Chapter 3
Ultrasound for Vascular Access

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Introduction

Central venous access is an invasive procedure that carries its own inherent life-threatening risks and complications (Table 3.1) [1–4]. Precision and protocol are required for implementation of a proper ultrasound technique. In the intensive care unit (ICU), central venous access is required for fluid management in shock patients, delivery of inotropes and vasopressors, measurements and monitoring

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Table 3.1 Complications of central venous access

Regional
Immediate
• Inadvertent arterial puncture
• Hematoma
• Pneumothorax
• Hemothorax
• Catheter malposition
• Air embolism
• Arrhythmias
• Thoracic duct injury (left neck)
• Brachial plexus nerve injury
Late
• Lumen occlusion
• Venous thrombosis
• Arteriovenous fistula
• Exit-site infection
Systemic
• Catheter-related bloodstream infection (CRBSI)

Table 3.2 Advantages of ultrasound-guided central venous access

• Increased cannulation success rate
• Increased first-attempt success
• Decreased complication rate
• Detection of anatomical variation
• Detection of thrombosis
• Optimal vessel selection (e.g., internal jugular, subclavian, femoral vein)
• Confirmation of catheter site
• Rule out complications (e.g., pneumothorax)

of central venous pressure, total parenteral nutrition, hemodialysis, plasmapheresis, transvenous pacemakers, and facilitation of vascular and cardiac procedures. Insertion is contraindicated at sites of infection or thrombosis. Relative contraindications include severe coagulopathy and bleeding disorders, systemic infection, presence of a right ventricular assist device, or pacing wires at the insertion site [5]. Advantages of ultrasound-guided vascular access (UGVA) are summarized in Table 3.2 and further analyzed in this chapter.

Traditional sites for central venous access are the internal jugular, subclavian, and femoral veins. Additionally, over the past decade, peripherally inserted central catheters (PICC) have gained popularity and have been increasingly used in patients needing prolonged central venous access. Ultrasound guidance has been used to augment successful placement of peripheral intravenous lines and arterial catheters – especially in patients with difficult anatomic landmarks or in the very young.

Technical and Patient Considerations

Vein Selection

A pre-procedural scan is strongly recommended to guide the selection of an optimal target vessel [6]. Criteria that favor the selection of a vein are:

1. Vessel patency (venous collapse during breathing or compression without signs of thrombosis)
2. Easy accessibility (measure the distance between the skin surface and the vessel wall)
3. Diameter (vessel size less than three times the caliber of catheter may carry a greater risk for thrombosis) [7].
4. Anatomical variation
5. Intended purpose (i.e., neck surgery often requires infra-clavicular vascular access)
6. Intended duration for catheter placement

Complication rates after the implementation of landmark techniques differ between sites. The internal jugular vein carries the highest risk of accidental arterial puncture and hematoma, the subclavian carries the highest risk for pneumothorax, hemothorax, and catheter malposition, while the femoral vein carries the highest risk for thrombosis and infection (Table 3.3) [1, 5, 8]. The 2011 Guidelines for the Prevention of Intravascular Catheter-Related Infections recommends the use of the subclavian vein site (rather than internal jugular or femoral veins) in adult patients to minimize the risk of infection. However, the aforementioned guidelines were based on data obtained prior to the introduction of standardized insertion bundles and modern anti-infective techniques such as the use of chlorhexidine gluconate (CHG) dressing devices. Recent studies show that CHG-impregnated sponge dressing when used with the standard care decreases the incidence of major catheter-related infections from 1.4 to 0.6 per 1,000 catheter-days [9].

Table 3.3 Complication rates in different central veins[a]

Complication	Internal jugular [1]	Subclavian [8]	Femoral [5]
Arterial puncture %	10.6	5.4	6.25
Hematoma %	8.4	5.4	–
Pneumothorax %	2.4	4.9	–
Hemothorax %	1.7	4.4	–
Malposition %	–	11	–
Infection (rate per 1,000 catheter-days) [5]	8.6	4	15.3
Thrombosis (rate per 1,000 catheter-days) [5]	1.2–3	0–13	8–34

[a]Results associated with the landmark/blind method

Pre-procedural Preparations

- Selection of probe: a high-frequency (10–15 MHz) linear probe (Fig. 3.1) is commonly used for UGVA, while low frequency curved-array probes (Fig. 3.2) are reserved for vessels that might be located deeper than expected for various reasons (i.e., obese patients, subcutaneous edema, anatomical anomalies, etc.). Hockey-stick probes bearing smaller footprints are oftentimes used in pediatric patients and in neonates (Fig. 3.3).
- Sterile techniques should be followed in all cases: hand washing, full sterile barrier protection, sterile probe cover and gel (Figs. 3.4) [6].
- The ultrasound machine should be positioned opposite to the operator to facilitate direct and straightforward visualization of the screen (Fig. 3.5).

Fig. 3.1 A high-frequency linear probe is commonly used for vascular scanning

Fig. 3.2 A low-frequency convex probe can be used to scan vessels located at greater depth from the skin surface as low-frequency enhances the deeper penetration of the ultrasound beam

Fig. 3.3 A hockey-stick probe combines high-frequency scanning with a smaller footprint and is commonly used in pediatric patients

Fig. 3.4 A standard central venous access kit and ultrasound probe with a sterile cover

Tips to Differentiate Veins from Arteries

- Shape: arteries tend to be circular and veins elliptical.
- Size: the vein is usually larger than the adjacent artery and increases in size with Trendelenburg positioning.
- Compressibility: veins are easily compressible.
- Color flow fills venous lumen completely (color mode).
- Normal central venous flow on Doppler mode demonstrates spontaneity, phasicity, and augmentation.

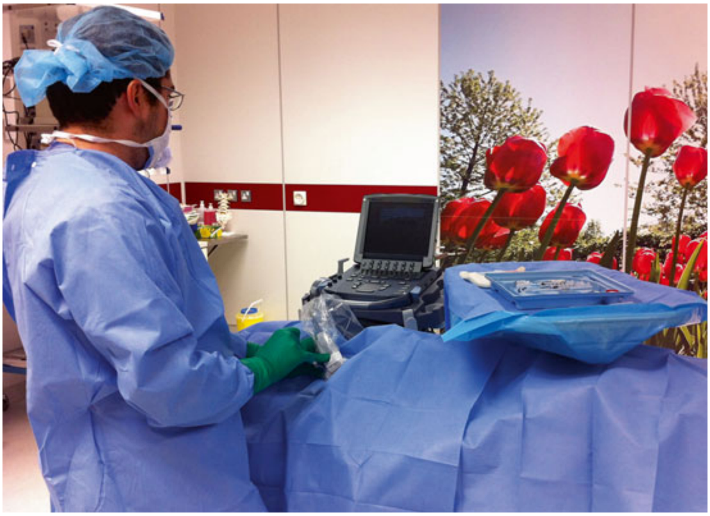

Fig. 3.5 The ultrasound machine is positioned opposite to the operator to facilitate direct and straightforward visualization of the screen in this supraclavicular cannulation of the right subclavian vein

Procedure Checklist and Bundle

The American Society of Anesthesiologists Task Force on Central Venous Access recommends the use of a central line insertion work and safety checklist and bundling of required equipment to minimize errors, risk of infection, and complications [10]. These simple measures (Pronovost's checklist) have shown tremendous reduction (up to 66 %) in central line-associated bloodstream infections (CLABSIs) [11].

Image Acquisition and Interpretation

A few practical tips when performing an ultrasound-guided central venous cannulation for the first time include:

- Always adhere to a strict sterilization process by implementing a sterile probe cover and sterile gel as previously mentioned.
- Initially, avoid pressing too hard with the probe on the cannulation site as normal veins are collapsible vessels (Fig. 3.6).

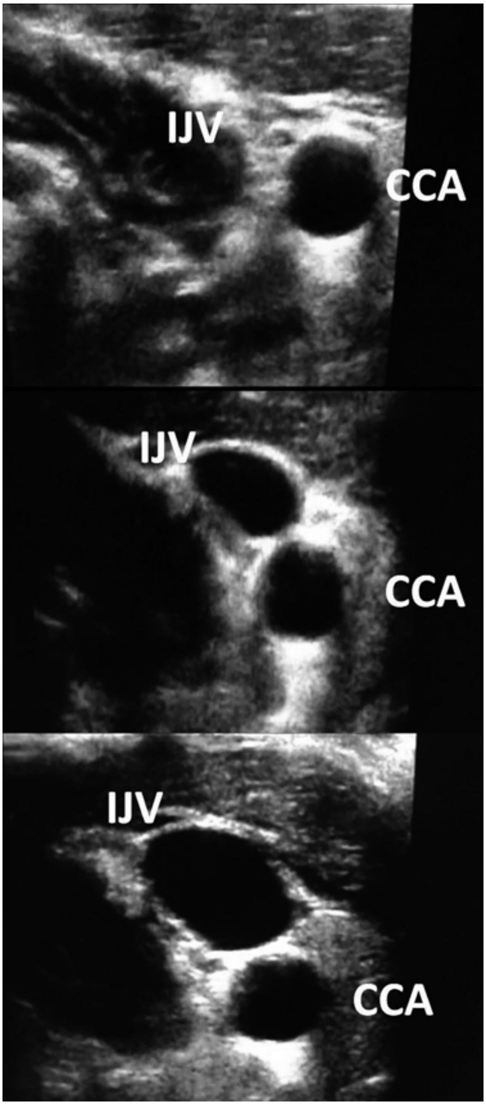

Fig. 3.6 Applying full probe pressure this patent internal jugular vein (IJV) which accompanies the common carotid artery (CCA) in the left lateral neck fully collapses and vanishes (*top*) while using less (*middle*) and light (*bottom*) probe pressure the vein gradually reappears until it reaches its full size (*bottom*)

- Optimize the two-dimensional image: center the image on the screen and adjust depth, gain, and focus, while obtaining the proper orientation of anatomy with standardization of the dot on the left.
- Once the two-dimensional image of the vein is obtained, check its patency by applying probe pressure to exclude thrombosis (Video 3.1).

Two-dimensional ultrasound can demonstrate either a short-axis view (a transverse view of the vessels) or a long-axis view (a longitudinal view of the vessels). The

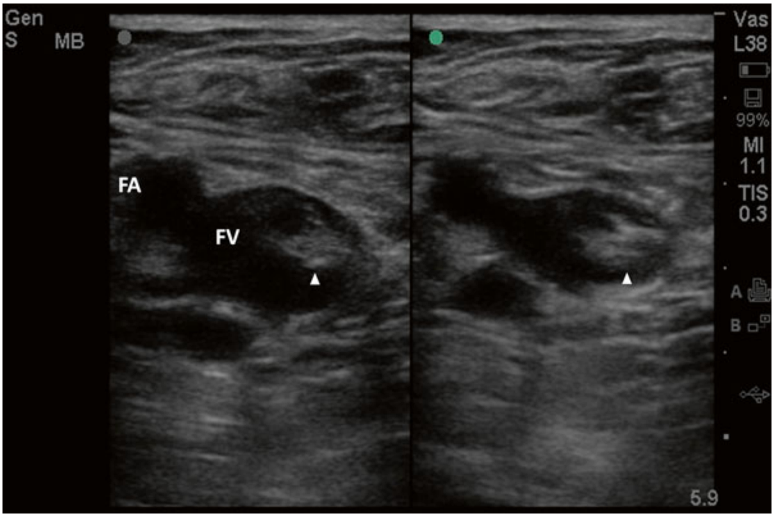

Fig. 3.7 Femoral vein thrombosis: Compression with the probe fails to collapse the vessel. *FA* femoral artery, *FV* femoral vein, *Arrow head* denotes thrombus

longitudinal axis view allows for continuous visualization of the needle trajectory and reduces the risk of posterior wall puncture. However, it requires advanced procedural skill and experience to synchronize the needle trajectory within the real-time ultrasound image. When using color-Doppler mode, operators should interpret the generated color (blue or red) dependent on probe orientation. Flow directed towards the probe will generate a red shift and flow directed away from the probe will generate a blue shift. Thus, red and blue shades in color flow do not necessarily represent the respective artery and vein but the direction of flow towards or away from the probe.

Pre-procedural scanning: detection of vessel size and patency and exclusion of possible thrombosis (Fig. 3.7). Notably, pre-procedural lung ultrasound should also be performed to exclude pneumothorax (Fig. 3.8) and thus confirm the presence of a normal aeration pattern.

For obvious reasons, catheter insertion should not be attempted when a preexisting clot exists in the target vessel. It is essential to scan the latter prior to catheterization to exclude thrombosis, especially in ICU patients. Notably, 90 % of potential thrombi originate from the femoral-popliteal system; however, upper extremity deep venous thrombosis may also occur in ICU patients. In a cohort of critical care patients, Blaivas et al. reported an incidence of upper extremity deep vein thrombosis around 11.25 % [12]. Risk factors included central venous catheter-associated

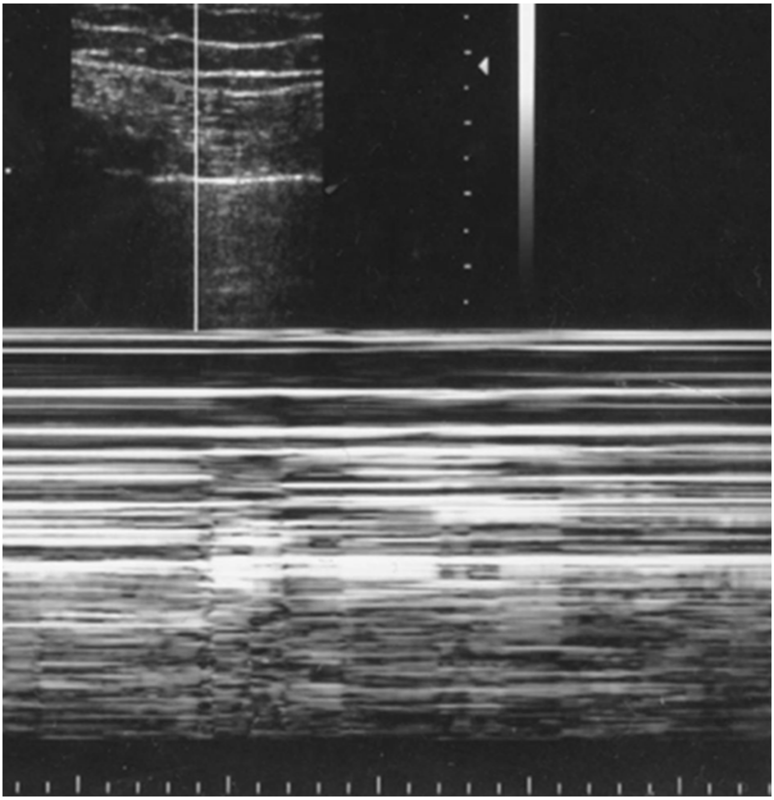

Fig. 3.8 Depiction of the barcode sign (indicative of pneumothorax) on M-mode in a patient's left anterior chest (mid-clavicular line) prior to cannulation

thrombosis, malignancy, total parenteral nutrition, hypercoagulable states, and obesity (body mass index or BMI ≥35 kg/m^2).

Ultrasound signs of venous thrombosis include lack of complete vein compression, presence of intraluminal echoes (although acute thrombus can be echolucent), decrease or absence of color flow. Also, venous Doppler demonstrates decreased or absent spontaneity, phasicity or augmentation and either dilated or contracted veins (Fig. 3.9). The sonographic detection of thrombosis aids in the diagnosis of catheter-related infections [13].

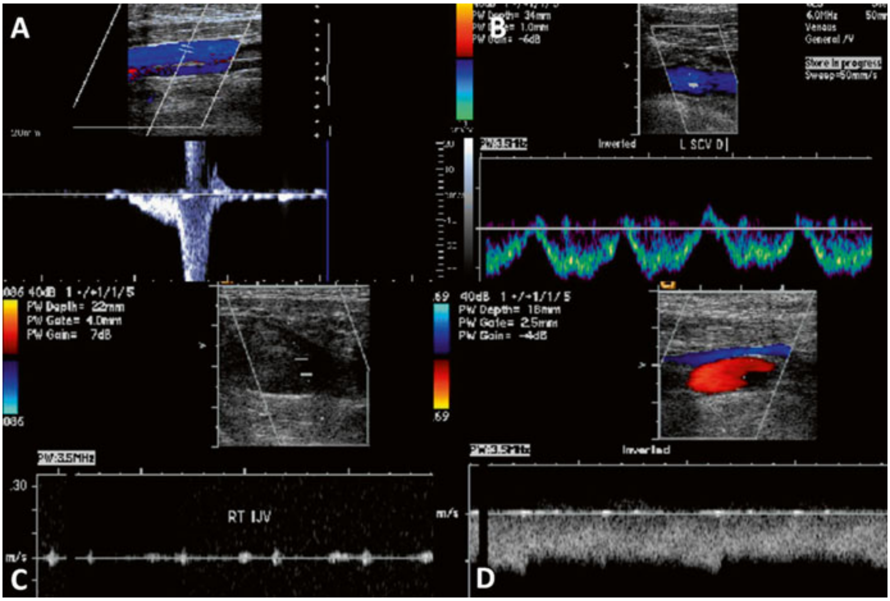

Fig. 3.9 Normal venous flow is spontaneous (automatically heard with Doppler), phasic (flow increases and decreased with respiration), and augmented (increased with distal compression). Although normal Doppler signs may be present with partially occlusive thrombosis, the usual Doppler findings include: absence of spontaneity (no venous flow) indicating venous obstruction, continuous flow indicating proximal obstruction or extrinsic compression, while distal compression does not produce augmentation. Note the flow augmentation in a normal brachial vein that has been compressed distally (**a**) and the spontaneous, phasic flow occurring in a normal subclavian vein (**b**). Observe the absence of flow in a totally thrombosed internal jugular vein (**c**) and continuous flow in an extrinsically compressed internal jugular vein (**d**)

Basic Competencies

Operators who perform ultrasound-guided placement of central venous catheters should be familiar with the sonoanatomy of the cannulation site and possess basic ultrasound skills such as the ability to differentiate between arteries and veins, detect venous thrombosis, and select the optimal vessel for cannulation. We recommend using real-time techniques where the operator moves the probe and needle slowly, in a simultaneous fashion, to ensure that the needle tip is visualized continuously [6]. This technique can be performed by a freehand approach or by the implementation of needle guides which keep the needle attached to the plane of the probe at all times. The former approach is technically demanding as it depends largely on the fine coordination of probe positioning and needle movement; however, it allows a great degree of freedom in maneuvers and adjustments of the penetrating needle trajectory (Figs. 3.10 and 3.11).

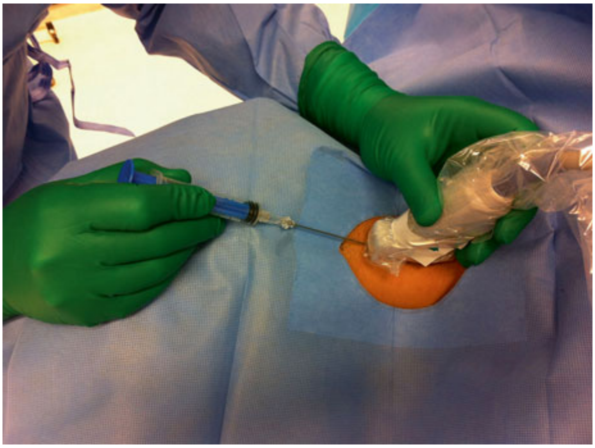

Fig. 3.10 Freehand access cannulation of the internal jugular vein on the long axis requires fine coordination of movements (note that the plane and trajectory of the needle follows the plane of the probe)

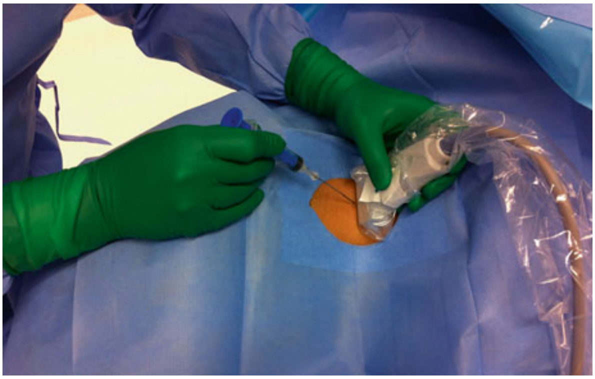

Fig. 3.11 Freehand access cannulation of the internal jugular vein on the short axis is relatively easier compared to the long-axis approach. However, needle visualization on the short-axis approach is more problematic (note that the angle of the penetrating needle is around 40–45°)

Internal Jugular Vein Cannulation

Anatomy

The internal jugular vein drains blood from the brain, face, and neck. It begins at the jugular foramen in the skull, merges through the carotid sheath (along with the common carotid artery medially and vagus nerve posteriorly), and joins the subclavian vein behind the medial end of the clavicle to form the brachiocephalic vein. Rotating the head will lead to overlapping of internal jugular vein with the common carotid artery. The thoracic duct ascends on the left side of the neck along the left margin of the esophagus until C-7, where it bends laterally behind the carotid sheath and then turns down again to drain into the left brachiocephalic vein [14].

Procedure

A high-frequency linear transducer is placed over the groove between the sternal and clavicular head of the sternocleidomastoid muscle at the lateral side of the neck (Figs. 3.10 and 3.11). Pre-procedural scanning is performed to identify the adjacent structures and evaluate the vein's depth, caliber, and patency (Figs. 3.12, 3.13, and 3.14). Electrocardiogram monitoring is necessary to evaluate the occurrence of possible dysrhythmias during guide wire insertion. Strict sterility is achieved by means

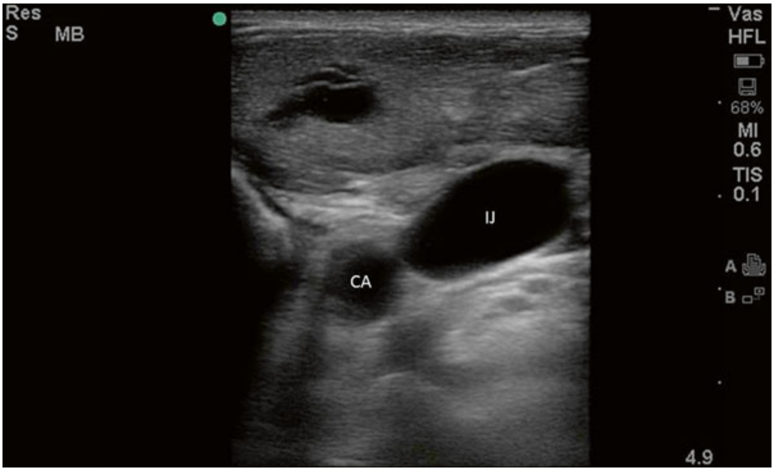

Fig. 3.12 Transverse view of the internal jugular vein and carotid artery. *CA* carotid artery, *IJ* internal jugular vein

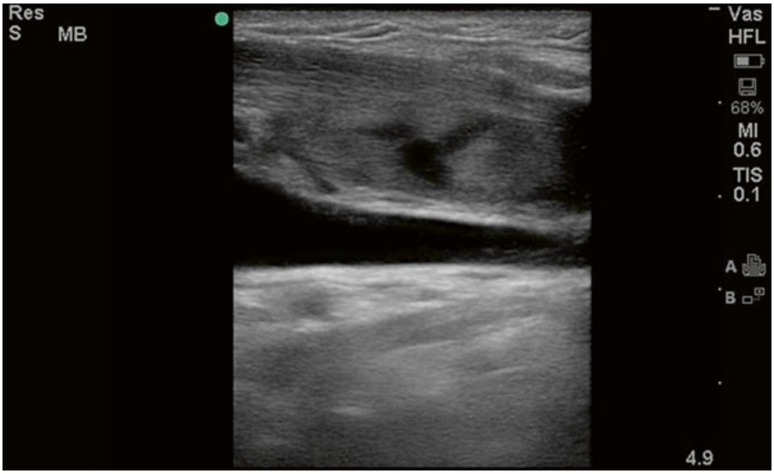

Fig. 3.13 Longitudinal view of the internal jugular vein

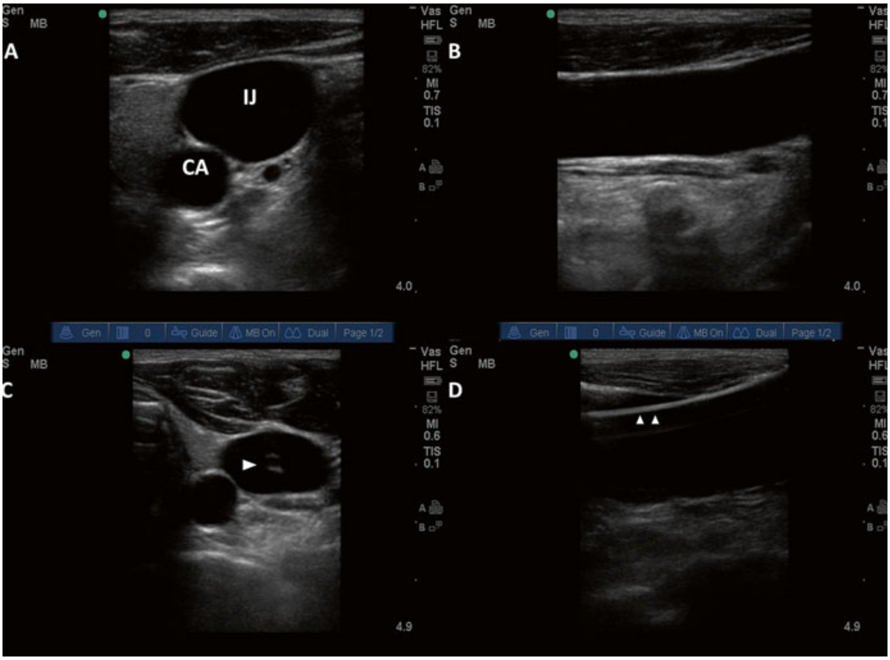

Fig. 3.14 Internal jugular vein cannulation (short-axis technique): (**a**) transverse view *IJ* internal jugular vein, *CA* carotid artery; (**b**) longitudinal view of the internal jugular vein; (**c**) needle tip in the vessel lumen denoted by *arrow head*; (**d**) guide wire confirmation in longitudinal view denoted by *arrow heads*

of a sterile probe cover and sterile single-use gel as previously described. The internal jugular vein can be cannulated using either the long-axis or short-axis techniques. When using the short-axis technique the penetration angle of the needle is usually around 45 ° to the skin (Fig. 3.11).

Subclavian Vein Cannulation

Anatomy

The axillary vein is the continuation of the brachial vein into the chest wall and becomes the subclavian vein as it passes medially under the first rib. The subclavian vein joins the internal jugular vein at the medial border of scalenus anterior, where it gives rise to the brachiocephalic vein (also known as the innominate vein). Notably, the dome of the pleura is adjacent to the subclavian vein. In the blind landmark technique, the deltopectoral groove formed at the inferior junction of the middle and medial third of the clavicle is the most common needle insertion site [14].

Procedure

The patient is placed in a supine position with a slight retraction of the shoulder to best expose the vein. The needle bevel should be directed anteriorly during insertion and then be turned caudally upon venipuncture to direct the guide wire toward the right atrium. Electrocardiographic monitoring and sterile techniques should be applied as previously described. Ultrasound-guided cannulation of the subclavian vein can be achieved using either a supraclavicular or an infraclavicular approach (Figs. 3.15, 3.16, 3.17, 3.18, 3.19, and 3.20).

- *Supraclavicular approach*

  Key points of this approach include:

  – Scan the neck and localize the internal jugular vein. Follow the vein caudally to the junction of the subclavian vein, orient the probe in the longitudinal axis in the supraclavicular fossa, and angulate it anteriorly. The subclavian vein is usually seen (within 1–2 cm) at the level where it joins the brachiocephalic vein medially.
  – Identify the adjacent structures (e.g., artery and pleura).

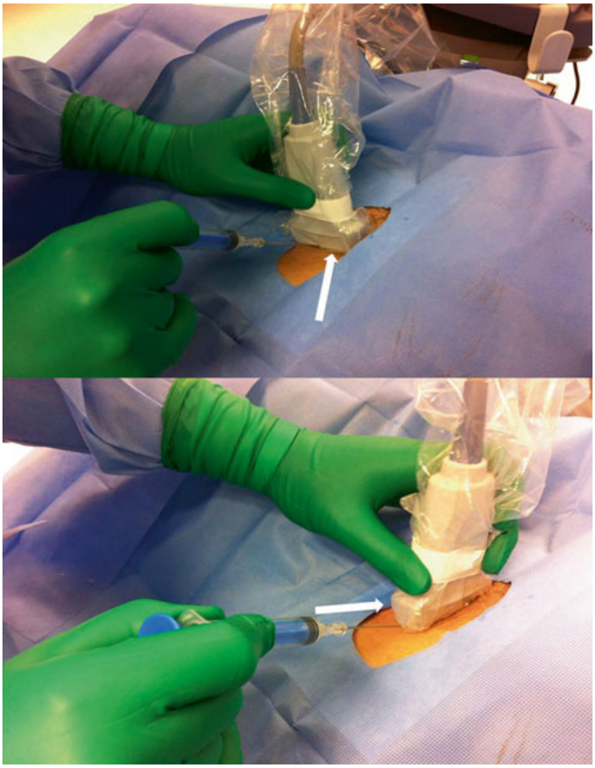

Fig. 3.15 Supraclavicular short-axis approach (*top*) and infraclavicular long-axis approach (*bottom*) in the cannulation of the subclavian vein (the *arrow* is showing the position of the clavicle)

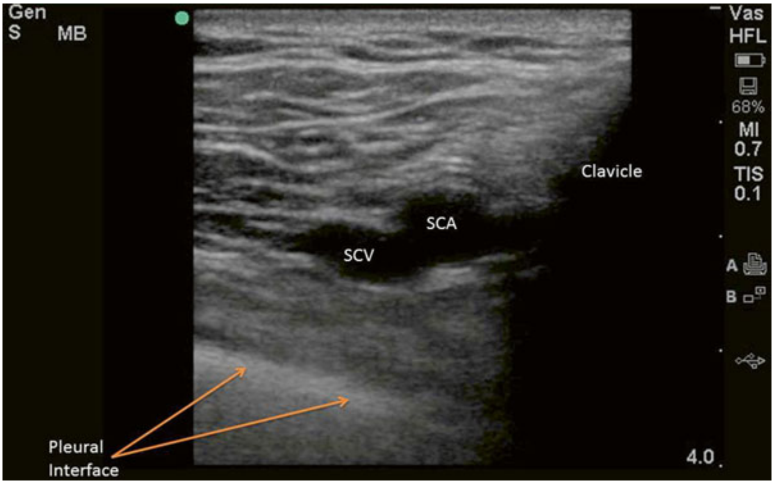

Fig. 3.16 Transverse view of the infraclavicular subclavian vasculature demonstrating the relationship of the vessels to the pleural interface and clavicle. *SCA* subclavian artery, *SCV* subclavian vein

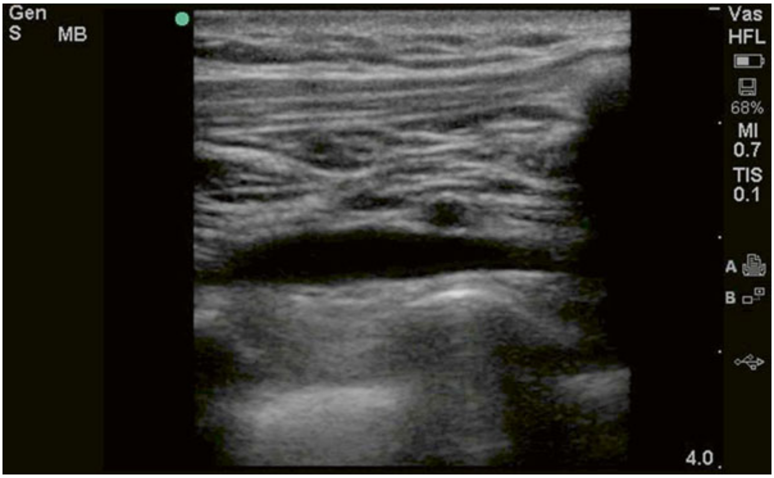

Fig. 3.17 Longitudinal view of the infraclavicular subclavian vein

– At the back of the clavicle insert the needle just lateral to the probe (long-axis), while directing the needle tip slowly towards the sternal notch.
– Under ultrasound guidance the guide wire is introduced; then, the ipsilateral internal jugular vein is scanned before catheter insertion to rule out malpositioning of the guide wire.

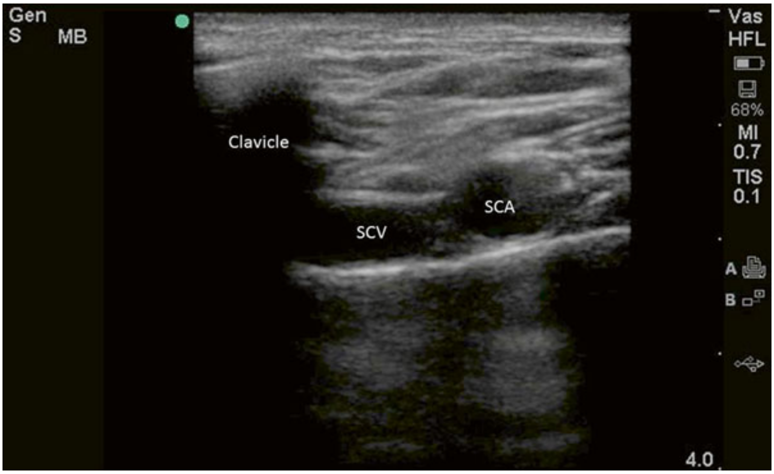

Fig. 3.18 Transverse view of the supraclavicular subclavian vasculature demonstrating the relationship of the vessels to clavicle. *SCA* subclavian artery, *SCV* subclavian vein

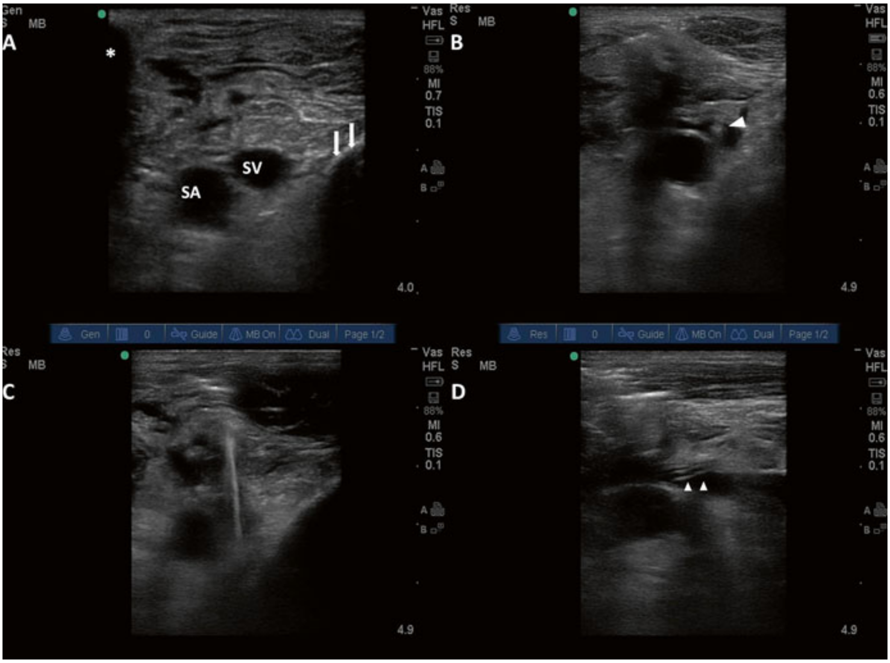

Fig. 3.19 Subclavian vein cannulation (short-axis technique): (**a**) transverse view *SA* subclavian artery, *SV* subclavian vein, *Arrows* pleural line, * clavicle; (**b**) needle tip in the vessel lumen denoted by *arrow head*; (**c**) guide wire insertion in the subclavian vein; (**d**) longitudinal view and catheter confirmation in the subclavian vein denoted by *arrow heads*

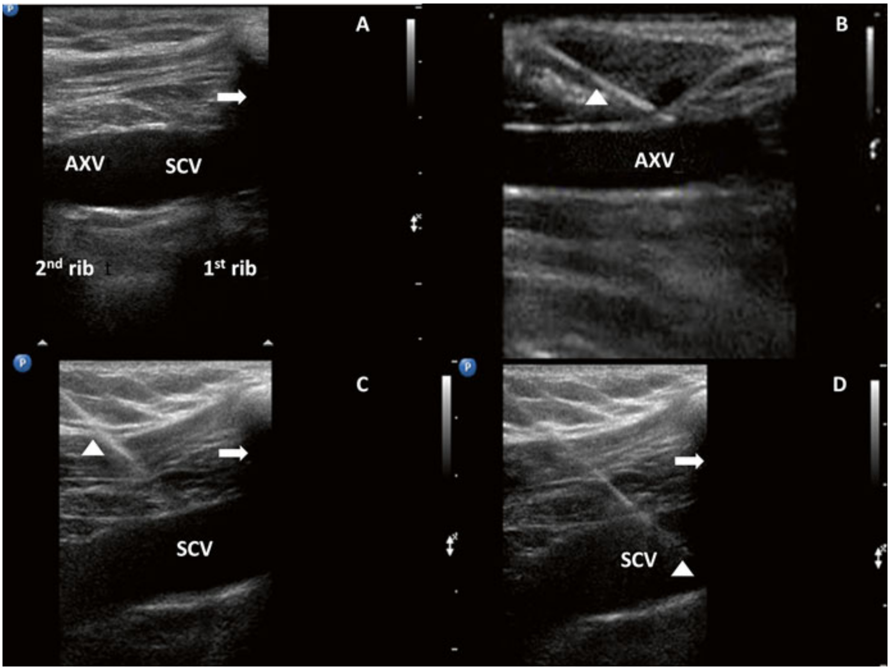

Fig. 3.20 Cannulation of the subclavian vein (*SCV*) on the longitudinal axis (infraclavicular approach): (**a**) transition of the axillary vein (*AXV*) to SCV at the level of the first rib (*arrow* sternum shadow); (**b**) echogenic needle (*arrowhead*) advancing towards the AXV; (**c**) echogenic needle (*arrowhead*) advancing towards the SCV (*arrow* sternum shadow); (**d**) echogenic needle (*arrowhead*) in the SCV lumen (*arrow* sternum shadow)

- *Infra-clavicular and axillary approaches*:
  - Place the probe on the lateral chest wall just below the clavicle. The subclavian vein can be visualized and cannulated using either a long-axis technique (the probe marker is oriented laterally) or a short-axis technique. The penetration point of the needle can be located either medially/towards the sternum (in this case the subclavian vein itself is usually cannulated) or laterally/towards the axilla (in this case the axillary vein is usually cannulated) [8, 15].
  - Using a smaller gauge needle might be safer when puncturing deeper vessels (e.g., axillary) when compared with the traditional central venous line introducer needle [16].

Tips to differentiate between the subclavian vein and artery include:

1. Although the vein is not pulsatile, it is important to distinguish transferred pulsatility and respiratory variation of the vein from arterial pulsation.
2. The vein is usually anterior to the artery.
3. Pulsed-wave Doppler demonstrates the characteristic pulsation of the artery and respiratory hum of the vein.

Factors that are associated with difficult subclavian vein cannulation and high rates of complications include obesity (BMI >30 kg/m^2), history of previous

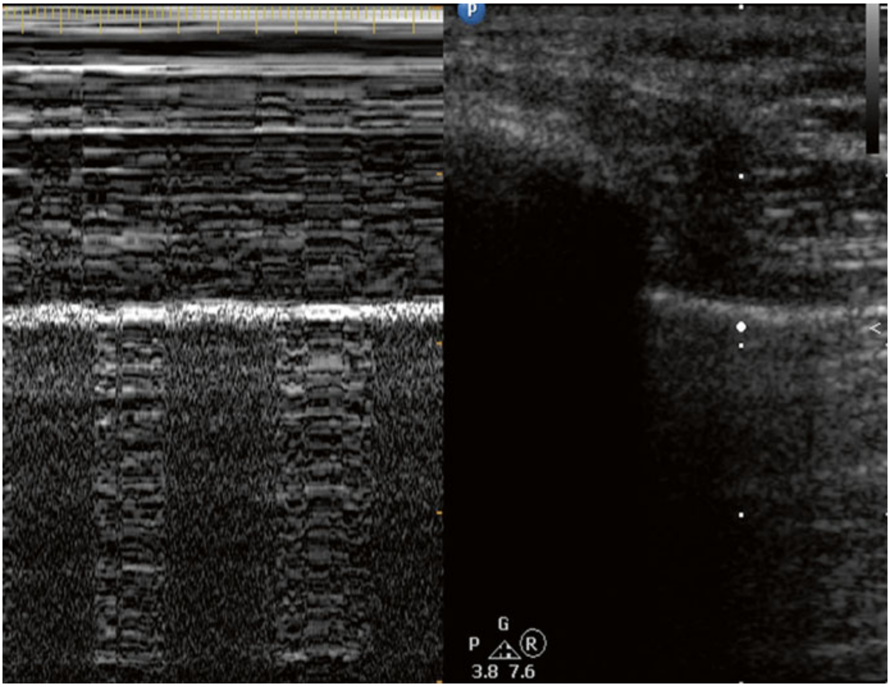

Fig. 3.21 Depiction of the lung point sign (indicative of pneumothorax) on M-mode in a patient following the placement of a subclavian vein catheter

catheterization, and prior radiotherapy or regional surgery. The current evidence recommends the use of ultrasound for high-risk patients [4].

Post-procedural evaluation to rule out pneumothorax (Fig. 3.21) by lung ultrasound (i.e., absence of lung sliding, barcode sign on M-mode, absent B-lines, lung-point sign are all suggestive of pneumothorax) should be performed after the cannulation of the internal jugular and subclavian veins due to their close proximity to the pleura.

Femoral Vein Cannulation

Anatomy

The common femoral vein is formed by the superficial (continuation of the popliteal vein) and deep femoral veins; it lies to the medial side of the common femoral artery (inside the femoral sheath) and passes behind the inguinal ligament to form the external iliac vein. The greater saphenous vein empties into the common femoral vein about 4 cm below the inguinal ligament. The femoral triangle, which is formed superiorly by the inguinal ligament, medially by the adductor longus muscle, and laterally by the sartorius muscle, includes the neurovascular bundle (femoral vein, artery, and nerve). Due to its proximity to the perineum, infection is a major complication for femoral vein catheters [14].

Procedure

The femoral vein is visualized at the inguinal crease (Figs. 3.22 and 3.23). Sweeping the probe caudally aids in identifying its tributaries and its relationship to the adjacent artery (i.e., possible overlapping), as well as in detecting any other venous

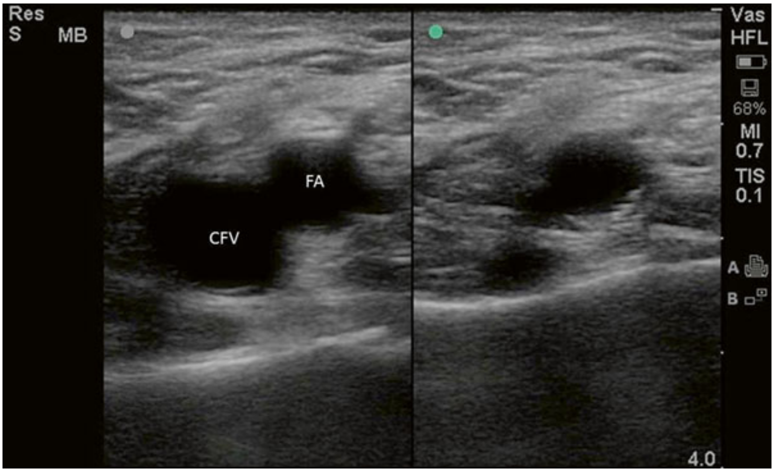

Fig. 3.22 Transverse view of the femoral vasculature demonstrating compression of the common femoral vein. *CFV* common femoral vein, *FA* femoral artery

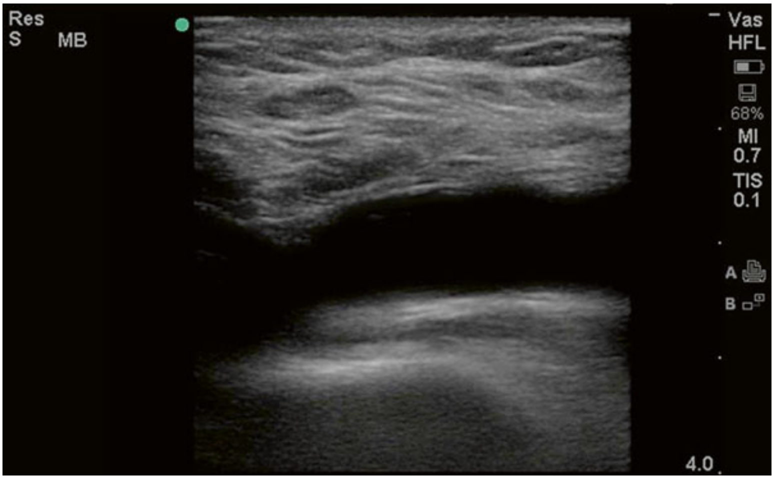

Fig. 3.23 Longitudinal view of the common femoral vein

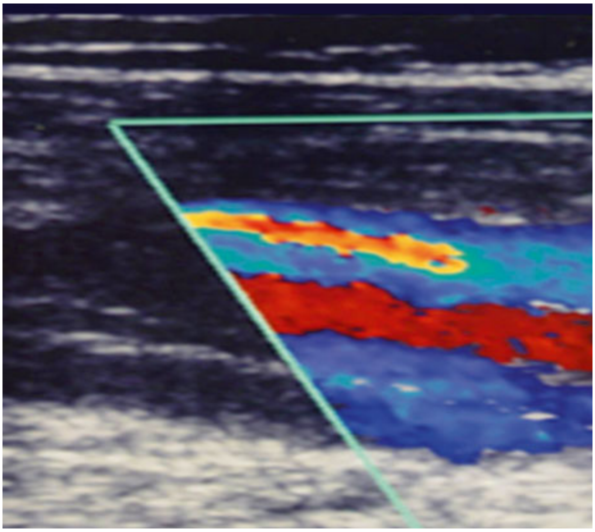

Fig. 3.24 The femoral artery (*red color*) is accompanied by a double system of femoral veins (*blue color*)

anomalies such as thrombosis or a double femoral venous system (Figs. 3.7 and 3.24). The best entry point is devoid of branching veins. Current evidence recommends the use of ultrasound to identify overlapping vessels and patency [4].

Tips for facilitating access of the femoral vein:

1. Slightly abduct the hip with external rotation.
2. Reverse Trendelenburg position can increase the common femoral vein cross-sectional area by more than 50 % [4].

Advanced Competencies

Experienced operators usually cannulate a central vein using a real-time longitudinal axis approach, which allows better control of the needle trajectory and avoidance of posterior wall puncture (Fig. 3.20). However, complications may occur even under ultrasound-guidance. Advanced competencies regarding ultrasound-guided vascular access also include the ability of the physician to diagnose abnormal vascular anatomy, such as the presence of pseudoaneurysms, fistulas, and non-thrombotic vessel obstructions (Fig. 3.25).

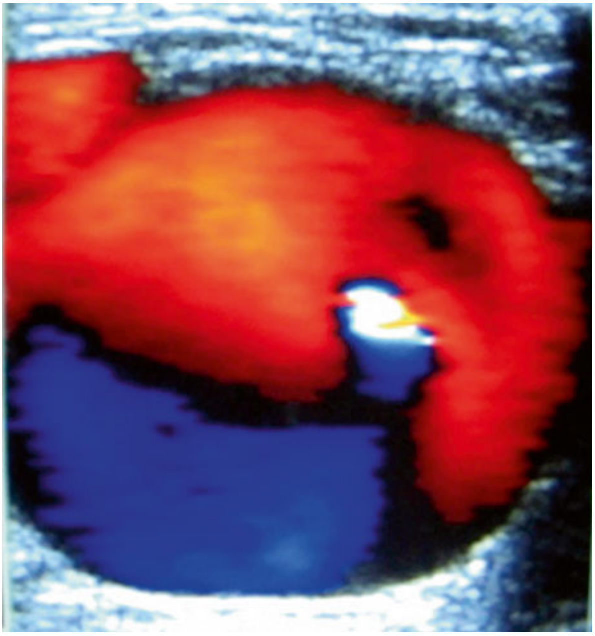

Fig. 3.25 Color mode depicting a traumatic pseudoaneurysm of the femoral artery after a blind femoral vein cannulation (observe the typical "yin–yang" sign on color mode)

Ultrasound-Guided Arterial Cannulation

The procedure for arterial cannulation is the same as for venous cannulation. Real-time guided cannulation is preferred over the skin-marking static-imaging technique (Fig. 3.26) [4]. Ultrasound-guided arterial cannulation is helpful in many scenarios commonly encountered in ICU practice such as obese patients, abnormal anatomy, hypoperfusion, non-pulsatile artery, and previously unsuccessful cannulation attempt [17]. A meta-analysis has demonstrated that ultrasound-guided radial artery cannulation improves first pass success [18].

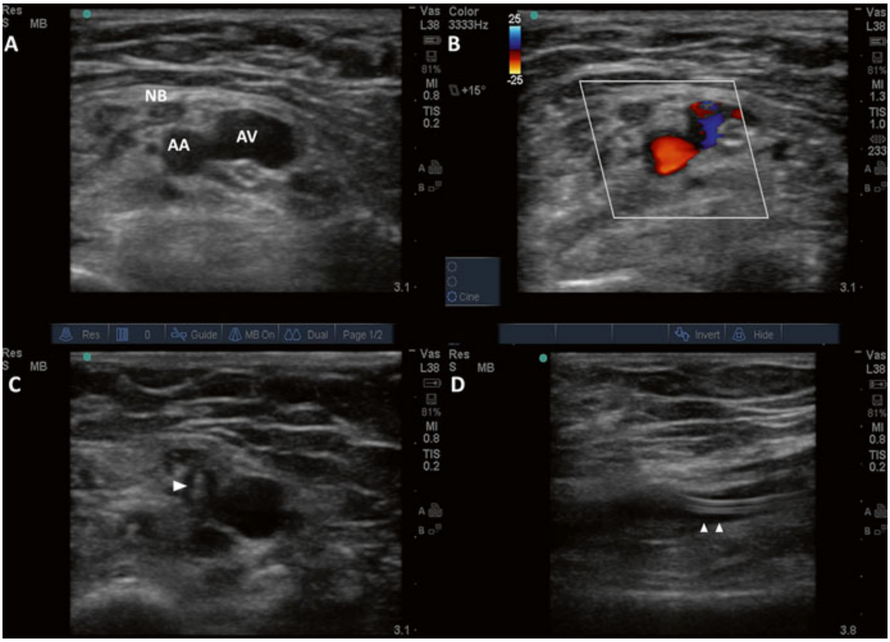

Fig. 3.26 Axillary artery cannulation: (**a**) transverse view *AA* axillary artery, *AV* axillary vein, *NB* nerve bundle; (**b**) Color-Doppler confirmation of the artery and vein; (**c**) needle tip in the vessel lumen denoted by *arrow head*; (**d**) longitudinal view and catheter confirmation in the axillary artery (*arrow heads*)

Ultrasound-Guided Venous Access Considerations in Pediatric Patients and Neonates

The current recommendations support the use of real-time ultrasound during internal jugular and femoral vein cannulation to improve success and to reduce the incidence of complications in pediatric patients [4].

Internal Jugular Vein Cannulation

The neck should be scanned along the course of the vein to identify the best access point for cannulation. Trendelenburg positioning and liver compression techniques are used for increasing the vein size [4]. After the guide wire insertion, another scan should be performed to confirm its presence within the vein before dilatation and catheter insertion.

Subclavian Vein Cannulation

A hockey-stick probe, as previously mentioned, at the supraclavicular level assists in obtaining a longitudinal view. Needle insertion is performed via infraclavicular route under direct ultrasonic guidance [19].

Femoral Vein Cannulation

Femoral vein access in pediatrics is a challenging procedure due to the high prevalence of anatomic variations. Hopkins et al. [20] demonstrated an overlap between the femoral artery and vein in 36 % of patients placed in straight leg position and in 45 % of patients placed in frog leg position. Moreover, the overlap increased distal to the inguinal ligament (75 % in straight leg position and 88 % in frog leg position 1 cm below the inguinal ligament on the left ($p=0.02$) versus 93 % in straight leg position and 88 % in frog leg position at this level on the right). Vein diameter was significantly greater in the frog leg position versus straight leg position on the left, but not on the right, and diameter change with the frog leg position varied by age. Thus, the authors suggested considering placing the patient ≥2 years of age in a frog leg position (60° leg abduction and external hip rotation) to increase the diameter of the femoral vein and to cannulate the vessel by means of sonography. Cannulation should be done at the level of the inguinal crease where less overlap occurs. Additional tips to improve venous visualization in small children include putting a small towel under the child's buttock, reverse Trendelenburg positioning, and gentle abdominal compression [4].

Peripheral Vascular Access in Pediatrics

Peripheral venous access can be a challenge, especially in small, obese, or dehydrated children, and in cases of previously failed venipuncture. Ultrasound-guided peripheral vascular access may improve the success rate in difficult cases when performed by trained physicians [21]. Recently, the High-frequency Ultrasound in Kids Study (HUSKY) group [22] demonstrated that high-frequency (50 MHz) micro-ultrasound (HFMU) facilitated better visualization in sub-10-mm spaces when compared to conventional ultrasound. HFMU may be a valuable tool for accessing peripheral vasculature in pediatrics.

Peripherally Inserted Central Lines

PICCs are inserted via a peripheral vein in the arm with a tip that terminates centrally, at the junction of the right atrium and superior vena cava. It can remain in position for prolonged periods of time and carries less incidence of infection than

Fig. 3.27 Surveillance scanning after the placement of a subclavian vein catheter in a cancer patient has depicted a catheter-associated chronic thrombosis. However, this is not by itself an indication for removing the catheter. Absolute indications include: catheter malfunction and documented catheter-associated bloodstream infection

traditional central venous catheters [6], and it is a preferable choice in patients who need prolonged central access. Ultrasound can be used to optimize the selection of an upper extremity vein for insertion of the PICC line and facilitate catheter surveillance (Fig. 3.27).

Special Challenges

Challenging cannulation scenarios commonly occur in the ICU (e.g., previous cannulation attempts, prohibitive bracing, tubing, or dressings at access sites, significant anatomic anomalies, presence of subcutaneous air and/or edema, etc.). The advent of ultrasound guidance has afforded the opportunity to adapt insertion procedures to establish venous access. Sofi and Arab reported successful ultrasound-guided cannulation of the internal jugular vein in a prone-positioned patient during a surgery complicated by unpredicted massive blood loss [23]. Castillo et al. reported a patient with kyphosis and a fixed chin-on-chest deformity in whom successful cannulation was performed by ultrasound-guided catheterization of the left axillary vein using a micropuncture technique [16].

Evidence Review and Evidence-Based Use

The US Agency for Healthcare Research and Quality (AHRQ) lists ultrasound-guided vascular access as one of the top 11 evidence-based practices, while several other evidence-based guidelines support the use of the ultrasound method over the landmark technique [4, 24, 25]. Virtually all medical societies related to the care of critically ill patients advocate for the use of ultrasound for obtaining vascular access [4, 6, 10]. Current recommendations of the American Society of Cardiovascular Anesthesiologists include [4]:

- *Internal jugular vein*: Trained clinicians should use real-time ultrasound whenever possible to improve cannulation success and to reduce the incidence of complications (Category A, Level 1 evidence).
- *Subclavian vein*: High-risk patients may benefit from ultrasound screening before cannulation to identify vessel location, patency, and thrombus (Category A, Level 3 evidence).
- *Femoral vein*: Ultrasound should be used for examining the femoral vein for identification of vessel overlap and examining patency (Category C, Level 2 evidence).
- *Pediatric patients*: Trained clinicians should use real-time ultrasound during internal jugular cannulation whenever possible to improve cannulation success and reduce the incidence of complications (Category A, Level 1 evidence; Category C, Level 2 evidence for femoral vein cannulation).
- *Arterial lines*: Although the council does not recommend routine real-time ultrasound use for arterial cannulation in general, in the case of radial artery, supporting evidence does exist as previously mentioned (Category A, Level 1 evidence).
- *Peripheral venous access*: The council does not recommend routine use of real-time ultrasound use. However, there is supporting evidence advocating the use of ultrasound for PICC insertion (Category B, Level 2 evidence).

Pitfalls and Precautions

Complications may occur even under ultrasound guidance. Oftentimes these complications are due to lack of experience. One of the major complications, especially when using a short-axis approach, is puncture of the posterior vessel wall. The incidence has been reported to be as high as 64 % in a resident-based study [26]. Additional training with simulation models and optimization of the ultrasound technique (i.e., less probe pressure over the vein, use of an in-plane technique) could minimize the incidence of the aforementioned complication. French et al. suggested the use of four-dimensional imaging (real-time three-dimensional imaging) to reduce the errors in identifying vessels and complications during ultrasound-guided central venous cannulation; however, this method is not yet widely available [27].

Hereby, we wish to underline once again the advantages of the three-step real time ultrasound technique. The ultrasound method facilitates the identification of the vein prior to the needle insertion and confirms the proper placement of the guide wire prior to dilation, thus avoiding the pitfall of dilating an artery (Fig. 3.28). The

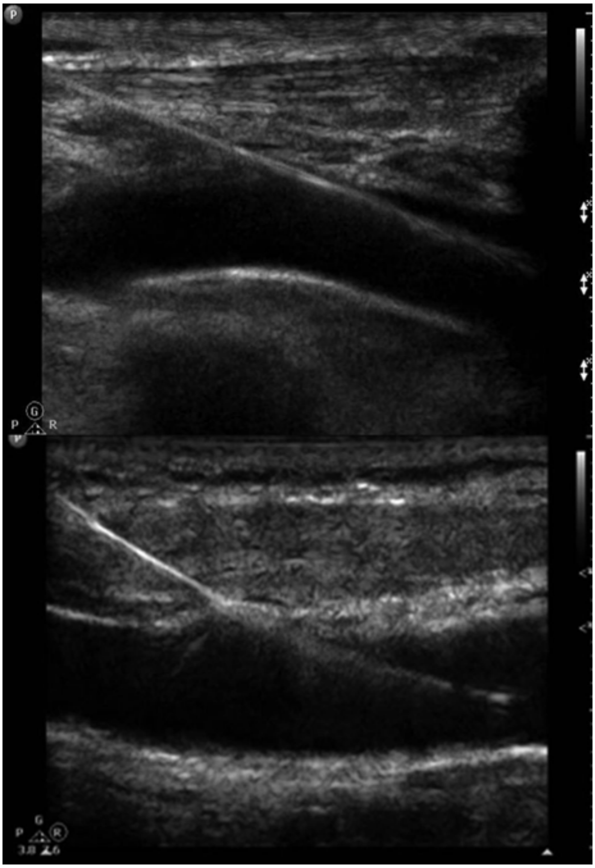

Fig. 3.28 Sonographic identification of the guide wire prior to dilation in the subclavian (*top*) and the internal jugular (*bottom*) veins, respectively

latter may occur in critical care patients who have coded and have severe hypotension. Finally, post-procedural scanning enables the prompt identification of various complications (i.e., catheter malpositioning, hematoma, pneumothorax, etc.)

Notably, recent randomized case–control studies have demonstrated that echogenic technology significantly improved cannula visibility, decreased access time and mechanical complications during the real-time ultrasound-guided internal jugular vein cannulation via a transverse approach and subclavian vein cannulation via a longitudinal approach (Fig. 3.20) [28]. Apart from the aforementioned technological developments, the implementation of a real-time ultrasound technique is essential in both training and routine practice. We strongly advocate using a three-step approach for the optimization of the ultrasound method in the ICU (Fig. 3.29).

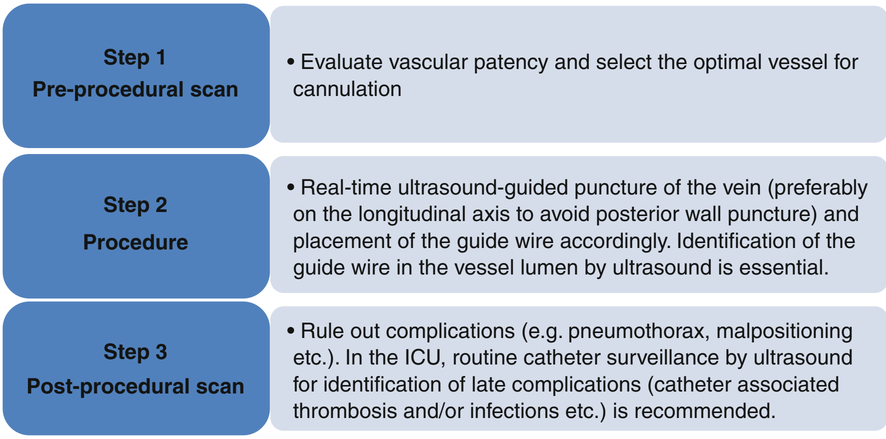

Fig. 3.29 A three-step approach for the optimization of ultrasound-guided central venous access in the ICU

Training Requirements

Further discussion regarding this topic is available in its own chapter, but in general here is what is recommended. Recommended training and curriculum for ultrasound-guided central venous access includes knowledge of [4, 29] principles of ultrasound physics and knobology/equipment operation; infection control standards; basic sonoanatomy: differentiation between arteries/veins, image optimization; ultrasound guided cannulation procedural steps and indications; complication prevention; and catheter surveillance.

Summary

Real-time ultrasound-guided catheterization of the vein is a skill that requires proper training and considerable experience. The implementation of a simple three-step approach (pre-procedural scanning, real-time technique, post-procedural scanning including catheter surveillance) may optimize ultrasound-guided central venous access in the ICU (Fig. 3.29). Ultrasound guided vascular access is one of the top 11 evidence based practices, while its implementation in routine practice increases the safety of the procedure and the satisfaction of patients, thus improving the standard of care.

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