis at the insertion site with a chlorhexidine-alcohol product
Employ maximal sterile barrier precautions during central line insertion, including sterile gloves
Avoid subclavian site if advanced kidney disease or chronic hemodialysis (to avoid subclavian vein stenosis)
Use antibiotic -impregnated central lines if the catheter is expected to remain in place >5 days if, after successful implementation of a comprehensive strategy to reduce rates of CLABSI, the CLABSI rate is not decreasing
Category IB: strongly recommended for implementation and supported by some experimental, clinical, or epidemiologic studies and a strong theoretical rationale; or an accepted practice (e.g. aseptic technique) supported by limited evidence
Maintain aseptic technique for the insertion and care of intravascular catheters
Hand hygiene should be performed before and after palpating catheter insertion sites as well as before and after inserting, replacing, accessing, repairing, or dressing a central line
Select a central line with the fewest number of ports/lumens essential for patient management
Use a guidewire exchange to replace a malfunctioning temporary catheter if no evidence of infection is present
Do not routinely replace nor exchange over a guidewire central lines to prevent catheter-related infections
When adherence to aseptic technique cannot be ensured (e.g., medical emergency), replace as soon as possible
Use ultrasound guidance to place central lines – if this technology is available and inserter trained in its use
Use a chlorhexidine-impregnated sponge dressing for temporary short-term catheters if the CLABSI rate is not decreasing despite adherence to basic prevention measures, including education and training, appropriate use of chlorhexidine for skin antisepsis, and maximum sterile barrier precautions
Category II: suggested for implementation and supported by suggestive clinical or epidemiologic studies or a theoretical rational
In adults, use an upper-extremity site for catheter insertion; replace a catheter inserted in a lower extremity site to an upper extremity site as soon as possible
Use new sterile gloves before handling the new catheter when guidewire exchanges are performed
Use a sutureless securement device to reduce the risk of infection for intravascular catheters
Use prophylactic antimicrobial lock solution in patients with long term catheters who have a history of multiple CRBSI despite optimal maximal adherence to aseptic technique
Do not remove CVCs or PICCs on the basis of fever alone. Use clinical judgment regarding the appropriateness of removing the catheter if infection is evidenced elsewhere or if a noninfectious cause of fever is suspected
Remove umbilical catheters as soon as possible when no longer needed or when any sign of vascular insufficiency to the lower extremities is observed. Optimally, umbilical artery catheters should not be left in place >5 days. Umbilical venous catheters should be removed as soon as possible when no longer needed, but can be used up to 14 days if managed aseptically

coagulopathy may be at greater risk from inadvertent arterial puncture, especially if the access site does not easily allow for direct pressure to the artery. This could make subclavian venipuncture higher risk compared to the femoral approach. For patients breathing spontaneously (less likely to hold still for the procedure) or those requiring high ventilator settings, the risk of an unplanned pneumothorax associated with the subclavian or internal jugular approach could make the femoral vein the preferred site. Subclavian and internal jugular sites may have lower catheter maintenance risks including lower infection rates compared to the femoral vein and thus may be preferred when central venous access is performed electively and the duration of cannulation is expected to be prolonged [2, 13]. Additionally, vein caliber can limit the size of catheter that can be inserted. This is of particular concern for infants and toddlers where lower extremity vessels are disproportionally smaller compared to above the diaphragm vessels. If a large-caliber vessel is required for flow-dependent extracorporeal therapies (e.g., CRRT, ECMO), then site selection may be determined by the necessary cannula size.

Femoral Venous Catheterization

Demographic and Historical Data

Studies from the 1950s reported high complication rates from femoral vein cannulation and as a result femoral venous access fell out of favor [14]. Today, femoral vein catheterization is frequently used in critically ill children because of its relatively low risk profile and high insertion success rate, in a variety of clinical settings.

Indications and Contraindications for Placement

Femoral veins are excellent central venous access sites in critically ill children. The femoral veins are attractive because they are perceived as a simple site for percutaneous insertion, especially by inexperienced operators and the cannulation can often be performed with minimal supplemental sedation. This is particularly important in children who are not receiving mechanical ventilation at the time of catheter placement. In addition, risks of life-threatening complications at the time of insertion are reduced because of easy compressibility of local vessels (femoral artery) and the remote location from the lung. The femoral vessels are also preferred if there are relative or absolute contraindications to accessing the jugular or subclavian veins. For example, in patients at risk for intracranial hypertension, placement of central venous catheters in the jugular or subclavian veins may precipitate vascular thrombosis, which could create obstruction to cerebral venous drainage and potentially life threatening increases in intracranial hypertension. In this clinical setting, a femoral venous catheter may be preferred [8]. In addition, patients with severe respiratory failure who require high mechanical ventilatory pressures may be at increased risk should a pneumothorax develop during the placement of a cervicothoracic central venous catheter. In this setting the femoral site may be preferred as well. In patients with a recognized coagulopathy, the femoral site is preferable because direct compression of the femoral vessels can occur, especially in the event of inadvertent puncture of the femoral artery [8]. Multiple studies demonstrate that femoral vein catheterization is a rapid and safe route for obtaining intravenous access in patients requiring massive intravenous fluid infusions or following cardiac arrest [4, 15, 16]. Furthermore, the femoral artery provides an easily recognized landmark to facilitate straightforward catheter insertion.

Some clinical situations warrant placement of central venous catheters at sites other than the femoral vein. Trauma to the lower extremity, pelvis, or inferior vena cava is a relative contraindication for femoral vein catheterization [8]. In addition, bulky abdominal tumors, inferior vena cava, common iliac, or femoral thrombosis, abdominal hematomas, venous anomalies and prior pelvic radiation are associated with increased risk of complications from femoral venous catheter placement [17].

In adult patients, practitioners have traditionally avoided femoral CVC placement because of concerns about the risk of deep venous thrombosis, excess infectious risks compared to other sites, and potentially inaccurate central venous pressure measurements derived from the femoral vessels [18–21]. While the jury may still be out in the adult critical care community regarding the use femoral catheters, evidence in children suggests a safer risk profile for femoral catheters than is observed in adults, especially when catheters are used for short periods of time [22, 23]. Perceived ease of insertion combined with a low insertion risk profile, often make the femoral vessels the preferred site in children [23, 24]. In adults and children, there is a wide range of reported rates for venous thrombosis associated with central venous catheters (1–60 %), however the thrombosis rates in children, are not significantly different between the femoral vessels and cervicothoracic vessels [25, 26]. Furthermore, in children, infectious complications associated with femoral venous catheters are similar and in one report less than that reported for cervicothoracic central venous catheters [27–29]. Finally, multiple studies have demonstrated that

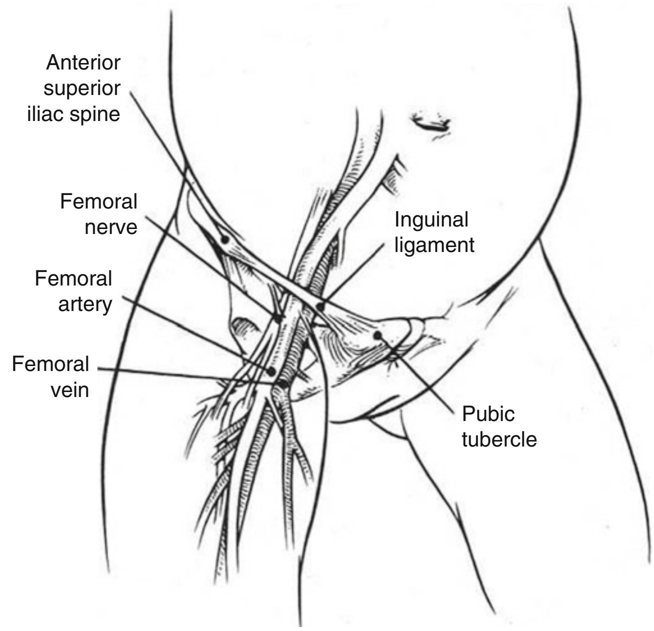

Fig. 29.1 Femoral Vein Anatomy (Source: PALS Provider Manual © 1997, American Heart Association, Inc)

in the absence of elevated intraabdominal pressures and even in the presence of high mechanical ventilatory support, central venous pressure measurements derived from femoroiliac veins are similar to measurements obtained from cervicothoracic veins and may accurately predict right atrial pressures [30–33].

Anatomy

The femoral vein lies in the femoral sheath, medial to the femoral artery immediately below the inguinal ligament (Fig. 29.1). The femoral triangle is an anatomic region of the upper thigh with the boundaries including the inguinal ligament cephalad, sartorius muscle laterally, and adductor longus muscle medially. The contents of the femoral triangle from lateral to medial are the femoral nerve, femoral artery and femoral vein. The femoral sheath lies within the femoral triangle and includes the femoral artery, femoral vein and lymph nodes. The femoral vein runs superficially in the thigh approaching the inguinal ligament in the femoral triangle. The vein dives steeply in a posterior direction, superior to the inguinal ligament, as it becomes the iliac vein. The femoral vein lies medial to the femoral artery in the femoral sheath inferior to the inguinal ligament. In patients with a palpable pulse, the femoral vein can be located just medial to the femoral arterial pulse inferior to the inguinal ligament. In pulseless patients, the femoral artery can be assumed to be at a point half-way along a line drawn from the pubic tubercle to the anterior superior iliac spine, at a level 1–2 cm inferior to the inguinal ligament. The femoral vein is located 0.5–1.5 cm medial to the center of the femoral artery, depending upon the size of the patient [34].

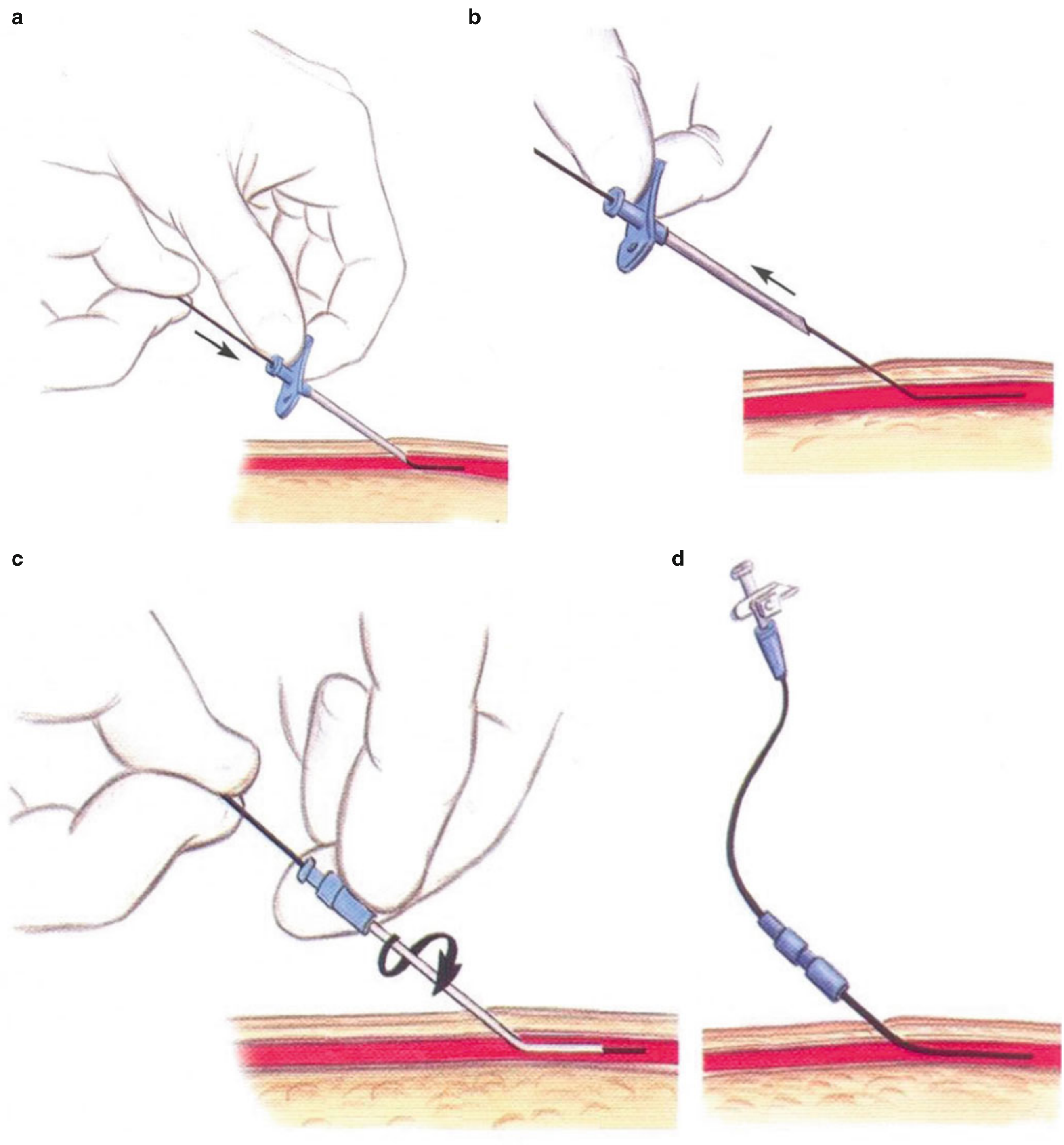

Fig. 29.2 Seldinger Technique for central venous catheter insertion. (**a**) Insert needle into the target vessel and pass the flexible end of the guidewire into the vessel. (**b**) Remove the needle, leaving the guidewire in place. (**c**) Using a twisting motion, advance the catheter into the vessel. (**d**) Remove the guidewire, and connect the catheter to an appropriate flow device or monitoring device (Source: PALS Provider Manual © 2002, American Heart Association, Inc)

Insertion Technique

Femoral vein insertion should be performed using the Seldinger technique [35]. The Seldinger technique was first described by Sven Seldinger in 1953 and enabled practitioners to insert a large size catheter over a guidewire that was placed in the vein by venipuncture with a small size needle (Fig. 29.2). The femoral site should be prepared and draped as for any surgical procedure and in non-emergent clinical situations, using full sterile barrier (Fig. 29.3) [36]. The optimal position of the leg can vary according to the preference of the operator – some prefer slight external rotation at the hip and others prefer full "frog leg" external rotation. The location of the femoral vein is 0.5–2 cm inferior to the inguinal ligament, just medial to the femoral artery. Because the overlying skin in the inquinal region, especially in babies, is often slack and redundant, it can be important to develop a method to maintain traction on the skin while palpating for the arterial pulse and then maintaining this traction while inserting the needle (Fig. 29.4a, b). The syringe should be held at a 30–45° angle from the skin, aimed cephalad over the femoral vein site. Some operators approach the vessel from the side maintaining traction on the skin and palpating the pulse with the opposite hand (Fig. 29.5), while others approach the vessel directly (Fig. 29.4b). Most operators locate the vein and obtain venous blood flashback by advancing the needle/syringe at a 30° angle toward the ischial ramus while withdrawing the syringe plunger, creating negative pressure within the syringe (Fig. 29.5). If venous blood is not returned, the needle/syringe should be slowly withdrawn, pulling back constantly on the plunger. If the vein is not located, redirect the needle searching from medial to lateral until the vein is located. To avoid lacerating the vessels, the needle should be withdrawn to the skin surface prior to changing direction. Puncture of the vein is indicated by blood return (flashback in the syringe) while advancing or slowly withdrawing the needle. An alternative method to locate the vein is to advance the needle/syringe over the vein site toward the ischial ramus to a depth of 1–2 cm without negative pressure in the syringe and then withdraw the needle applying negative pressure to the syringe, thus obtaining venous blood flashback on the withdrawal of the needle. The advantage of this method is that it allows the operator to firmly rest the hand on the thigh during needle/syringe withdrawal, which allows the operator to freeze when venous blood flashback occurs. This is especially important in small infants where the cross-sectional area of the needle and that of the vein are similar in size and as a result it is easy for the needle to move outside the lumen of the vessel as the syringe is gently removed from the needle. By freezing the operator's hand in position, this method allows for greater success with guidewire placement (Fig. 29.6). Kanter et al. demonstrated by use of ultrasound that the greatest probability of successful puncture of the

Fig. 29.3 Full sterile barrier during elective insertion of central venous catheter

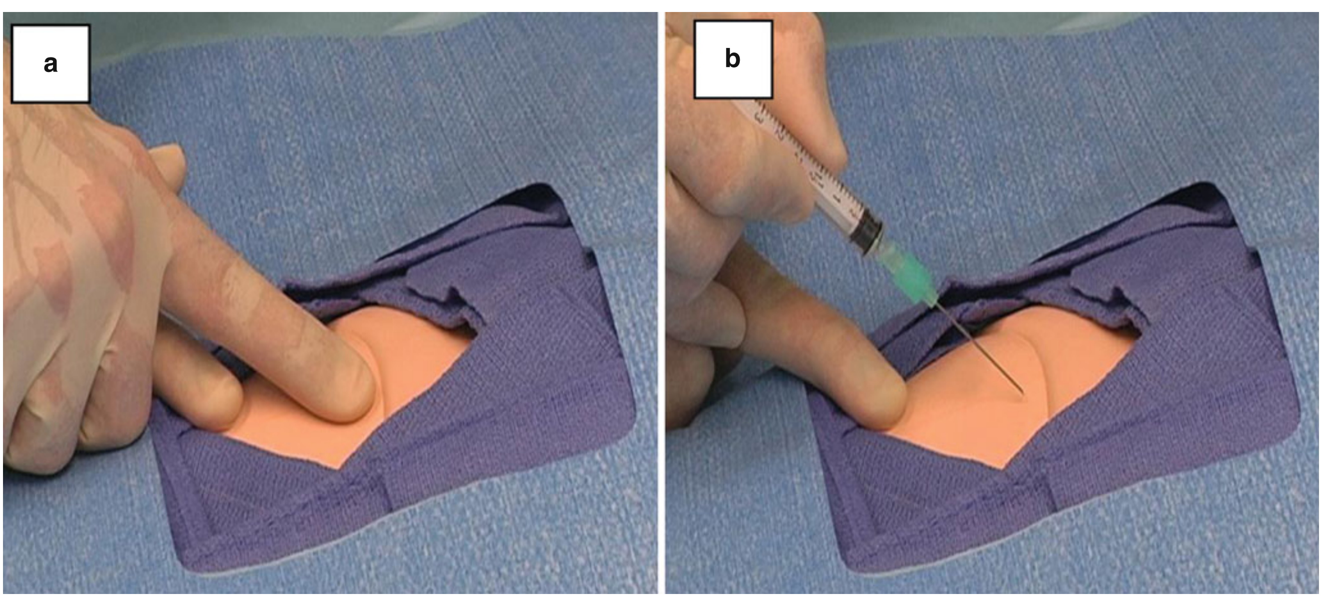

Fig. 29.4 (**a**) Palpation of femoral pulse with traction on redundant skin. (**b**) Skin traction is maintained as initial skin puncture occurs. The needle is advanced through the vessel and venous flashback occurs as the needle is withdrawn using negative pressure on the syringe

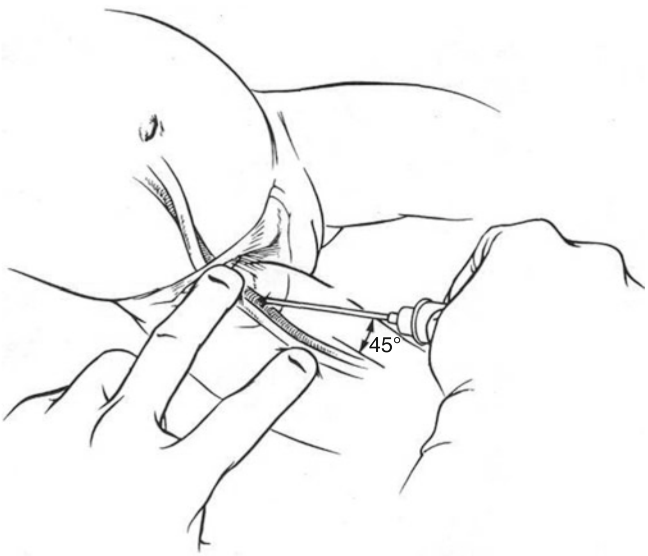

Fig. 29.5 One approach to the femoral vessel – needle and syringe advanced at 45° angle to the skin (Source: PALS Provider Manual © 1997, American Heart Association, Inc)

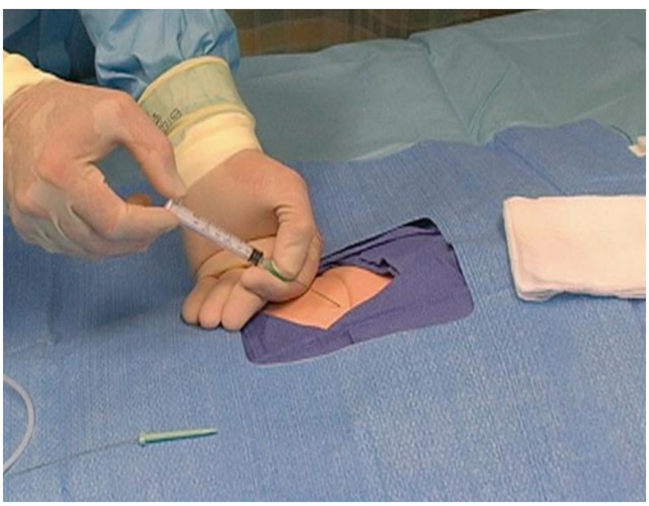

Fig. 29.6 Operator's hand resting on infant's thigh allowing the hand to freeze when venous flashback occurs

femoral vein was located 4–5 mm medial to the femoral artery pulse [37]. In addition, if it is assumed that entry into the central half of the vein will result in successful catheterization, successive attempts 5 mm and 6 mm medial to the pulse would result in cumulative successful insertion in 53 and 61 %, respectively, with no arterial punctures. A third attempt 4 mm medial to the pulse further increases cumulative success to 78 %, but the arterial puncture rate would increase to 3 %. Ultrasound guided central venous puncture is becoming common practice in adults and may increase insertion success rates and reduce insertion complication rates, especially for inexperienced operators or in difficult access patients such as obese patients, patients with poor arterial pulses, or those with partial vessel thrombosis [38].

As described by Seldinger, after observing blood return, the syringe is disconnected from the needle hub and the guidewire is advanced through the needle and into the vein. It is important to leave part of the wire in view at all times. The advancement of the wire should be smooth without meeting any resistance. If resistance occurs during guidewire advancement, it is possible the wire is meeting a previously unrecognized thrombus, is advancing into the subcutaneous tissue, or most likely is advancing into the ascending lumbar veins which drain into the common iliac veins proximal to the femoral vein. Once the wire is in good position, remove the needle over the wire, holding the guidewire in place. Make a small ¼ to ½ cm skin incision at the site of entry of the guidewire into the skin. Be certain that the bevel of the scalpel blade is away from the guidewire. Hold the dilator near its tip and advance the dilator over the guidewire into the femoral vein. The dilator should be advanced using a gentle boring motion. Holding the guidewire in place, remove the dilator while applying light pressure to the femoral site, as bleeding is likely to occur when the dilator is removed. Place the catheter over the guidewire and insert into the femoral vessel. Once the catheter is inserted, remove the guidewire and aspirate blood through the catheter to ascertain placement and patency of the catheter. Secure the catheter in place and cover with a sterile dressing.

Important warnings to consider during cannulation of the femoral vein include: (1) puncture of the femoral artery requires application of direct pressure for 5–10 min or until hemostasis is achieved; (2) never push the guidewire or catheter against resistance, properly placed guidewires float freely; (3) the guidewire can be sheared off if pulled out of the needle against resistance, if resistance is met on withdrawal of the guidewire, pull out the needle and the guidewire simultaneously; (4) the guidewire should remain in view at all times because guidewires have remained in vessels or have floated into the central circulation when not properly monitored (Fig. 29.7).

Confirmation of Placement

Confirmation of proper CVC position is required after placement of all CVCs. A post-procedure x-ray is the initial and usually only confirmatory test needed after femoral vein catheter insertion [39]. Some have questioned the value of confirmatory x-rays for uncomplicated placement of femoral venous catheters, however unsuspected catheter tip placement in the ascending lumbar veins can occur with potentially serious consequences, especially if such placement is unrecognized [40]. Several clinical variables can alert the clinician to possible improper femoral catheter placement: (1) guidewire that meets resistance during advancement - suspect ascending lumbar placement or thrombosis; (2) bright red blood or arterial pulsation when vessel puncture takes place – suspect arterial placement; (3) catheter tip on x-ray that points too cephalad – suspect ascending lumbar placement (Fig. 29.8); (4) catheter tip on x-ray that crosses the midline from the right groin position or tip that is too cephalad from the left – suspect arterial placement (Fig. 29.9). If the location of the catheter tip is in question a dye study should be performed to confirm proper placement in the vascular bed (Figs. 29.8b and 29.9b). Placing a transducer on the end of the catheter or sending blood from the catheter for blood gas determination may help distinguish arterial from venous placement.

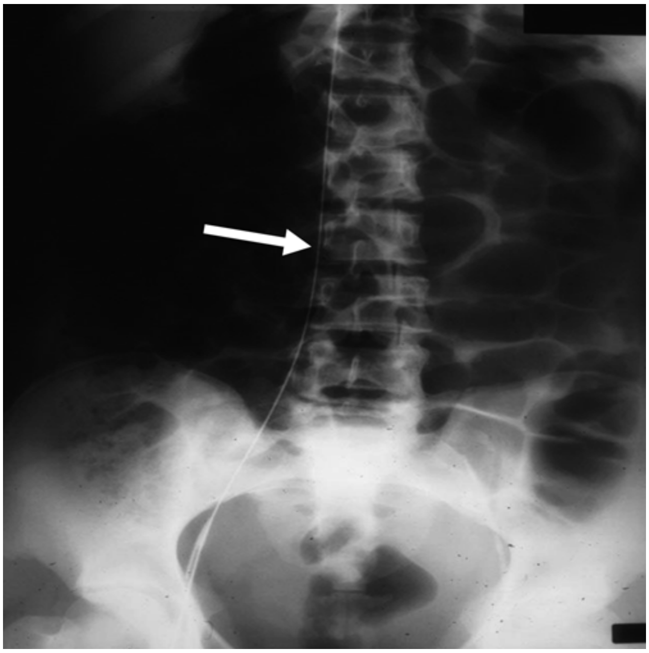

Fig. 29.7 Guidewire left in right femoral vein hemodialysis catheter (*arrow*)

Complications and Risks

Femoral venous catheterization in children is generally regarded as safe, but as with all central venous catheters, complications do occur. In a prospective study evaluating femoral vascular catheterization in children, Venkataraman et al. reported that 74 of 89 (83 %) femoral venous catheterizations had no complications during catheter insertion and the other 15 (17 %) had either minor bleeding or hematomas at the insertion site [6]. During 13 of these femoral vein catheterizations, there was inadvertent puncture of the femoral artery. Overall catheterization success rate was 94.4 %. Less experienced operators required significantly more attempts (2.6 ± 1.5) to attain success than experienced operators (1.5 ± 0.5). Forty-five (51 %) patients were ≤1 year of age. The median duration of catheterization was 5 days

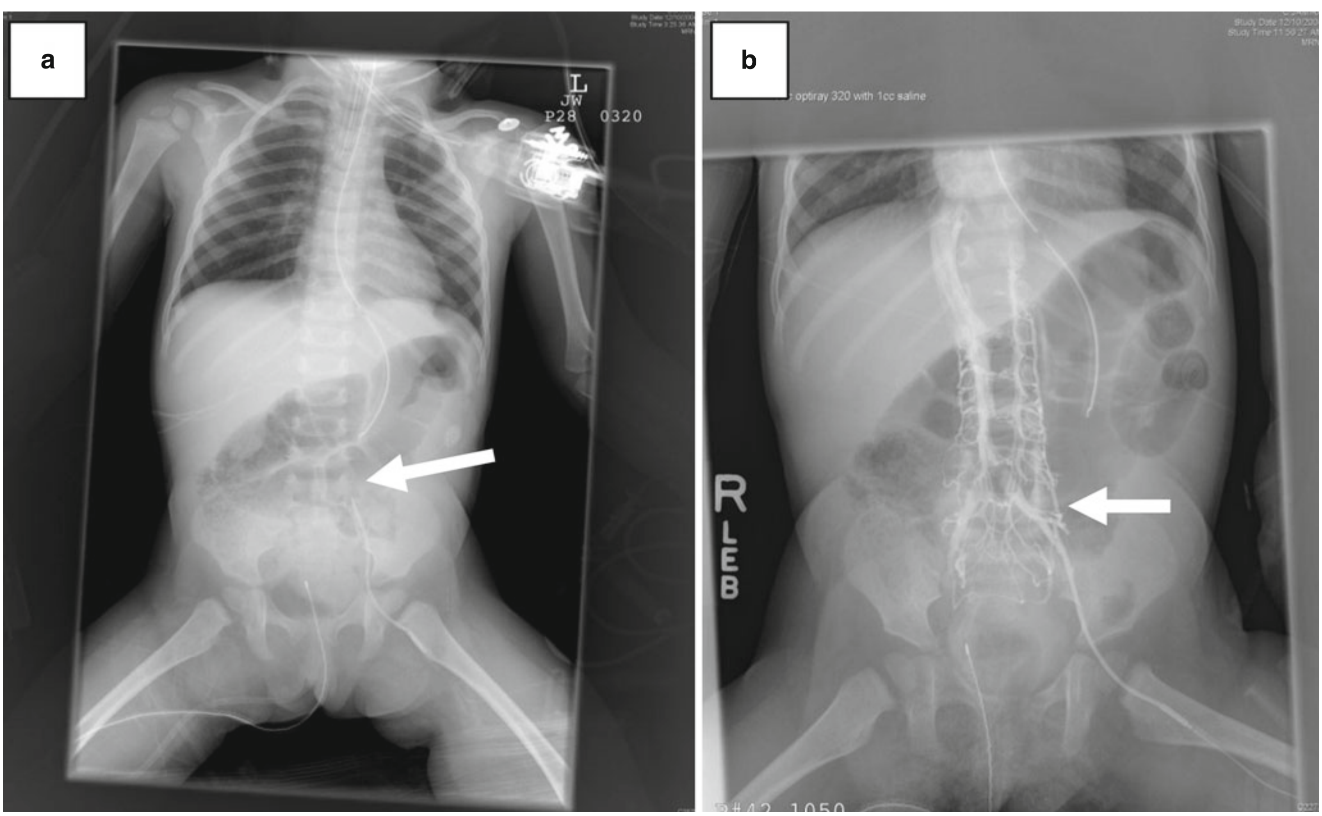

Fig. 29.8 (**a**) Left femoral venous catheter tip pointing cephalad. (**b**) Dye confirmation of ascending lumbar catheter placement

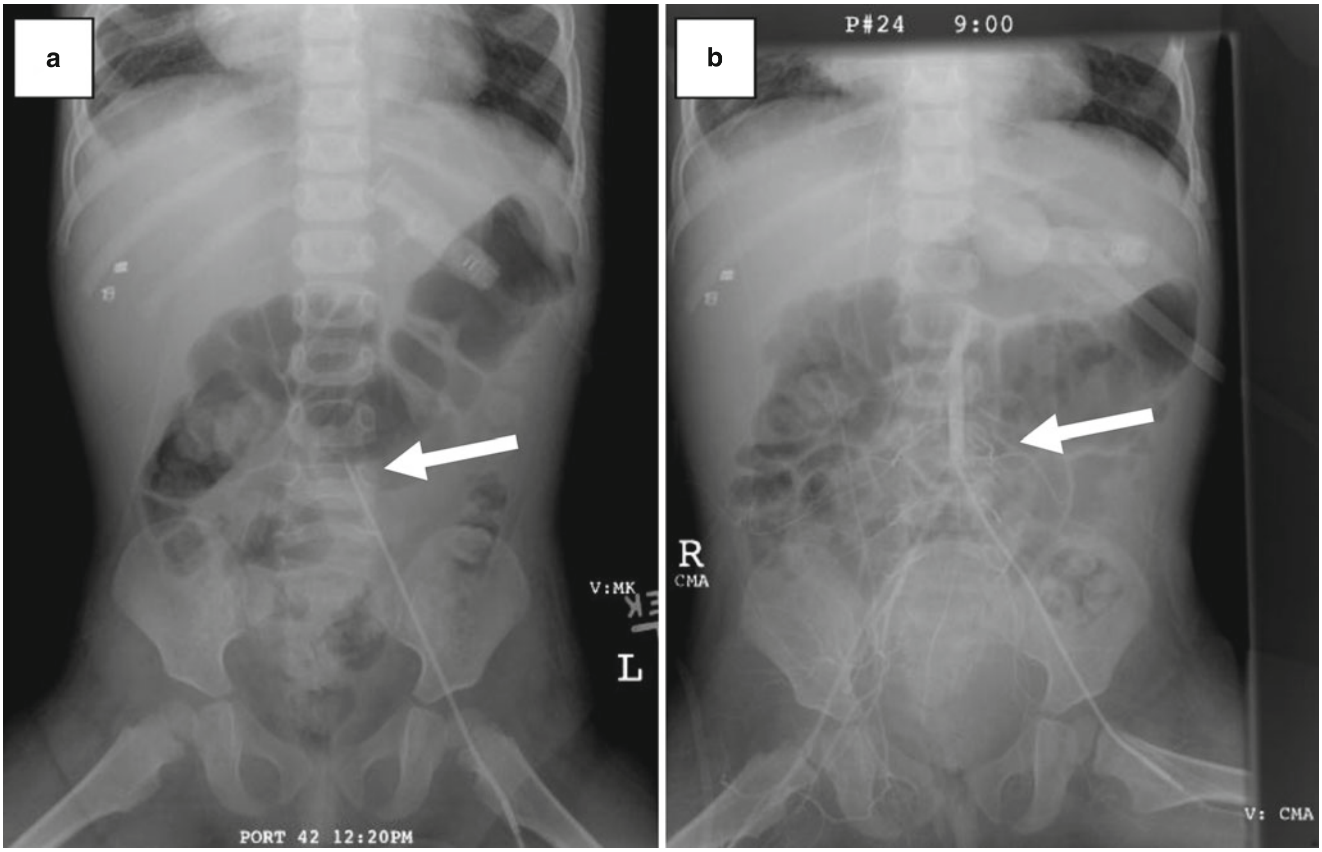

Fig. 29.9 (**a**) Left femoral catheter considered venous in patient with low blood pressure and marginal oxygenation. (**b**) Dye study (*aortagram*) confirming unexpected arterial placement

with 21 % as ≤3 days duration, 43 % as 4–7 days, 26 % as 7–14 days, and 10 % as >14 days. Long-term complications were uncommon. Sixty-eight patients had no long-term complications, eight had leg swelling (all <1 year of age) and 11 patients had either suspected or confirmed catheter related blood stream infection. Kanter also examined the safety and effectiveness of femoral central venous catheter insertion [8]. This prospective observational study included 29 pediatric patients who underwent attempted percutaneous femoral venous catheter placement. Femoral catheterization was successful in 86 % of patients attempted. Arterial puncture was the only significant complication of insertion, occurring in 14 % of patients and was not associated with adverse sequelae. The most significant complication associated with indwelling femoral central venous catheters was leg swelling or documented thrombosis, which occurred in 11 % of 74 critically ill patients during a 4 year period of observation. Lastly, Stenzel et al. prospectively reviewed complication rates over a 45 month period for percutaneously placed femoral and non-femoral central venous catheters [29]. Of the 395 catheters placed during this time period, 41 % were femoral. The mean duration of catheterization was 8.9 days. No complications occurred during femoral catheter insertion. Of the 162 femoral catheters, nine non-infectious complications occurred, which included four thromboses, one vessel perforation, one embolism, one catheter discontinuity, and two bleeding episodes. Stenzel concluded, "Femoral venous catheterization offers practical advantages for central venous access over other sites. The low incidence of complications in this study suggests that the femoral vein is the preferred site in most critically ill children when central venous catheterization is indicated."

Subclavian Vein Catheterization

Demographic and Historical Data

The infraclavicular approach to subclavian vein catheterization was originally introduced in 1952 [41]. Supraclavicular approaches to the subclavian vein have been described but have not gained wide popularity as the primary approach for subclavian vein catheterization, though complication rates between the two approaches are similar [42]. Groff and Ahmed were among the first to describe their experience with subclavian vein catheterization in children [43]. They reported upon 28 patients all less than 1 year of age (20 newborns plus eight infants less than 6 months of age). Complications included one hemothorax, one pneumothorax, and two hydrothoraces. They concluded that subclavian catheterization in children was safe. More recently, Venkataraman et al. described their experience with infraclavicular subclavian catheterization placement by non-surgeons in 100 consecutive patients [10]. One-third of their patients were less than 1 year of age. The overall success rate was 92 % and even under emergency conditions the success rate was 89 %. Minor complications were few and included bleeding at the site, hematomas, and self-limited premature ventricular beats. There were six major complications, four pneumothoraces, and two catheter related blood stream infections. Others have concluded that subclavian vein catheterization in children, even under emergency conditions, is safe and is associated with few major complications, especially when performed by experienced operators [11, 44, 45].

Indications

In adult patients, internal jugular and subclavian vessels are preferred sites for central venous catheterization because the rates of infection and deep venous thrombosis appear less than that found with femoral central venous catheterization, however in children these differences are less clear [2]. Furthermore, in children, operator experience and need for minimal sedation when placing femoral catheters, are important drivers of the decision process regarding which vessel is preferred. For long-term central venous access, the subclavian vein has long been the preferred route for central venous access in children because it is easily inserted via the tunneled approach, is well tolerated, and is associated with few complications [46]. For elective or emergency percutaneous central venous access in children, the subclavian vein can be catheterized safely as described previously, however some specific clinical situations may further guide the decision to use this vessel. In obese or edematous patients, the clavicle can act as an easily identifiable landmark to assist in vessel cannulation, thus making the subclavian vein the preferred approach [47]. In patients with shock, the subclavian vein may be preferred because it is less likely to collapse than the internal jugular vein. The subclavian approach is not ideal in uncooperative patients, especially non intubated children, in patients with abnormal chest anatomy, patients with previous clavicular fracture, or those with bleeding diathesis [48]. In the event of unplanned subclavian artery puncture during catheterization attempts, patients with significant coagulopathy may be at greater risk because it is difficult to apply direct compression to the artery. Lastly, some report that the technique for subclavian vein catheterization is not enhanced using ultrasound guidance, whereas femoral and internal jugular vein catheterization success rates and complication rates can be improved using ultrasound guidance [49, 50]. Using ultrasound guidance, Gualtieri et al., were able to demonstrate increased success rates for subclavian vein catheterization, especially for less experienced operators [51]. They also reported no major complications.

For cervicothoracic central vein catheterization, controversy exists regarding which vessel is preferred – internal jugular or subclavian veins. No pediatric specific data exists which compares the rates of success and complications for these two approaches, however a recent systemic review has been published for adult patients [52]. Pooled data from 17 reports from 1982 to 1999 were analyzed which included nearly 2,000 jugular catheters and 2,500 subclavian catheters. Despite the many potential problems routinely associated with such a large data aggregation from multiple reports, some conclusions can be derived. Arterial punctures occurred with greater frequency with the internal jugular approach; however catheter malposition was significantly more common with subclavian vein catheterization. If rapid and correct catheter tip position is required (patient in shock requiring inotropes or hemodynamic monitoring), the jugular approach is preferred. There was no difference in the incidence of hemothorax, pneumothorax, or vessel occlusion between the two approaches. Data was too disparate to draw firm conclusions regarding comparative catheter related infection rates. Operator success rates were not reported in this review.

Anatomy

The subclavian vein begins as a continuation of the axillary vein at the lateral border of the first rib, crosses over the first rib, and passes in front of the anterior scalene muscle (Fig. 29.10). The anterior scalene muscle separates the subclavian vein from the subclavian artery (Fig. 29.10b). The vein continues behind the medial third of the clavicle where it is immobilized by small attachments to the rib and clavicle. At the medial border of the anterior scalene muscle and behind the sternocostoclavicular joint, the subclavian vein combines with the internal jugular to form the innominate or brachiocephalic vein.

Insertion Technique

The patient is positioned in a supine, head-down position of at least 15–30º (Fig. 29.11). A rolled towel or sandbag is placed under the shoulders longitudinally between the scapulae. Jung et al. demonstrated that tilting the head toward the catheterization side appears to reduce the incidence of catheter malposition during the right infraclavicular subclavian approach in infants [53]. Introduce the needle 1 cm below the junction of the middle and medial thirds of the clavicle

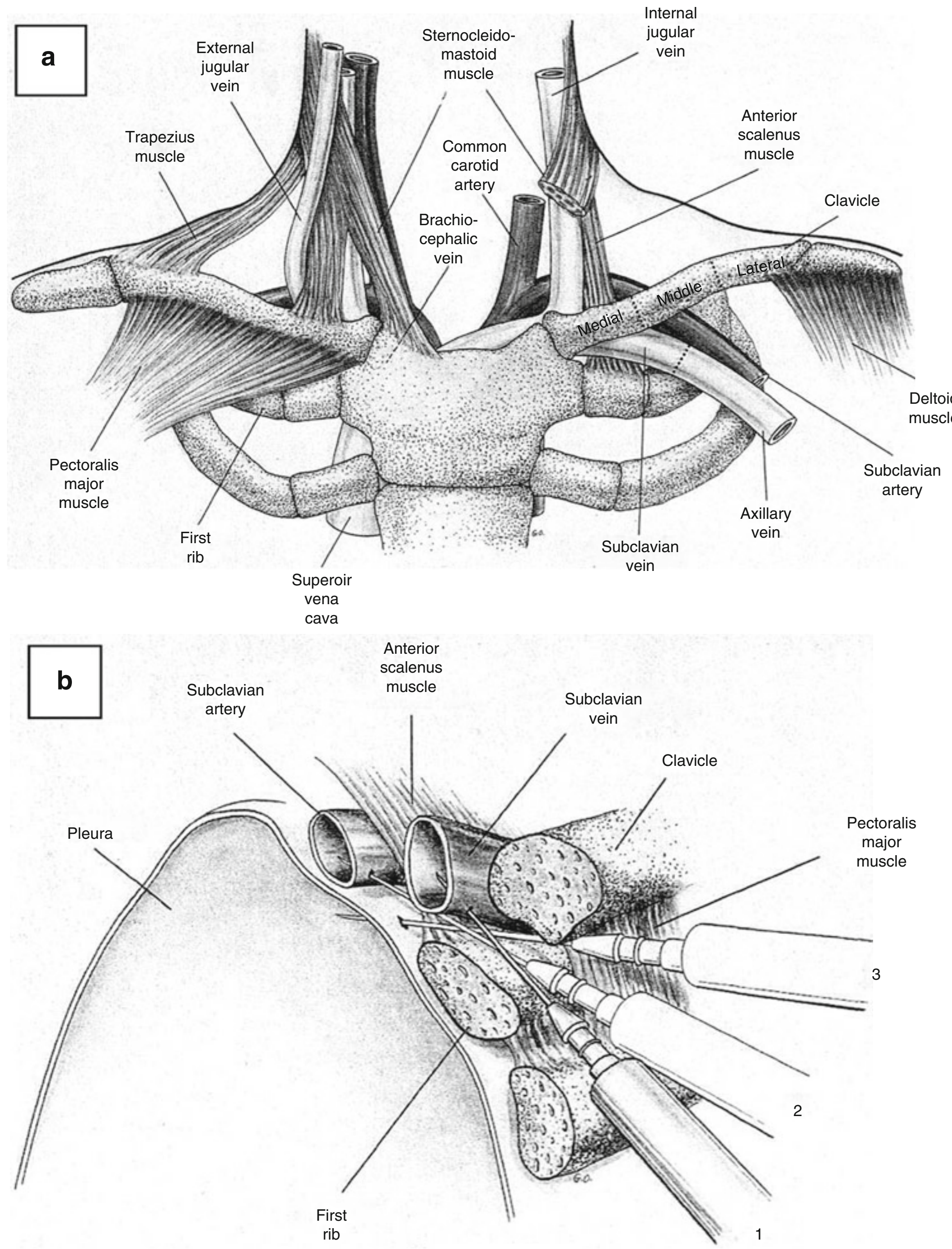

Fig. 29.10 (**a**) Clavicular landmarks and vascular anatomy. (**b**) Sagittal view: Course of subclavian artery and vein between boney structures and anterior scalenus muscle (Reprinted from Novak and Venus [47]. With permission from Lippincott Williams & Wilkins)

(Fig. 29.11b). The sternal notch acts as a landmark to direct insertion of the needle. The syringe and needle should be held parallel to the frontal plane just beneath the posterior aspect of the clavicle or "marched down" the clavicle to avoid puncturing the pleura or subclavian artery. The bevel of the needle should be oriented caudally as the vein is entered to minimize catheter tip malposition. In children, especially infants, blood "flashback" into the syringe may occur either during advancement or withdrawal of the needle/syringe, therefore it is important to withdraw the needle slowly and always with negative pressure exerted on the syringe hub. Upon entering the subclavian vein, using the Seldinger technique, a guidewire is placed through the needle to lie in the anticipated area of the superior vena cava. The catheter should be appropriately anchored to the skin and a sterile dressing placed over the site.

Proper patient position, especially in children, is an important factor that can impact successful subclavian vein catheterization. Land et al. demonstrated that when the shoulder is in neutral position the subclavian vein is overlapped by the medial third of the clavicle, thereby allowing this segment of the bone to serve as a landmark for insertion [54]. These results were confirmed by Tan et al. who demonstrated through anatomic dissection that infraclavicular subclavian venipuncture should be performed with the shoulders in a neutral position and slightly retracted, hence the vertical

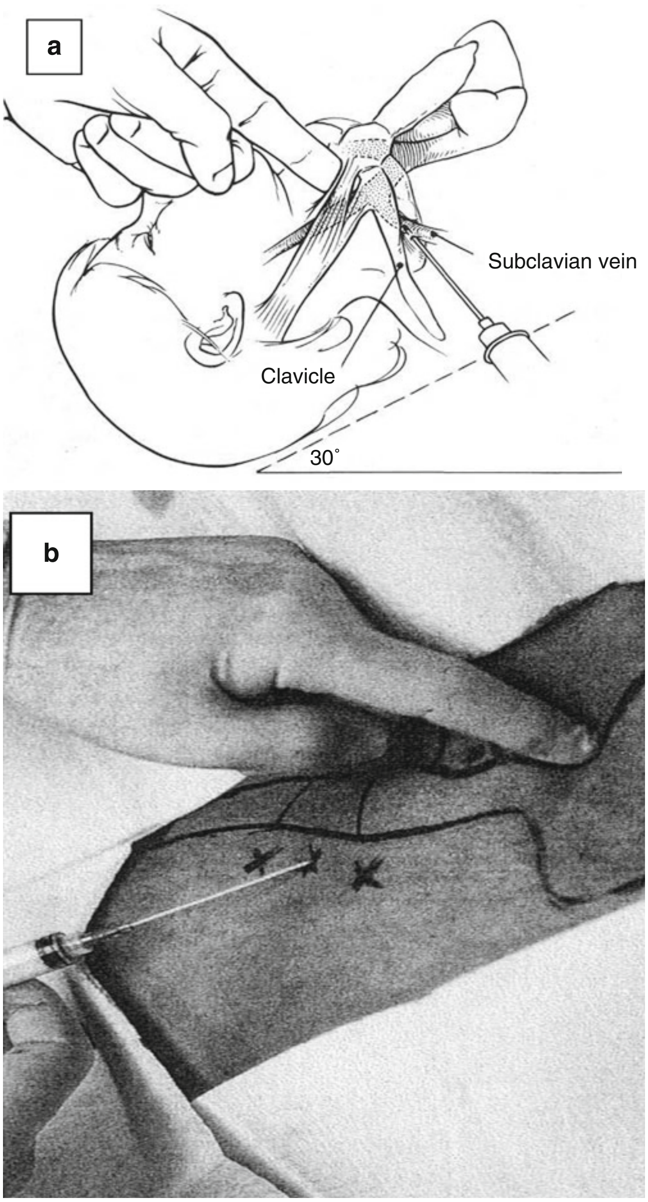

Fig. 29.11 (**a**) Subclavian vein anatomy – infraclavicular approach (Source: PALS Provider Manual © 1997, American Heart Association, Inc). (**b**) Medial infraclavicular approach (Reprinted from Novak and Venus [47]. With permission from Lippincott Williams & Wilkins)

placement of a small towel or sandbag between the scapulae will allow the shoulders to fall back into a proper position and facilitate vessel cannulation [55].

Confirmation of Placement

Significant morbidity and mortality exists with malposition of central venous catheters. Case reports demonstrate cardiac tamponade and perforation secondary to CVC insertion and catheter migration [56, 57]. A retrospective case review in children demonstrates a mortality rate of 34 % for CVC-related pericardial effusions [58]. Furthermore the Food and Drug Administration (FDA) states "the catheter tip should not be placed in or allowed to migrate into the heart" and recommends that CVC tips be positioned outside of the right atrium, preferably in the distal superior vena cava [1]. Andropoulos describes a formula for catheter insertion length that predicts positioning of the catheter tip above the right atrium 97 % of the time [59]. His report derives the formula by analyzing 452 right internal jugular and subclavian catheterizations in infants undergoing open heart surgery. The correct length of catheter insertion (cm) = (height in cm/10) – 1 for patients ≤ 100 cm in height and (height in cm/10) – 2 for patients >100 cm in height. This author has had anecdotal success in predicting proper catheter tip placement by using a "paper tape measure" to determine the distance on the chest surface from the proposed insertion site to the sternal-manubrium junction, which approximates the superior vena cava – right atrial junction.

After subclavian vein catheterization, confirmation of catheter tip placement is usually done by chest radiography however controversy exists regarding the necessity for post-procedural chest radiographs following cervicothoracic central venous catheter placement. McGee et al. described the results of a prospective, randomized, multicenter trial in adults and found that using conventional insertion techniques, the initial position of the catheter tip was in the heart in 47 % of 112 catheterizations [60]. Gladwin et al. demonstrated that the incidence of axillary vein or right atrial catheter malposition from internal jugular venous catheterization was 14 % [61]. The positive predictive value of a decision rule based on a questionnaire designed to detect potential mechanical complications and malpositioned catheters was 15 %. The sensitivity and specificity of the decision rule for detecting complications and malpositions was 44 and 55 %, respectively. This suggests that clinical factors alone do not reliably identify malpositioned catheters. Others report that chest radiography may not be necessary to confirm proper catheter placement if: (1) the procedure is performed by an experienced operator; (2) the procedure is "straightforward"; and (3) the operator requires <3 or 4 needle passes to access the vessel [62–64]. In children, no current "official" data driven recommendations exist regarding post-procedure chest radiography, however this author has observed many unexpected catheter tip placements, even in straightforward procedures, such that post-procedure chest radiography seems warranted. Figure 29.12 depicts several catheters wherein the malposition was not clinically evident and was discovered only at the time of confirmatory chest radiograph.

Complications

Reported complications from subclavian venipuncture include failure to locate the vein, puncture of the subclavian

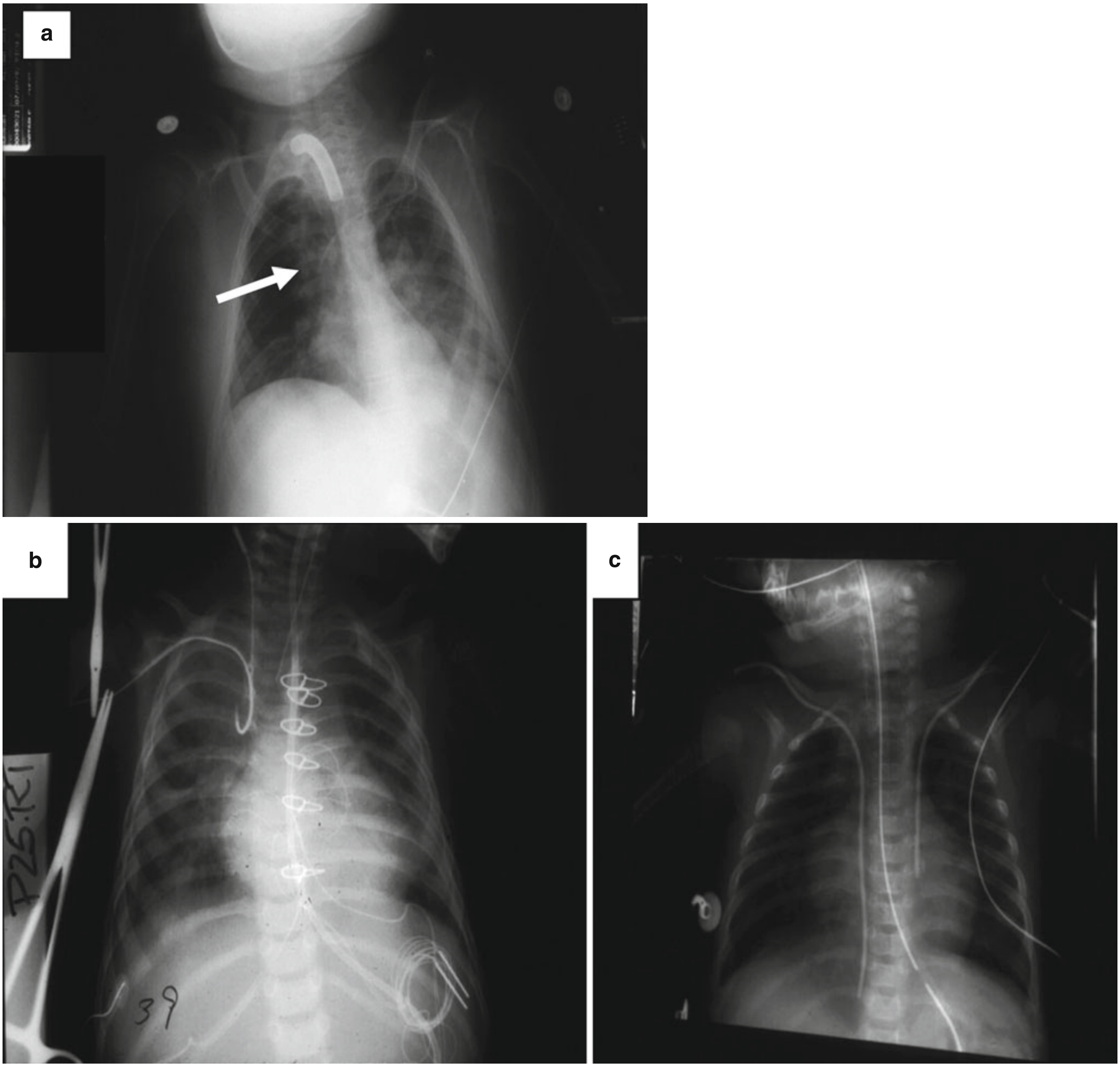

Fig. 29.12 Malpositioned subclavian catheters: (**a**) Catheter tip against lateral wall of superior vena cava (SVC). (**b**) Catheter curled in SVC. (**c**) Catheter through RA into IVC in patient with bilateral vena cavae

artery, catheter misplacement, pneumothorax, mediastinal hematoma, hemothorax, injury to adjacent nerve structures, and cannulation of the thoracic duct when cannulating the left subclavian vein. The incidences of these complications vary from 0.5 to 12 % [49, 52, 65, 66]. In general, life-threatening mechanical complications (tension pneumothorax, hemothorax) are uncommon in adults and children, occurring in <3 % of catheter insertions [10, 19, 44, 49]. In the report by Mansfield, complications occurred in greater than 25 % of those patients wherein catheterization was unsuccessful [49]. In adults, the overall failure rate of subclavian vein catheterization ranges from 10 to 19 % and is primarily dependent upon operator experience [67]. Where controversy once existed, more studies are being published which suggest that ultrasound-guided subclavian vein cannulation is the preferred method based upon data showing lower complication rates, shorter time to access, and fewer attempts to achieve vessel cannulation [49, 51, 68]. Additional discussion will follow in the section pertaining to ultrasound guided central venous cannulation.

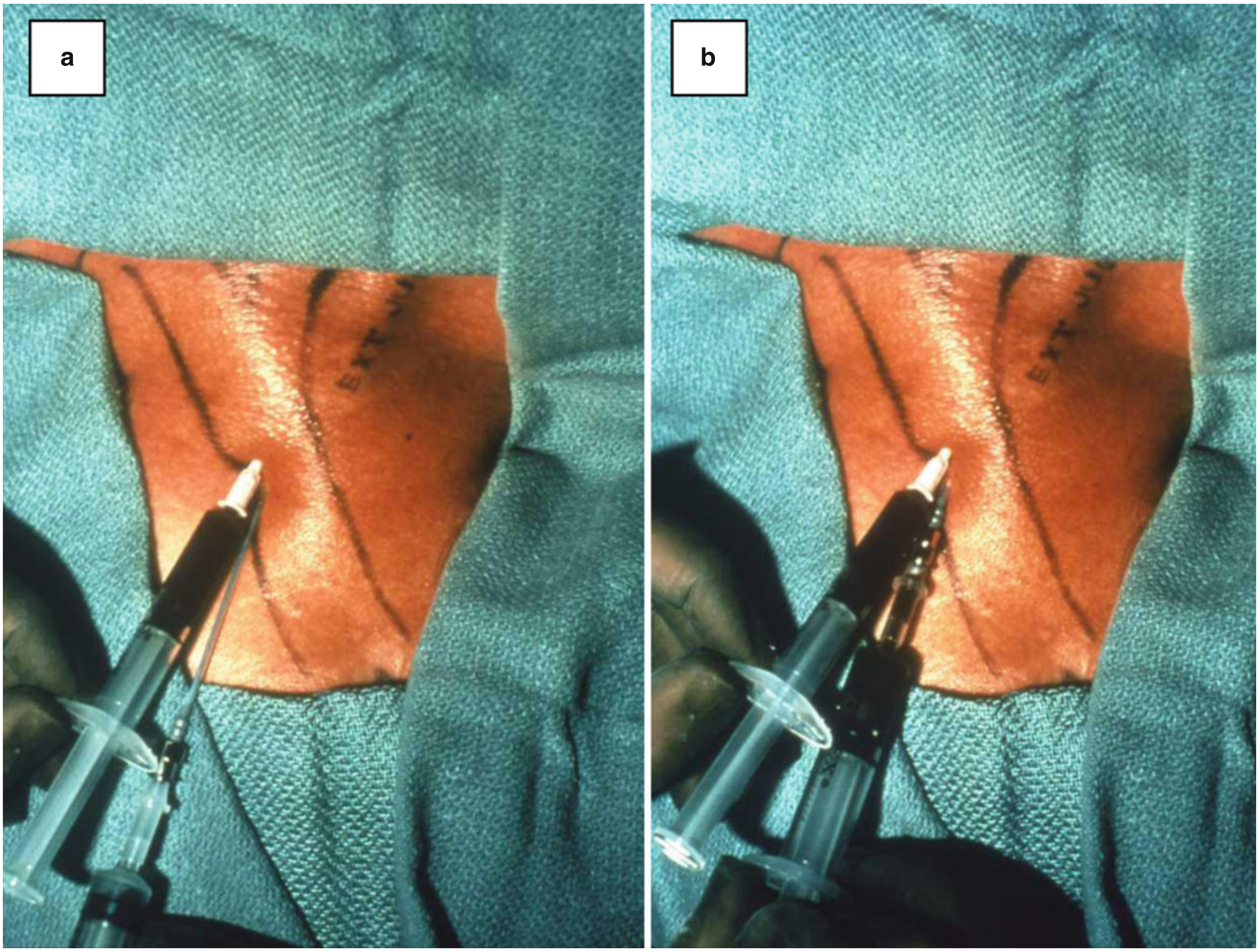

Fig. 29.13 "Finder needle" technique for IJV catheterization – anterior approach. (**a**) Small bore "finder needle" in place at apex of the triangle created by the clavicle and the sternal and clavicular bellies of the SCM and insertion of a large bore needle along the same trajectory. (**b**) Finder needle and large bore needle in place

Internal Jugular Vein Catheterization

Demographic: Historical Data: Indications for Placement

English et al. were the first to describe the safety and efficacy of internal jugular vein (IJV) catheterization in children [69]. They reported upon a series of 85 infants and children and found a 91 % success rate of catheterization and reported few complications using the medial approach to the vein. Prince et al. expanded upon the IJV experience in children and reported an overall catheterization success rate of 77 %. They also reported three patients with local hematomas at the site of insertion when the carotid artery was punctured [70]. They attributed their low rate of complications to the use of a small gauge "finder needle" to locate the vein and avoid unnecessary probing for the vein location (Fig. 29.13). Hall and colleagues described their success with two approaches (posterior and medial) to IJV catheterization in children [71]. Successful catheterization occurred in >90 % of attempts and multiple attempts did not increase complication rates. The only complications were three arterial punctures. In this series, the IJV approach was used successfully in 20 patients who required resuscitation.

Internal jugular vein catheterization is associated with a high rate of successful catheter placement. Non-emergent catheterizations are successful in more than 90 % of patients. Use of the IJV for emergency catheterization during cardiopulmonary resuscitation is more difficult primarily because management of the airway, including tracheal intubation and bag ventilation, make access to the neck less available and identification of surface landmarks for catheter insertion more difficult. IJV cannulation is often considered when other central vascular approaches are less desirable, such as in the presence of coagulation abnormalities or chest trauma. The low incidence of pneumothorax makes the IJV

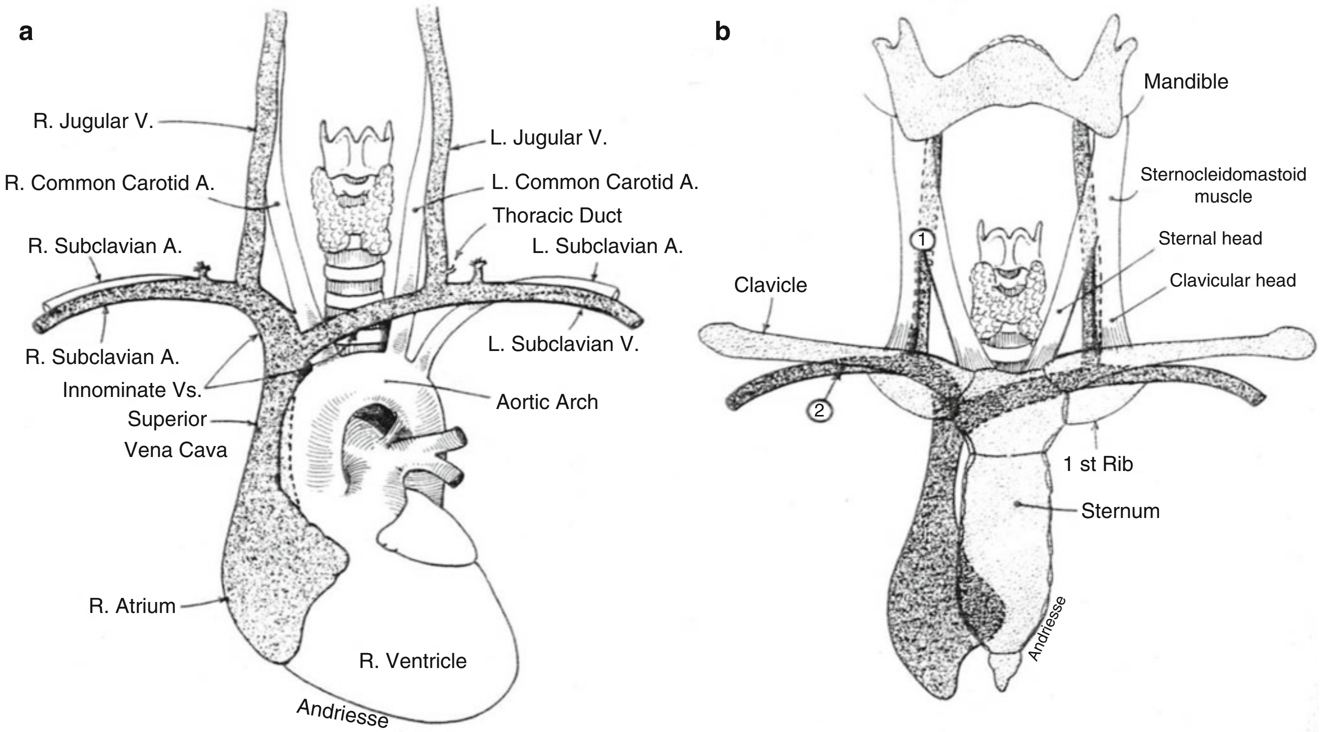

Fig. 29.14 Internal jugular vein related structures and surface anatomy (Reprinted from Todres and Cote [122]. With permission from Elsevier)

preferable in patients with significant pulmonary disease and lung hyperinflation (pleural dome elevated in the thorax) such as patients receiving high levels of positive pressure mechanical ventilatory support to treat respiratory failure. In addition, for patients with significant coagulation dysfunction, the IJV is favored because local compression of the vein or carotid artery is possible, whereas this is not an option with subclavian vein catheterization. The right IJV is also an optimal insertion site during emergency transvenous pacing, since it facilitates passage of the pacemaker through the tricuspid valve. In addition the right IJV may be preferred because of the position of the pleural dome, the absence of the thoracic duct, and the less acute angle at the junction of the IJV and innominate vein [47]. Cervical trauma with swelling or anatomic distortion at the insertion site may make IJV catheterization difficult or relatively contraindicated [72]. In adults, significant carotid artery disease is a relative contraindication to IJV catheterization.

Anatomy

The internal jugular vein emerges from the base of the skull through the jugular foramen, and enters the carotid sheath anterior and lateral to the carotid artery (Fig. 29.14).

The internal jugular vein usually runs beneath the triangle formed by the sternal and clavicular heads of the sternocleidomastoid muscle (SCM) as it approaches the underside of clavicle. The caliber of the IJV increases as it approaches the clavicle. The vein is closer to the skin surface at the level of the clavicle as well. Beneath the clavicle the right internal jugular vein joins the subclavian vein to form the innominate vein, which continues in a straight path to the superior vena cava. The left internal jugular vein joins the left subclavian vein at nearly a right angle; consequently any catheter inserted into the left IJV must negotiate this turn [73] (Fig. 29.15d). The carotid artery usually lies medial and posterior to the IJV in the carotid sheath. In children positioned with their head in the neutral position, Roth et al. demonstrated that the IJV was most often found antero-lateral and anterior (54 and 24 %, respectively) in relation to the carotid artery [74]. The stellate ganglion and the cervical sympathetic trunk lie medial and posterior to the IJV. Near the junction of the IJV and the subclavian vein is the pleural dome, with the left pleural dome slightly more cephalad than the right. The lymphatic duct is adjacent to the junction of the left IJV and innominate vein. Anatomic variation of the IJV is common and clinical maneuvers can significantly affect vessel dynamics (vessel caliber). These variations can have an important impact upon success rates for IJV catheterization. Using ultrasound, Mallory et al. determined that palpation of the carotid artery decreases the IJV lumen cross-sectional area [75]. He suggests that when attempting IJV cannulation, a mental note should be made regarding

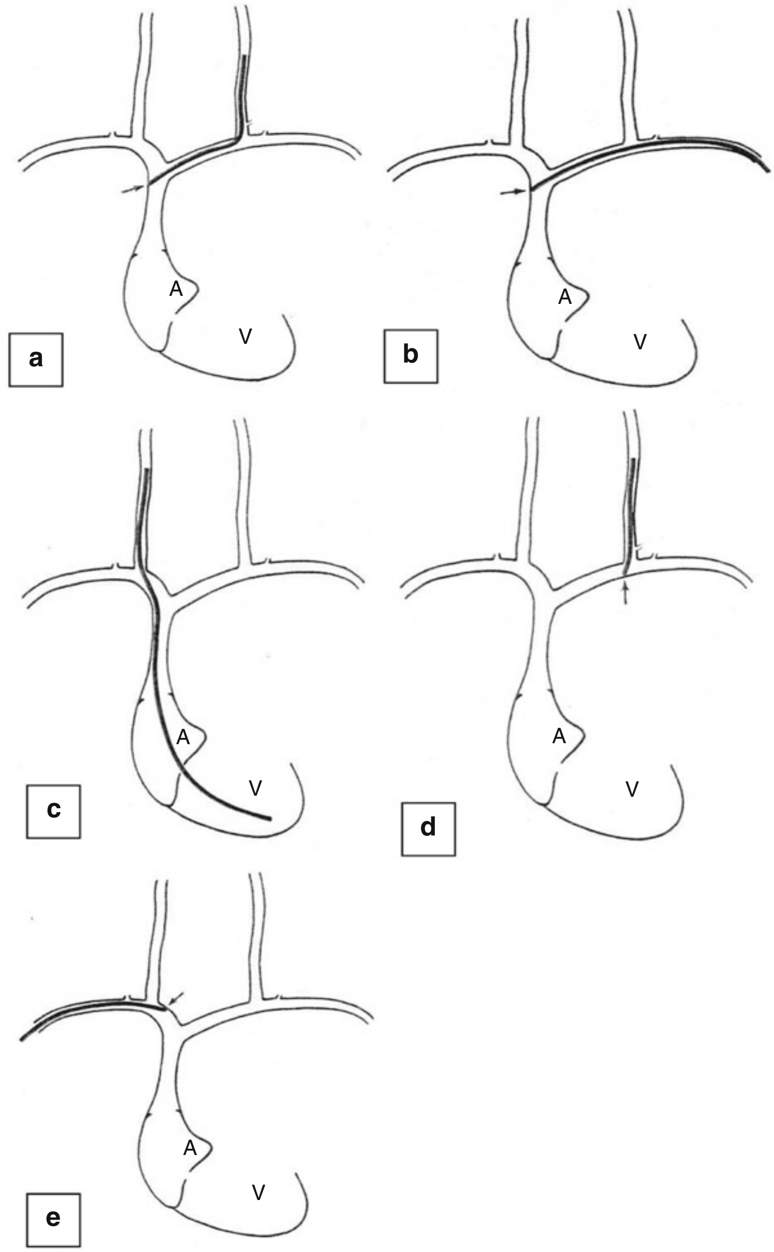

Fig. 29.15 Cervicothoracic catheter placement – catheter tip malpositions: (**a**, **b**) Catheter tips striking lateral wall of superior vena cava – vessel erosion risk. (**c**) Ventricular placement. (**d**) Short left IJV catheter striking innominate vein wall – vessel erosion risk. (**e**) Short right subclavian catheter striking lateral wall of innominate vein – vessel erosion risk (Reprinted from Todres and Cote [122]. With permission from Elsevier)

the position of the carotid artery; however the artery should not be palpated during actual needle/syringe insertion. Maneuvers that increase the cross-sectional area and internal diameter of the IJV include: (1) Trendelenburg position with a 15–30º of head-down tilt; (2) the valsalva maneuver; and (3) retracting the skin over the vein in a direction opposite to the direction of the advancing needle. In addition, clinical conditions which increase right atrial pressures also increase the vessel lumen cross-sectional area. In another report locating the position of the IJV by ultrasound demonstrated, in adults, that in 3 % of patients studied the IJV lumen did not increase in response to valsalva, in 1 % the IJV lumen was >1 cm lateral to the carotid artery, in 2 % the IJV was positioned medially over the carotid artery, and in 5 % the IJV was positioned outside the area which is predicted by surface landmarks [76]. Suk et al. reported that using a skin traction method using tape to stretch and secure the skin in the cephalad and caudal positions increased the ultrasound-measured cross-sectional area of the IJV by 40 % in infants and 34 % in children [77].

Insertion Technique

Detailed step by step videos on the placement of central venous catheters and the use of ultrasound guidance have

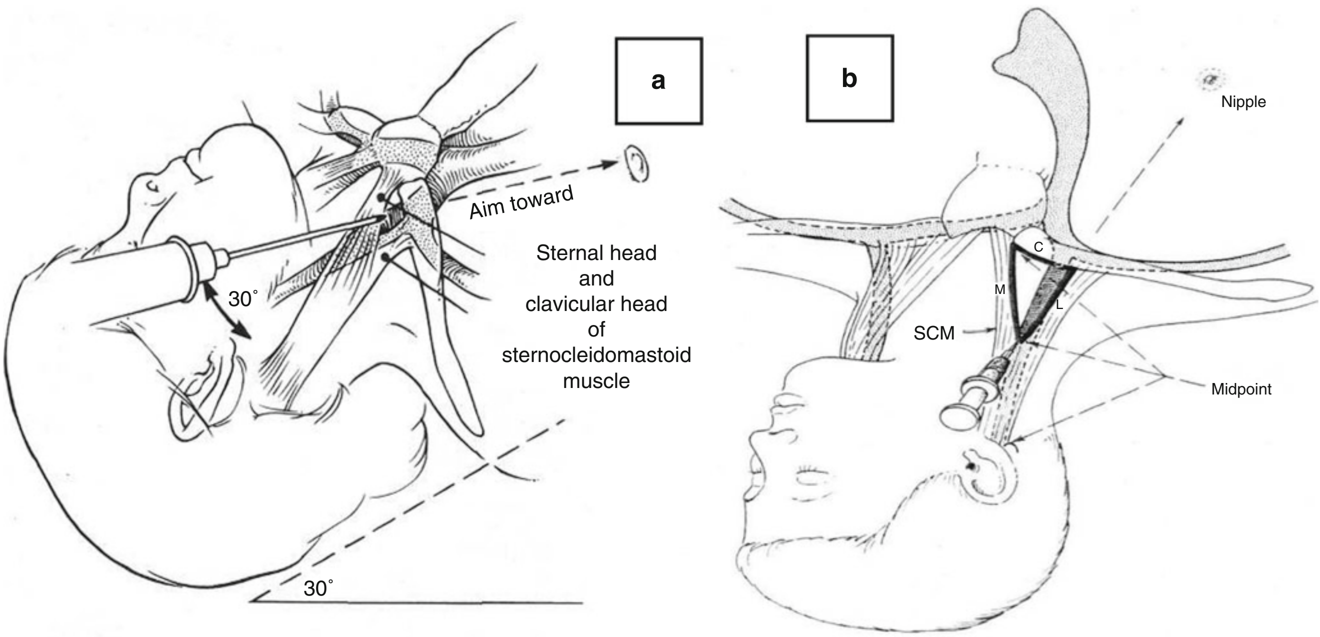

Fig. 29.16 Internal jugular vein anatomy: (**a**) Medial approach (Source: PALS Provider Manual © 1997, American Heart Association, Inc). (**b**) Medial approach with triangle between bellies of SCM (Reprinted from Todres and Cote [122]. With permission from Elsevier)

been published [78, 79]. Here we detail the insertion technique using the surface landmark method. The patient is positioned in Trendelenburg position (unless contraindicated, such as with elevated intracranial pressure) with head down 15–30º. For the medial approach (Fig. 29.16) the two bellies of the SCM should be palpated by placing the index finger in the triangle created by the clavicle and the sternal and clavicular bellies of the SCM. Retract the skin cephalad to the insertion site prior to inserting the needle into the skin. This may increase the vessel lumen cross-sectional area. During actual venipuncture, avoid trying to retract the carotid artery medially and away from the IJV as this is likely to decrease the IJV lumen diameter. For the medial approach, the approximate insertion site is one half the distance along a line from the sternal notch to the mastoid prominence. Insert the needle at an angle about 20–30º above the plane of the skin. Advance the needle while applying slight negative pressure on the syringe. Venous flashback indicating venipuncture may occur during needle advancement or withdrawal, therefore if unsuccessful during advancement then the needle should be withdrawn slowly. The needle should be completely removed from the skin prior to redirecting to avoid vessel laceration. This is particularly important in small infants. Before attempting to place the guidewire (Seldinger technique), it is important to demonstrate free flow of "blue" blood into the syringe. Do not try to place the wire if blood cannot be easily withdrawn, if the blood in the syringe is pulsating, or if the blood is obviously very oxygenated (bright red). Gently twist the syringe off the needle hub, maintain the needle in the same position and always occlude the needle hub with your finger to prevent air aspiration. The guidewire should be advanced without meeting any resistance. Resistance to wire advancement usually means the lumen of the needle is now outside the vessel. In this case, the wire can be removed and needle position slightly adjusted. If in trying to remove the wire, resistance is encountered, this can mean the wire is bent near the needle bevel. In this case the wire and needle should be removed together. This reduces the risk of shearing off the end of the wire. Once the guidewire is successfully advanced, the needle can be removed while holding the guidewire in place. Be careful not to advance the guidewire to its full length as cardiac arrhythmias may occur. Make a small ¼–½ cm skin incision at the site of entry of the guidewire into the skin. Be certain that the bevel of the scalpel blade is away from the guidewire. Hold the dilator near its tip and advance the dilator over the guidewire into the IJV. The dilator should not be fully advanced as its purpose is to dilate the subcutaneous tissue and make a hole in the vessel. Holding the guidewire in place, remove the dilator while applying light pressure to site. Place the catheter over the guidewire and insert into the IJV. Once the catheter is inserted, remove the guidewire and aspirate blood through the catheter to ascertain placement and patency of the catheter. Secure the catheter in place.

Posterior and anterior approaches to the IJV can also be used. These have similar success rates for cannulation and because the insertion sites are higher (more cephalad) in the neck, these approaches may carry lower risk of pneumothorax. Figures 29.16 and 29.17 depict all three approaches.

Some have suggested that using a "finder needle" to locate the IJV both reduces the incidence of carotid artery puncture

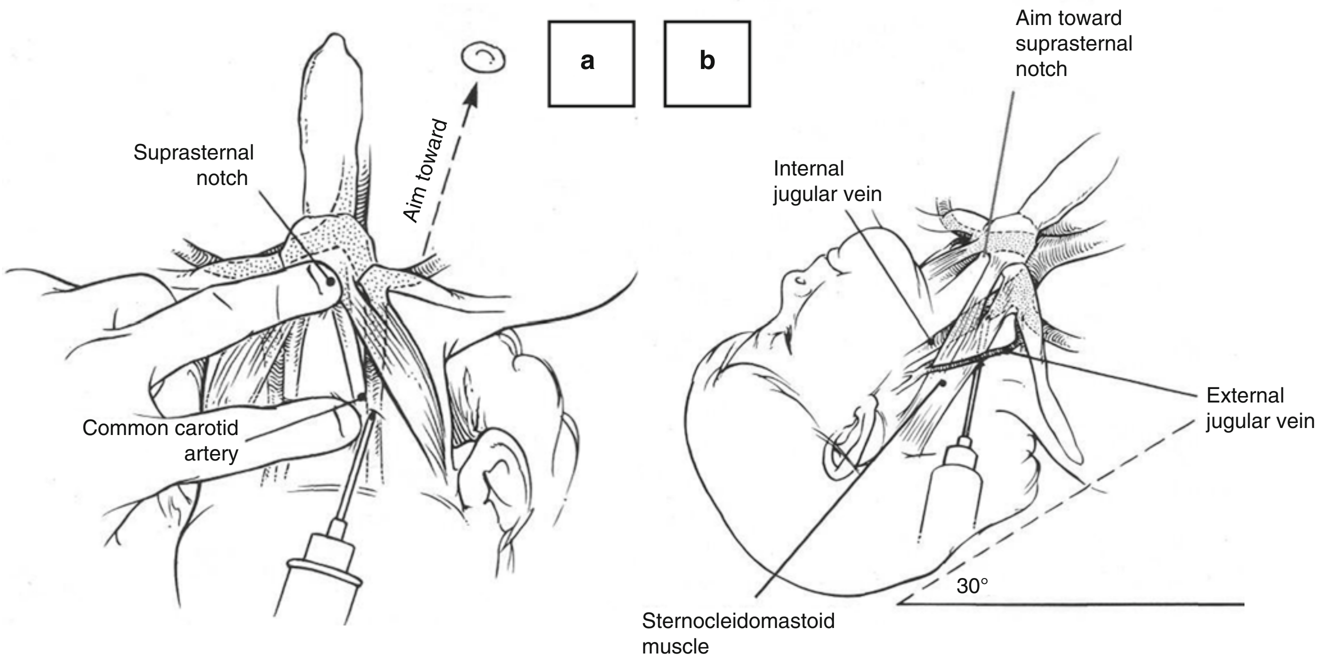

Fig. 29.17 Alternative approaches to IJV catheterization: (**a**) Anterior. (**b**) Posterior (Source: PALS Provider Manual © 1997, American Heart Association, Inc)

and if advertent arterial puncture occurs, the smaller bore "finder needle" will cause less damage to the arterial wall and reduce the sequelae that might occur from carotid artery hematoma. Figure 29.13 demonstrates first finding the IJV with a small bore needle and then advancing the larger bore needle along the same trajectory as the "finder needle." Alternatively, the finder needle can be removed and the large bore introducer needle advanced in the same plane as the initial finder needle. This technique may be most useful in obese patients with poor surface landmarks or in patients with coagulopathy wherein puncture of the artery may be more problematic than usual.

Confirmation of Placement

Optimal location of a catheter in the internal jugular vein is in the superior vena cava near the junction with the right atrium, but not in it. Chest radiography is commonly used to confirm the position of the central venous catheter tip. Clinical controversy regarding the need for post procedure chest radiography is similar to that described for subclavian vein catheterization. As reported previously, Gladwin found that 14 % of IJV catheter tips were malpositioned in a series of 107 consecutive adult patients [61]. Given the risk of unrecognized catheter malposition, which because of small patient size, may be greater in children than adults, post procedure chest radiography is warranted even in patients who are clinically unchanged post procedure.

Complications

Other than complications related to catheter maintenance (infections and thrombosis), complications related to catheter insertion are uncommon. Arterial puncture is the most common complication and is usually easily resolved with direct pressure to the punctured vessel. Nicolson reported an 8 % incidence of arterial puncture but minimal sequelae from the arterial puncture because she used the finder needle technique to avoid puncturing the artery with the large bore needle that is needed to pass the guidewire [80, 81]. Arterial puncture is significantly more common with IJV catheterization than with subclavian vein catheterization, with a reported incidence of 2–11 % in adults [52, 73, 82]. Pneumothorax or hemothorax are rare complications with an average incidence of 0–0.2 % [27, 76, 83, 84].

Catheter tip malposition is a frequent complication of all central venous catheters and IJV catheters are no exception. As previously described, dysrhythmias, pericardial tamponade, and mediastinal effusions have been reported when stiff plastic catheters erode through thin vessel walls [58, 85, 86]. Figure 29.18 depicts several IJV catheter malpositions in children. Figure 29.18b shows a short left IJV catheter with its tip at the IJV – innominate junction. Subsequent chest radiograph reveals a widened mediastinum filled with lipid as a result of vessel erosion by the catheter and extravasation of parenterally administered lipid into the mediastinum (Fig. 29.18c). Figures 29.19 and 29.15 depict both correctly positioned and malpositioned cervicothoracic catheters. Malpositioned catheters are at high risk for vessel erosion.

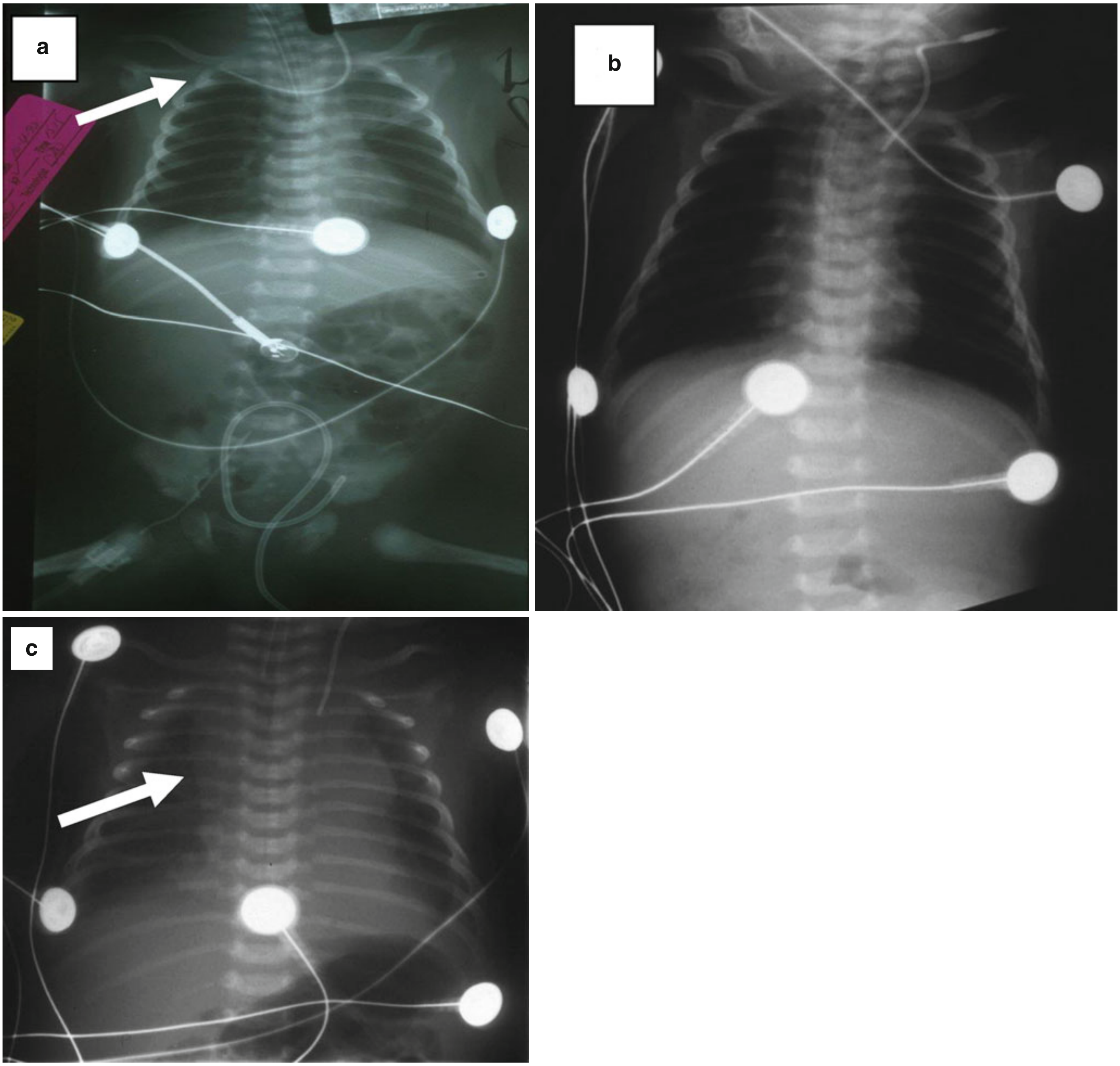

Fig. 29.18 (**a**) Left IJV catheter malposition in right subclavian vein – no recognized complications. (**b**) Left IJV malpositioned in innominate vein. (**c**) Catheter erodes through vessel wall – widened mediastinum with lipid extravasation

Axillary Vein Catheterization

Demographic and Historical Data: Indications for Use

The axillary vein is an alternative, and less commonly discussed, access site for central venous catheterization in children. A percutaneous approach to axillary vein catheterization was first described in 1981 and a modified technique further described in very low birth weight infants [87, 88]. These reports demonstrated a high success rate for cannulation with minimal complication rates. Oriot's report included axillary vein catheterization in 226 neonates with only nine failures [88]. In a few patients, non-persisting extrasystoles occurred during catheter insertion but disappeared with correct positioning of the catheter. No intrathoracic complications were noted. Metz reported on a cohort of 47 critically ill children (age 14 days to 9 years) who underwent 52 separate attempts at axillary vein catheterization. His reported success rate for cannulation was 79 % [89]. The most common reasons the axillary vein was used included: (1) poor alternative access sites; (2) need for hyperalimentation; (3) need for central

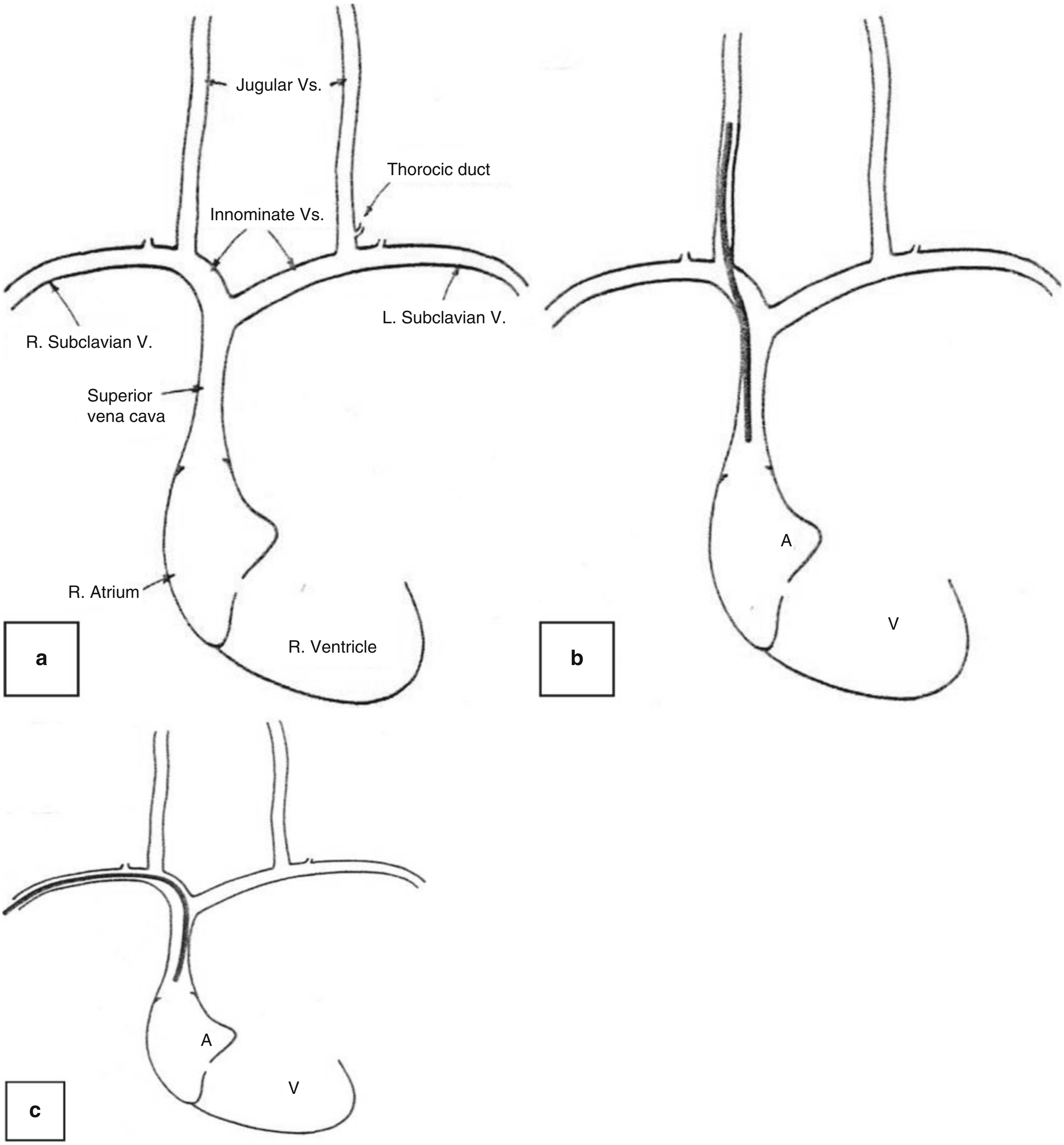

Fig. 29.19 Cervicothoracic catheter placement – proper catheter tip positions: (**a**) Normal vascular anatomy. (**b**) Right IJV. (**c**) Right subclavian vein (Reprinted from Todres and Cote [122]. With permission from Elsevier)

venous pressure monitoring; and (4) preservation of femoral vessels for cardiac catheterization.

Martin has recently reported his experience with single lumen axillary catheters placed in 60 adults in a surgical intensive care unit [90]. Insertion complications were infrequent and deep venous upper extremity thrombosis occurred in 11 % of the patients. He concluded that because the thrombosis rates were similar between axillary vein and cervicothoracic catheters, the axillary vein offered an attractive alternative when other sites were unavailable.

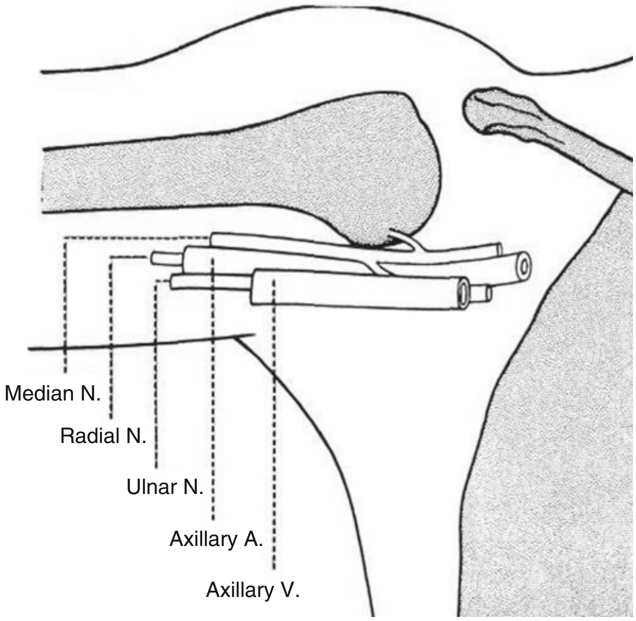

Fig. 29.20 Axillary vein anatomy (Reprinted from Metz et al. [89]. With permission from American Academy of Pediatrics)

Anatomy

The axillary vein begins at the junction of the basilic and brachial veins running medial, anterior and caudal to the axillary artery. In the chest at the lateral border of the first rib it becomes the subclavian vein. The artery and vein lie within the axillary fascia and the brachial plexus runs between the artery and vein (Fig. 29.20).

Technique

Catheter insertion is accomplished with the child placed in the Trendelenburg position, if not contraindicated, and the arm abducted between 100º and 130º. The position of the axillary artery is determined by palpation while retracting the redundant axillary skin with the opposite hand. The vein is punctured parallel and inferior to the artery as described by Gouin [91]. A 22-gauge short Teflon catheter can be used to cannulate the vein as if inserting a peripheral venous catheter. Alternatively, a thin-walled needle appropriate for the central venous catheter use can be used to obtain venous flashback. The needle/syringe should be inserted using negative pressure on the syringe hub. Once venous blood is obtained, the syringe is carefully disconnected from the needle and the guidewire inserted as per standard Seldinger technique. The axillary vein in children is very mobile in the axillary soft tissue and the greatest challenge to cannulation is fixing the vein in position so that the needle can enter the vessel. Firm traction of the redundant skin can help with this issue.

Complications

Complications associated with axillary vein insertion include failed cannulation, catheter malposition, arterial puncture, transient paresthesia, pneumothorax and axillary hematoma [92, 93]. The frequency of complications reported by Metz in a pediatric cohort is low – with complications of insertion occurring in 3.8 % – one pneumothorax and one hematoma [89]. Four additional complications occurred while the catheter was in place and these included venous stasis of the arm, venous thrombosis of the subclavian vein proximal to the catheter tip, parenteral nutrition infiltration secondary to catheter dislodgment, and one catheter-related infection.

The axillary vein route has a lower rate of successful cannulation and results in higher incidence of catheter malposition and arterial puncture when compared with IJV catheterization, however the IJV route had a greater risk of pneumothorax [93]. Axillary vein catheter insertion success was 84 %, which is lower than IJV catheterization. Martin concluded that this rate of success was acceptable when other sites are less unavailable.

Ultrasound-Guided Central Vein Catheterization: The New Standard?

Traditionally percutaneous insertions of CVCs have been performed by utilizing anatomic surface landmarks. Recently, bedside use of Doppler ultrasound has been used to facilitate vessel visualization. In some settings, the use of ultrasound increases catheter placement success rates, especially for novice operators, and reduces complications. Doppler ultrasound assist with catheter placement was first reported in 1984 [94]. Gualtieri et al. demonstrated in a prospective, randomized study that subclavian vein catheterization was successful in 23 of 25 (92 %) attempts using ultrasound guidance compared to 12 of 27 (44 %) using conventional landmark techniques [51]. In the hands of less experienced operators, ultrasound guidance improves subclavian vein cannulation success and in high-risk patients with obesity or coagulopathy, the use of ultrasound improved cannulation success with fewer significant complications [95].

In adults, multiple reports have shown that ultrasound guided central venous access is associated with decreased number of attempts, higher access success rates, and fewer catheter insertion related complications compared to surface landmark techniques [50, 96–98]. A randomized, controlled clinical trial in adults compared the overall success rate for IJV cannula placement by comparing dynamic (real-time) ultrasound, static ultrasound and surface anatomical landmarks. The odds for successful cannulation using dynamic ultrasound was 54 (95 % CI 6.6–44.0) times higher compared to landmark methodology [38]. Recently, Fragou et al.

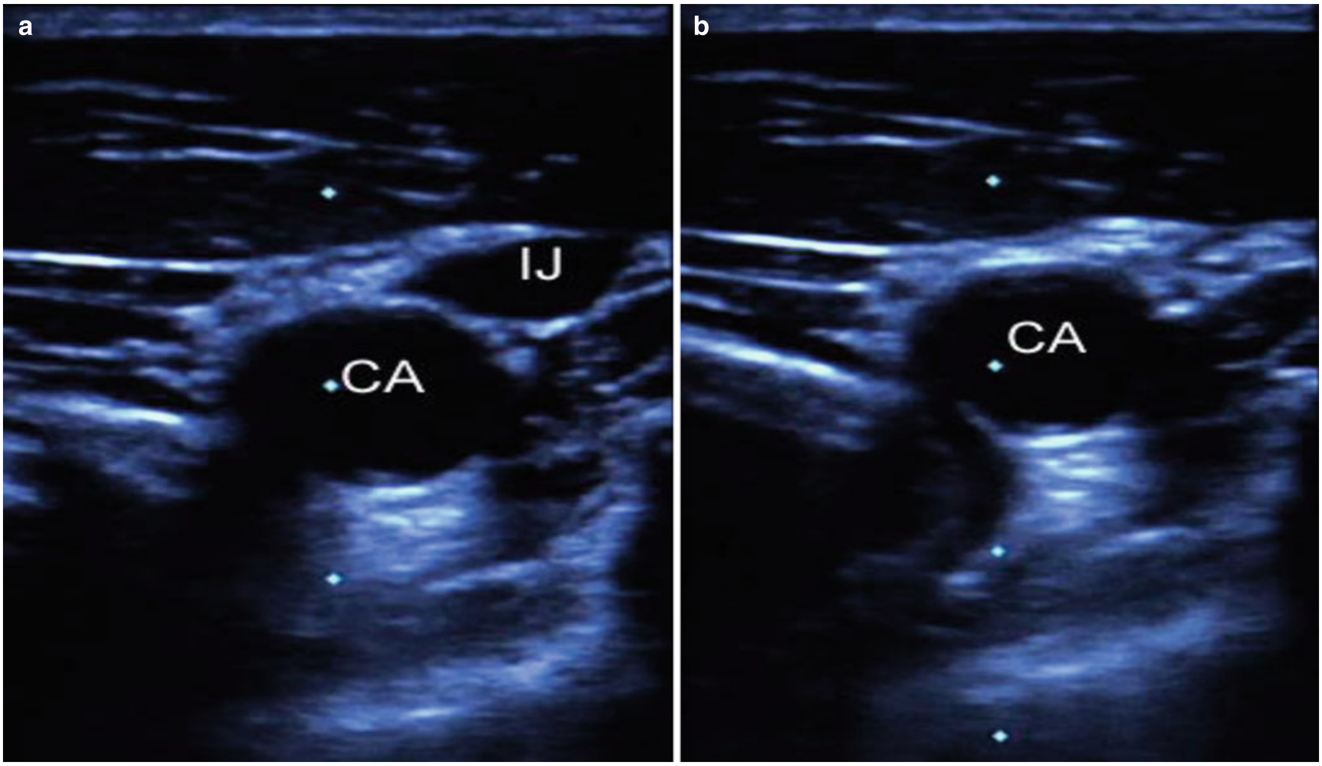

Fig. 29.21 Ultrasound image of internal jugular (*IJ*) vein and carotid artery (*CA*) with the ultrasound probe lightly touching the skin (**a**) and with gentle pressure compressing the IJ vein but maintaining the diameter of the CA (**b**)

compared ultrasound-guided infraclavicular subclavian vein cannulation to landmark methodology and found significantly shorter access time, fewer attempts, and complications in the ultrasound group compared to the landmark group. Catheter misplacement was not different between groups. They suggest that ultrasound-guided subclavian vein cannulation should be the method of choice [68].

Similar findings regarding the benefits of ultrasound guidance have been demonstrated in pediatric patients. The success rate for IJ catheter placement in infants prior to cardiac surgery was 100 % in the ultrasound group compared with a 77 % success rate in the group who underwent catheter placement by landmarks only [99]. In a separate study, Verghese also demonstrated that US-guidance for IJ catheter placement led to quicker cannulation times and fewer attempts [100]. In a recent meta-analysis, Sigaut et al. analyzed five clinical trials that compared ultrasound guidance to anatomical landmarks during IJV access in pediatric patients [101]. The authors found that ultrasound guidance had no effect on the rate of complications or IJV failure rate. However, in this study, four of the five studies were performed in cardiac surgery patients and therefore the results may not be generalizable to the heterogeneous pediatric intensive care unit population.

Prospective clinical data on the use of ultrasound guidance in the general PICU population is limited. Froehlich et al. performed a prospective study in a quaternary multidisciplinary pediatric intensive care unit [102]. The overall success rate and time to success of CVC placement was not significantly different between the landmark and ultrasound groups. However, 40 % (37/93) of the patients in the landmark group required four or more attempts compared with only 20 % (24/119) of the patients in the ultrasound group. The number of inadvertent arterial punctures was less in the ultrasound group compared with the landmark group, and all arterial punctures occurred at the femoral site. A national survey of the use of bedside ultrasound in pediatric critical care was recently conducted by Lambert et al. [103]. Seventy percent of responders stated they currently use bedside ultrasound. Pediatric ICUs with greater than 12 beds, greater than 1,000 yearly admissions, and university-based institutions with either a pediatric critical care medicine fellowship or a cardiovascular thoracic surgery program were more likely to use bedside ultrasound for CVC placement. The preferred site for bedside ultrasound was “almost always” or “frequently” the IJV. Importantly, formal training on bedside ultrasound use occurred in 20 % of ultrasound using responders. Figure 29.21 depicts IJV and carotid artery images as observed using ultrasound guidance.

The advantages associated with ultrasound guided central venous catheter placement include detection of anatomic variations and exact vessel location, avoidance of central veins with pre-existing thrombosis that may prevent successful central venous catheter placement, and guidance of both guidewire and catheter placement after initial needle insertion. The greatest benefit for use of ultrasound guidance may occur for the inexperienced operator and for all operators in high-risk clinical situations. The results from randomized controlled clinical trial in adults, comparing success rates for catheterization and complication rates were so compelling in favor of real-time ultrasound guided placement of percutaneous central venous catheters that some have called ultrasound guidance the "new standard of care" [36, 104].

In summary, the use of ultrasound guided CVC placement in pediatrics occurs commonly and should be in the arsenal available to all practitioners who place central catheters. These authors believe that the data in children pertaining to ultrasound use is sufficient to require that it be available for bedside use, but not sufficient to require its use in all circumstances. Clinicians should continue to use their judgment about when to apply this important adjunct for line placement. Furthermore inexperienced operators and physicians in training may benefit the most from the use of bedside ultrasound during CVC placement.

Complications Associated With Central Venous Catheter Placement

Central venous catheters are associated with numerous complications, some minor and others life-threatening. These complications are primarily related to mechanical complications at the time of catheter insertion or complications that occur during maintenance of the catheter. Catheter associated blood stream infections and catheter related thrombosis are major complications that occur during catheter maintenance and have been the subject of excellent recent reviews and are topics of other chapters in this text [105, 106]. They will not be the subject of this review. Furthermore, mechanical complications associated with insertion have been previously discussed under the heading for each type of catheterization and the reader is referred to those sections. A brief summary will be included here.

A retrospective review of over 1,400 central venous catheters placed in children demonstrated that age, sex, type of catheter, primary disease, indication for placement, level of physician training, and operator experience were not associated with increased complication risks [22]. Conversely, in a study by Sznajder et al. the complication rate for inexperienced physicians was double the rate of more experienced physicians when performing central venous catheter insertion [67].

Pneumothorax

In children, pneumothorax is reported as a complication in 1–2 % of CVC insertions placed by surgical staff surgical and in 4 % of patients when performed by nonsurgical staff [10, 22, 107]. More recent data indicates that a pneumothorax occurred in only two out of 156 patients (1.2 %) who underwent central venous catheter placement by pediatricians skilled in emergency procedures [108].

Arterial Puncture

Using classic Seldinger technique arterial puncture occurs during central venous catheter insertion in 1.5–15 % [8–10, 22, 94, 109]. Merrer et al. demonstrated that catheter insertion during the night was significantly associated with the occurrence of mechanical complications including arterial puncture [19].

Catheter Malposition: Femoral Catheters

It is important to determine catheter placement because malposition of central venous catheters can result in both morbidity and mortality [40, 110]. Malposition of femoral catheters in the ascending lumbar vein is an infrequent complication but if left in place can result in tetraplegia. Zenker et al. reviewed contrast radiographs taken immediately after insertion of 44 transfemoral catheters in a neonatal intensive care unit [40]. Malposition of catheters in the left ascending lumbar vein was detected in two newborns. Paravertebral malposition has been previously reported in neonates [111–113]. These reports demonstrate that catheter position was initially misinterpreted or assessed inadequately until the onset of complications. In newborns, the vertebrolumbar and azygous systems represent an extensive, highly variable, intercommunicating network in which alterations in pressure and flow direction may occur. The large capacity of the lumbar veins and the vertebral plexus can compensate for occlusion of the inferior vena cava. Use of catheters misplaced in this posterior system can give rise to retroperitoneal, peritoneal or spinal epidural fluid extravasation [98, 114, 115]. Ultrasonography, lateral radiography, or venogram is required in cases in which the location of the catheter tip is in question. Catheters in the ascending lumbar vein or vertebral plexus should be removed immediately. Warning signs that may indicate catheter malposition include: (1) loss of blood return on aspiration; (2) subtle lateral deviation, or "hump," of the catheter at the level of L4 or L5 on frontal abdominal radiographs in catheters placed from the left side (Fig. 29.8); (3) a catheter path directly overlying the vertebral column rather than the expected path to the right of midline for a catheter in the inferior vena cava; (4) resistance to guidewire advancement during insertion [96]. A lateral abdominal radiograph may confirm the posterior position of the catheter, however this author has found that a venogram (injecting dye directly into the catheter – Fig. 29.8) is the best method to confirm proper placement of these catheters.

Catheter Malposition and Post Procedure Chest Radiographs: Cervicothoracic Catheters

As noted previously, Fig. 29.15 depicts cervicothoracic catheter malpositions that are potentially hazardous. Three recent reports describing experience in adult patients conclude that a postprocedure chest radiograph is unnecessary in the asymptomatic patient after IJV catheterization when using fluoroscopy or ultrasound during catheter placement [116–118]. Similar recommendations are made for subclavian vein approach. A study in adults focusing on the subclavian vein catheterization concluded that postprocedure chest radiograph has minimal benefit and is not necessary, unless the patient shows sign of clinical deterioration post procedure [119]. Others have advocated that a postprocedure chest x-ray may be omitted in cases after line placement when experienced clinicians use good technique and good clinical judgment [61, 120]. In pediatrics little data driven recommendations are available, however Janik reports that routine chest x-ray is not indicated after uneventful central venous catheter insertion when monitored with concurrent fluoroscopy [121]. These recommendations were based on a low rate of complications of 1.6 %. In addition, all children who had pulmonary complications displayed signs and symptoms suggestive of impaired respiratory function. This recommendation may not be relevant to the pediatric ICU setting where catheters are rarely placed with fluoroscopic guidance. In the ICU, these authors recommend chest radiography after all percutaneously placed central venous catheters, regardless of post procedure clinical status.

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