Guidelines for Performing Ultrasound-Guided Vascular Cannulation: Recommendations of the American Society of Echocardiography

Annette Vegas, MD, FRCPC, FASE, (Chair), Bryan Wells, MD, FASE, (Co-Chair), Paul Braum, BS, RDCS, RCS, FASE, Andre Denault, MD, PhD, FASE, Wanda C. Miller Hance, MD, FACC, FASE, Claire Kaufman, MD, Mitalee Bremner Patel, RDCS, FASE, and Marcus Salvatori, MD, *Toronto, Ontario and Montreal, Quebec, Canada; Atlanta, Georgia; Houston, Texas; and Portland, Oregon*

Vascular access is a commonly performed procedure to facilitate patient care. This document provides expert consensus from diverse specialists on best practices and techniques for incorporating ultrasound (US) into vascular access procedures. This update replaces the 2011 American Society of Echocardiography guidelines for US-guided vascular cannulation. It includes recommendations for US-guided access to central and peripheral veins and arteries in adult and pediatric patients based on the strength of the scientific evidence present in the literature. The major roles of US during vascular access include (1) precannulation vessel assessment, (2) dynamic US guidance during cannulation, and (3) identification of local complications. This document discusses the general aspects of anatomic and US imaging of vessels, US-guided vascular cannulation techniques, and the identification of local vascular cannulation complications. Proper training should impart the cognitive knowledge and technical skills necessary to perform US-guided cannulation. There is an increasing body of literature indicating that US-guided vascular access improves success rates and reduces complications, although the quality of the evidence to date remains weak. A gap remains between the existing evidence and guidelines for the use of US in clinical practice. The availability of US equipment and clinical proficiency will more likely influence the role of US-guided vascular access as a standard of care than will future research studies. (J Am Soc Echocardiogr 2025;38:57-91.)

Keywords: Ultrasound, Artery, Vein, Cannulation, Catheter, Guidewire

TABLE OF CONTENTS

From Toronto General Hospital, University of Toronto, Toronto, Ontario, Canada (A.V., M.S.); Emory University School of Medicine, Atlanta, Georgia (B.W.); Northside Hospital and Health System, Atlanta, Georgia (P.B., M.B.P.); Montreal Heart Institute, University of Montreal, Montreal, Quebec, Canada (A.D.); Children's Memorial Hermann Hospital, University of Texas Health Science Center at Houston, McGovern Medical School, Houston, Texas (W.C.M.H.); Oregon Health & Science University, Portland, Oregon (C.K.).

The following authors reported no actual or potential conflicts of interest in relation to this document: Andre Denault, MD, PhD, FASE, Wanda C. Miller-Hance, MD, FACC, FASE, Mitalee Bremner Patel, RDCS, FASE, Annette Vegas, MD, FRCPC, FASE, and Bryan Wells, MD, FASE.

The following authors reported relationships with one or more commercial interests: Paul Braum, BS, RDCS, RCS, FACE is a member of the speakers bureau for Lantheus Medical Imaging and Edwards Lifesciences. Claire Kaufman, MD, has received a research grant from Boston Scientific for cryoablation research for Morton's neuroma.

Reprint requests: American Society of Echocardiography, Meridian Corporate Center, 2530 Meridian Parkway, Suite 450, Durham, NC 27713 (E-mail: ase@asecho.org).

0894-7317/$36.00

https://doi.org/10.1016/j.echo.2024.12.004

1. INTRODUCTION

Vascular access is a commonly performed procedure to facilitate patient care. Ultrasound (US) use is recommended as a safety practice to improve successful vessel cannulation and minimize complications during vascular access.[1] This document updates and replaces the 2011 American Society of Echocardiography (ASE) guidelines for US-guided vascular cannulation, while also providing expert consensus from diverse specialists on best practices and techniques for incorporating US into vascular access procedures.[2] This paper includes recommendations for US-guided access to central and peripheral veins and arteries in adult and pediatric patients based on the strength of the scientific evidence present in the literature. The document does not address the specifics of the sterile technique or line care after cannulation.

2. METHODOLOGY AND EVIDENCE REVIEW

The writing committee conducted a comprehensive search of medical and scientific literature in the English language using PubMed and MEDLINE. The committee identified and reviewed original research studies relevant to US-guided vascular access published in peer-reviewed scientific journals from 1990 to 2023 using the Medical Subject Headings terms "ultrasound," "catheterization," "complications," "jugular veins," "subclavian vein," "femoral vein," "artery," "adult," "pediatric," "randomized controlled trials," and "meta-analysis."

The writing committee chose the Grading of Recommendations Assessment Development and Evaluation (GRADE) system to assess the evidence levels and base the recommendation grade.[3] The grading scheme classifies recommendations as strong (grade 1) or weak (grade 2) on the basis of the quality of evidence as high (grade A), moderate (grade B), or low (grade C), as described in Table 1. The Grading of Recommendations Assessment Development and Evaluation system differs slightly from the American College of Cardiology and the American Heart Association approach, which uses recommendation classes of class 1 (strong), class 2a (moderate), class 2b (weak), and class 3 (no benefit) on the basis of quality of evidence level A (high quality), level B (moderate quality), and level C (limited data). Individuals nominated by the ASE reviewed the document with approval by the governing body for publication.

3. GENERAL CONSIDERATIONS

3.1. Vascular Cannulation Techniques

Cannulation of veins and arteries is an important aspect of clinical care for administering intravenous fluids and medications, patient monitoring, enabling treatments, and increasingly to facilitate percutaneous procedures. The frequent need for large vascular cannulas requires using a safe, reliable cannulation technique to optimize success and minimize complications. A strong direct correlation exists between multiple attempts at vessel cannulation and higher complication rates, increasing patient anxiety and discomfort, with the potential to delay monitoring and treatment.[4] These represent important quality-of-care considerations when choosing the best technique for vascular access.

Clinicians may practice the *landmark technique*, identifying target vessels by surface anatomy and palpation on the basis of the presumed vessel location, anatomic landmarks, and blind needle insertion until the appearance of blood. Confirmation of successful cannulation of the intended vessel usually relies on the character of blood aspirate (i.e., "dark" color for a vein or pulsatile "bright" red color for an artery), pressure measurement with a fluid column or pressure transducer, the display of the intraluminal pressure waveform on a monitor, or blood gas analysis.[5] When using the landmark technique, the operator may initially choose a smaller caliber (finder) needle to locate the vessel and minimize any unintended injury to the surrounding structures. Depending on the access site and patient population, landmark techniques for vascular cannulation reportedly have a 60% to 95% success rate.[6]

Using US imaging before or during vascular cannulation has emerged as an option to significantly improve success rates and reduce complications.[7] Static US imaging identifies the site of needle entry on the skin over the underlying vessel and offers the appeal of nonsterile imaging. In this technique, US acts as a vessel locator that enhances external landmarks. Real-time US guidance during needle advancement for vascular cannulation is a dynamic approach that is more effective but dictates a technique that includes skin antisepsis and sterility of probe covering and US gel. Both static and US-guided approaches are superior to the traditional landmark technique, with greater success for vascular cannulation.[8]

Practice recommendations for the use of US for vascular cannulation have been proposed by many specialties and governmental agencies, such as the Agency for Healthcare Research and Quality's evidence report.[1,9-13] Ultrasound fulfills many roles during vascular cannulation, as these guidelines further discuss (Table 2).

Key Points: Vascular Cannulation Techniques

- Clinicians may use the landmark technique or US-guided technique during vascular cannulation.
- Static US imaging and real-time US guidance are two US techniques for imaging before or during vascular cannulation.
- US imaging before or during vascular cannulation significantly improves success rates and reduces complications.

Abbreviations

2D = Two-dimensional

3D = Three-dimensional

ASE = American Society of Echocardiography

CA = Carotid artery

CFA = Common femoral artery

CFD = Color flow Doppler

CFV = Common femoral vein

CSA = Cross-sectional area

DNTP = Dynamic needle tip positioning

DPA = Dorsalis pedis artery

DVT = Deep vein thrombosis

IJV = Internal jugular vein

LAX = Long-axis

PICC = Peripherally inserted central catheter

PIV = Peripheral intravenous

PTA = Posterior tibial artery

PWD = Pulsed-wave Doppler

RCT = Randomized controlled trials

SAX = Short-axis

SCA = Subclavian artery

SCV = Subclavian vein

US = Ultrasound

3.2. Ultrasound Imaging of Vessels

Advances in medical technologies have made US devices affordable, portable, and capable of high-resolution imaging of tissue and blood flow. Ultrasound probes used for vascular access vary in size, shape, and emitted frequency (Figure 1A). The choice of probe depends on availability, operator experience, image quality, and patient characteristics. High-frequency linear probes (8-12 MHz) can provide superior spatial resolution of structures near the skin surface. Lower frequency probes (<5 MHz) provide improved tissue penetration but have lower spatial resolution and may be necessary to image deeper vascular structures. Small-footprint probes may be helpful in pediatric patients or in areas where US windows are small, such as near the clavicle.

Ultrasound modalities that image vessels and surrounding anatomy include two-dimensional (2D), color flow Doppler (CFD), and spectral Doppler interrogation. To interpret 2D images of blood vessels and surrounding structures, the operator should understand probe orientation, image display, US physics, mechanisms of image generation, and artifacts. The supplemental use of Doppler modes to confirm the presence and direction of blood flow requires an understanding of the mechanisms and limitations of Doppler analysis and display. Ultrasound machines may have dedicated presets for vascular imaging defaulting to shallow depths, lower 2D gain, lower dynamic range, and the appropriate CFD and pulsed-wave Doppler (PWD) scales. The operator may further optimize the image display by adjusting the image depth and gain (Figure 1B, Video 1).

The display of vessels can be in the transverse, longitudinal, or oblique orientation (Figure 2). Each orientation has advantages and disadvantages that can help the operator direct the cannulating needle at the correct entry angle and depth. Aligning the probe perpendicular to the course of the vessel displays a short-axis (SAX) image of the vessel and the surrounding structures. Positioning the probe coaxial to the vessel displays a long-axis (LAX) image of the vessel with less visualization of surrounding structures. Rotating the probe between the SAX and LAX views shows an oblique view with an elongated view of the vessel. Although there is no current recommendation to use three-dimensional (3D) imaging of vessels, biplane imaging may provide simultaneous real-time orthogonal SAX and LAX views without altering the probe position.[14]

The operator needs to appreciate the probe marker orientation relative to the image display and the patient. Vascular access imaging uses the general medical US screen convention with the probe indicator corresponding to the left side of the display, as shown by a mark on the screen. However, there is no accepted convention for probe marker orientation when placing the probe on the patient during vascular cannulation, so structures can appear on the right or left of the image display (Figure 3). What is important to know is which probe side corresponds to which side of the display. Side-to-side probe movement, sliding a finger under a probe side or slightly increasing the pressure on one probe side while observing underlying structures can help confirm probe orientation and the display of structures on the screen.

Key Points: US Imaging of Vessels

- The choice of US probe depends on availability, operator experience, image quality, and patient characteristics.
- US modalities, such as 2D, CFD, and spectral Doppler can help distinguish vascular structures.
- The display of vessels can be in the transverse, longitudinal, or oblique orientation.
- The operator needs to identify which probe side corresponds to which side of the image display.

3.3. Vessel Identification by Ultrasound

Detailed knowledge of vascular anatomy in the target area is crucial to achieving success and avoiding the cannulation of incorrect vessels. As reviewed in the following sections, textbook anatomy does not exist in every patient. General morphologic and anatomic characteristics can help distinguish a vein from an artery using 2D US scanning (Figure 4, Video 2). Veins are larger, thin walled, contain valves, are compressible with modest external surface pressure, and may change diameter with respiration or the patient's position. In contrast, arteries are smaller, round, thicker walled, valveless, not readily compressible by external pressure, and pulsatile under normal cardiac conditions. Systematic US scanning identifies the vessel size, location, patency, and anomalies thus avoiding futile attempts in patients with absent or thrombosed vessels.[15,16]

The diameter and shape of veins vary depending on the position and fluid status of the patient. Unless contraindicated, placing the patient in the Trendelenburg position or compressing the liver may increase the diameter of the jugular veins and reduces the risk for air embolism during subclavian vein (SCV) cannulation.[17] A Valsalva maneuver will further augment the jugular vein diameter and is most useful in hypovolemic patients.[17] The reverse Trendelenburg position may increase femoral and peripheral lower limb venous vessel size.

Adding Doppler interrogation can further help differentiate arteries from veins. Color flow Doppler at any velocity shows pulsatile systolic blood flow in an artery in either SAX or LAX orientation. Normal venous blood flow is low velocity, requiring a lower CFD velocity scale to show uniform color, representing continuous laminar flow (Figure 4, Video 2). A small PWD sample volume placed within the vessel lumen displays characteristic systolic flow predominance within an artery. A lower PWD velocity range shows multiphasic flow in a vein, on the basis of the cardiac cycle.[18]

The absence of arterial pulsatility cannot identify an artery during certain clinical conditions, such as cardiopulmonary bypass, nonpulsatile ventricular circulatory assistance, and cardiac or circulatory arrest. In addition, central veins may exhibit pulsatile venous flow during cannulation in patients with significant tricuspid regurgitation and elevated right heart pressures.[19] It is important to distinguish between abnormal pulsatile venous blood flow and altered blood flow from normal respiratory variation (respirophasic) or pulsation from adjacent vessels.

Key Points: Vessel Identification by US

- Detailed knowledge of vascular anatomy in the target area is crucial to achieving success and avoiding the cannulation of incorrect vessels.
- Veins are larger, thin-walled structures, compressible with modest external surface pressure, and may change diameter with respiration or the patient's position.
- Arteries are smaller, round, thicker walled, valveless, not readily compressible by external pressure, and pulsatile under normal cardiac conditions.

3.4. Ultrasound-Guided Vascular Cannulation

The choice of vessel puncture site is based on the clinical scenario, indication for vascular access, patient comfort and condition, operator experience, ease of access, and vessel characteristics. The operator may cannulate vessels using the Seldinger technique or modified Seldinger technique, as depicted in Figure 5 with preassembled sterile kits containing beveled needles or an angiocatheter comprising a plastic cannula over a beveled needle.[20] The modified Seldinger technique using an angiocatheter may be advantageous if the target vessel is small and the dimension changes with respiration. With this technique, the entire cannula lies in the vessel facilitating passage of the guidewire. In the Seldinger technique, it is possible for part of the needle bevel to be in the vessel allowing blood aspiration, but the other portion lies in the vessel wall impeding passage of the guidewire. Micropuncture kits for adults have a small 21-gauge needle through which a thin 0.018-inch guidewire passes using the Seldinger technique.

The operator performing US-guided vascular cannulation holds the US probe in the nondominant hand while the dominant hand controls the needle. The operator must pair the manual dexterity of performing probe and needle manipulation, a 3D task, to place a catheter into the target vessel while interpreting 2D US images.

The operator can use different approaches during US-guided vascular cannulation. The out-of-plane approach using a transverse or SAX view of vessels does not continuously image needle tip advancement throughout its course. To overcome this drawback, the US-guided dynamic needle tip positioning (DNTP) technique uses serial SAX views (Figure 6, Video 3). The operator identifies the needle tip, then moves the probe until it disappears and advances the needle until it reappears and eventually penetrates the anterior vessel wall. In the in-plane approach (Figure 7, Video 4), from a longitudinal or LAX view of the vessel, there is continuous tracking of the needle tip and shaft during advancement from skin penetration to vessel puncture. The narrow width of most US probes used for vascular applications may make it challenging to align the probe face coaxial to a large vessel and maintain a continuous image of the needle tip, though this is seldom a problem with the smaller vessels seen in pediatric patients. When comparing the SAX and LAX approaches, the SAX approach was faster, whereas needle visualization was better with the LAX approach.[21] The oblique axis is another option that may allow better needle shaft and tip visualization and offers the safety of imaging surrounding structures in the same view, thus capitalizing on the strengths of both the SAX and LAX approaches.[22]

Safe and successful US-guided vascular cannulation requires needle tip visualization with adequate needle tip angulation and depth control (Figure 8).[23] Probe manipulation may alter vessel imaging, creating needle and vessel misalignment with the potential for needle misdirection during advancement, resulting in failure of venous cannulation and inadvertent arterial puncture.

Direct visualization with US of the needle tip entering the vessel and the appearance of blood in the needle, angiocatheter flash chamber, or attached syringe confirms vessel cannulation. The operator sets the probe aside on the sterile field then advances the catheter over the needle or guidewire into the vessel. Alternatively, the operator can continuously use US to track the needle with cannula advancement throughout the entire course into the vessel before observing guidewire insertion. Ultrasound visualization of the guidewire in the vessel further confirms successful vessel cannulation and is an essential step before tissue dilatation, if required, and large-sized catheter or sheath insertion (Figure 9, Video 5).

Observational studies indicate that US can confirm the central venous guidewire placement using the linear probe or with transthoracic or transesophageal echocardiography.[24] Difficult cannulation may benefit from a second person with sterile gloves and gown assisting the primary operator by either holding the transducer or passing the guidewire.

Key Points: US-Guided Vascular Cannulation

- The most common methods for US-guided vascular cannulation include the Seldinger and modified Seldinger techniques.
- The operator can use different approaches during US-guided vascular cannulation, an out-of-plane approach in SAX views or an in-plane approach in LAX views.
- The US-guided DNTP technique uses serial SAX views to track the needle tip from the skin to the vessel lumen.
- US visualization of the guidewire in the vessel further confirms successful cannulation and is an essential step before dilatation, if required.

4. VENOUS CANNULATION

4.1. Overview

The indications for venous access and cannulation include therapeutic, monitoring, and diagnostic reasons in hospital and outpatient settings. Venous access sites may involve central or peripheral vein canulation. Central veins are defined as a major vein close to the heart, without valves that permit monitoring of right atrial pressure. Thus, central veins are the venae cavae (inferior and superior), brachiocephalic, subclavian, and iliac (common and external) veins. Accessing the central veins directly is usually not feasible because of their anatomic inaccessibility. However, several more peripherally located veins are often used to reach the central veins: internal jugular, axillary, and femoral veins. The preferential site for central venous cannulation is the upper body especially in ambulatory patients. The femoral vessels can better accommodate large cannulas such as those used for extracorporeal membrane oxygenation.

As previously discussed in section 3.3., US can help distinguish veins from arteries (Figure 4). The US examination of the target vein in SAX and LAX views should evaluate for depth, size, patency, and tortuosity of the vessel. It is easy to obscure arteries and veins

Table 1 Grading of Recommendation Assessment Development and Evaluation (GRADE) system

Grade of recommendation Clarity of risk/benefit	Quality of supporting evidence	Implications
1A Strong recommendation High-quality evidence Benefits clearly outweigh risk	• Consistent evidence from quality RCTs or other overwhelming evidence • Further research is unlikely to change estimations of benefit and risk	• Apply to most patients in most circumstances without reservation • Clinicians should follow unless there is a compelling rationale for an alternative approach
1B Strong recommendation Moderate-quality evidence Benefits clearly outweigh risk	• Evidence from RCTs with limitations,* or other very strong evidence • Further research can affect estimations of benefits and risk	• Applies to most patients • Clinicians should follow unless there is a compelling rationale for an alternative approach
1C Strong recommendation Low-quality evidence Benefits appear to outweigh risk	• Evidence from observational studies, unsystematic clinical experience, or flawed RCTs • Any estimate of effect is uncertain	• Applies to most patients • Some supporting evidence is low quality
2A Weak recommendation High-quality evidence Benefits balanced with risks	• Consistent evidence from quality RCTs or other overwhelming evidence • Further research is unlikely to change estimations of benefit and risk	• Best action may differ depending on patients or circumstances
2B Weak recommendation Moderate-quality evidence Benefits balanced with risks Some uncertainty in estimates of benefits and risks	• Evidence from RCTs with limitations,* or other very strong evidence • Further research can affect the estimation of benefits and risk	• Alternative approaches are likely to be better for some patients under some circumstances
2C Weak recommendation Low-quality evidence Benefits balanced with risks Uncertainty in estimates of benefits and risks	• Evidence from observational studies, unsystematic clinical experience, or from flawed RCTs • Any estimate of effect is uncertain	• Very weak recommendation • Other alternatives may be equally reasonable

RCT, randomized controlled trials.
Adapted with permission from Guyatt *et al*.[3]
*Study limitations: inconsistent results, methodologic flaws, indirect, or imprecise.

when imaging with US as even gentle probe pressure may compress the superficial vessels.

The landmark technique relies on the identification of local anatomy for target venous structures. During central venous cannulation, the operator creates a sterile field by using skin asepsis and sterile drapes and administers local anesthesia if necessary. The operator advances a needle or angiocatheter at a 30° to 45° angle to the vessel while watching for blood return using a Seldinger or modified Seldinger technique (Figure 5).

Ultrasound guidance during venous cannulation helps examine the vein and identify a suitable puncture site and facilitate cannulation in SAX or LAX using a Seldinger or modified Seldinger technique (Figure 5). During central venous cannulation, the operator creates a sterile field by using skin antisepsis, sterile US gel, and a sterile US probe cover. After the initial vessel puncture, US imaging of the vessel can help the operator confirm the guidewire position in the vein. A dilator over the guidewire may be necessary to create a subcutaneous tunnel that accommodates a large cannula or sheath.

4.2. Internal Jugular Vein

Anatomic and Ultrasound Considerations. The internal jugular vein (IJV) exits the external jugular foramen at the skull base posterior to the internal carotid artery (CA) and courses caudad toward an anterolateral position relative to the CA (Figure 10, Video 6). The IJV has a variable relationship to the CA: anterolateral (92%), >1 cm lateral (1%), medial (2%), and outside of the path predicted by landmarks in 5.5% of patients.[25] The amount of vessel overlap between the IJV and CA increases the likelihood of unintentional CA puncture by a through-and-through puncture of the IJV (Figure 11).[26]

Vascular anomalies and anatomic variations of the IJV and surrounding tissues occur in up to 36% of patients.[27] The IJV may be small and fixed in 3% or thrombosed or absent in 3% to 18% of patients.[28] Ultrasound identifies the disparity in size between the usually larger right IJV and the smaller left IJV, with a vein diameter <7 mm (cross-sectional area [CSA] < 0.4 cm^2) associated with lower cannulation success.[29]

Cannulation Techniques. The patient should be placed in the supine position with slight contralateral neck rotation (<30°) to

Table 2 Ultrasound roles during vascular access

- Identify anatomy and suitable vessel size for cannulation
- Determine vessel patency
- Real-time US guidance during needle insertion and catheter advancement
- Confirm guidewire position in a vessel
- Assess for complications

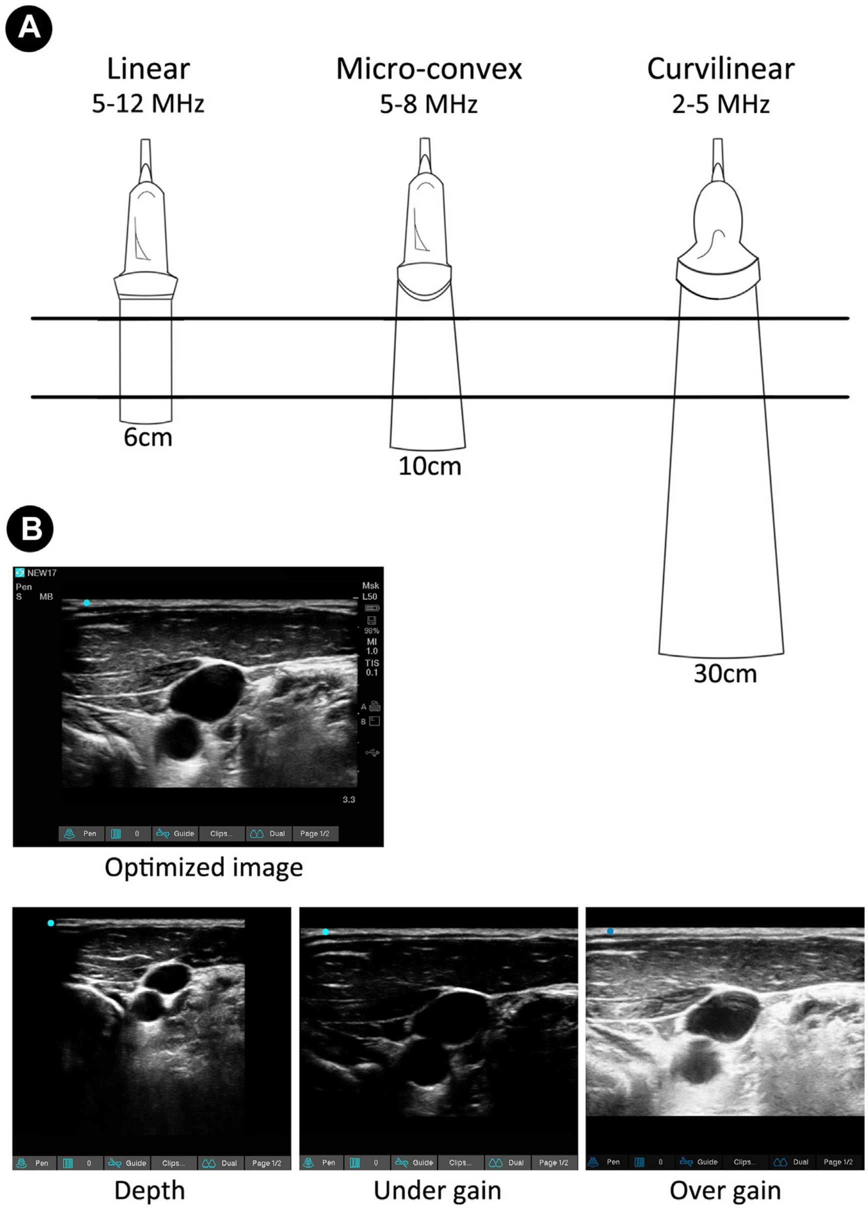

Figure 1 US probes and image optimization. **(A)** A selection of US probes for use during vascular access includes the linear (5-12 MHz), micro-convex (5-8 MHz), and curvilinear (2-5 MHz) transducers to allow an adequate depth of imaging. **(B)** The manufacturer's presets on the US machine establish the basic settings for vessel imaging. Further adjustments often improve the visualization of the target vessel. It is best to place the target vessel in the center of the display, reduce the image depth, and set the focal zone to the level of the vessel. Adjusting gain should show an anechoic vessel lumen with the echogenic vessel wall and surrounding tissue. Finally, adequate gain, neither too high nor too low, is necessary to follow the needle tip advancing toward the vessel. *US*, ultrasound. See Video 1.

optimize vessel size. Excessive contralateral neck rotation may expand the IJV-CA overlap, positioning the IJV anterior to the CA and increasing the likelihood of unintentional CA puncture.[30] The Trendelenburg position may modestly augment the IJV CSA but may also reduce the end-expiratory CSA in some patients.[31] Observational studies report the Trendelenburg position increases right IJV diameter in healthy adults, but the findings are equivocal in ill adult patients.[32] There is insufficient literature to evaluate whether Trendelenburg positioning improves insertion success rates or decreases the risk for mechanical complications.

The "blind" landmark technique for IJV cannulation identifies a triangle subtended by the two heads of the sternocleidomastoid muscle and the clavicle (Figure 12). This is a safe technique in experienced hands. A failure rate of 7.0% to 19.4% is due partly to the imprecise correlation between external landmarks and the vessel.[6] Furthermore, when initial landmark-guided attempts are unsuccessful, successful cannulation diminishes to <25% per subsequent attempt.[31] Static US imaging for skin marking can find variations in IJV anatomy and identify patients in whom the landmark technique is not likely to be successful.

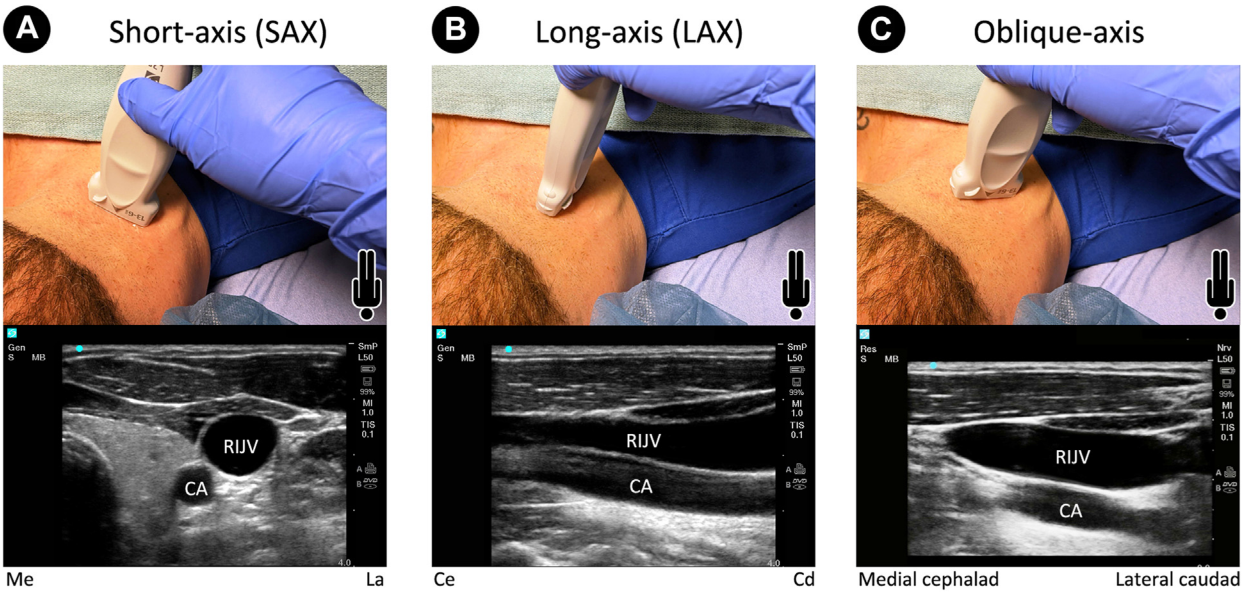

Figure 2 Vessel orientation. Probe orientation can be in **(A)** a transverse plane perpendicular to the vessels, creating a SAX view, or in **(B)** a longitudinal plane coaxial to the vessels, creating a LAX view. **(C)** Rotating the probe between the SAX and LAX views forms the oblique view, showing an elongated view of the vessels. The corresponding ultrasound images are of the RIJV and the CA. *CA*, carotid artery; *Cd*, caudad; *Ce*, cephalad; *La*, lateral; *LAX*, long-axis; *Me*, medial; *RIJV*, right internal jugular vein; *SAX*, short-axis.

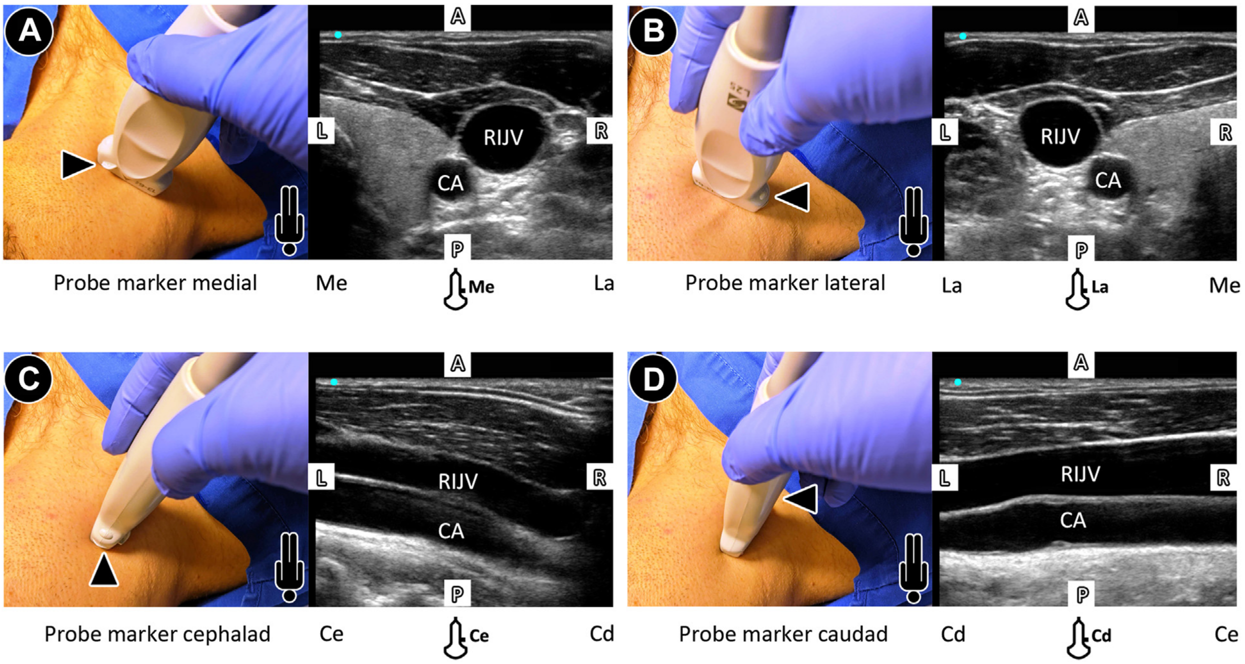

Figure 3 Image display. **(A-D)** Each US probe has a probe marker (black triangle) that distinguishes one side from the other. There is no accepted convention regarding probe marker placement during vascular access. General medical US uses a convention with the probe marker corresponding to the left side of the screen (*blue dot*). **(A** and **B)** In this example of imaging of the RIJV in SAX, the probe marker position is **(A)** medial (Me) or **(B)** lateral (La), with the corresponding images displayed. **(C** and **D)** Rotating the US probe 90° images the RIJV in LAX; the probe marker position can be cephalad (Ce) or caudad (Cd), as shown with the corresponding image displays. *A*, anterior; *CA*, carotid artery; *Cd*, caudad; *Ce*, cephalad; *Me*, medial; *P*, posterior; *R*, right; *RIJV*, right internal jugular vein; *L*, left; *La*, lateral; *LAX*, long-axis; *SAX*, short-axis; *US*, ultrasound.

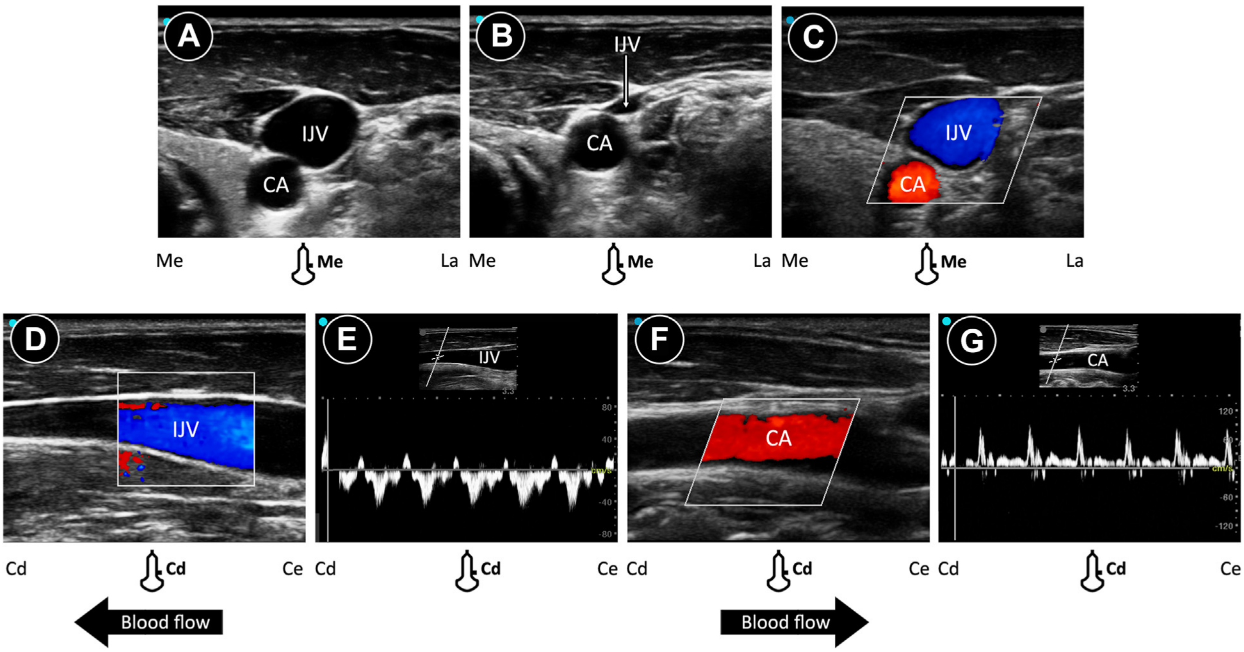

Figure 4 Vein and artery features in normal circulation. **(A)** Veins and arteries have different sizes, wall structures, and intraluminal pressure, which make it possible to distinguish each using 2D imaging. Usually, a vein has a thin wall and is larger compared with smaller, thicker walled arteries. **(B)** The low intraluminal pressure makes veins easily compressible by external pressure. **(C, D, F)** Color flow Doppler in both SAX and LAX views shows **(C)** low-velocity continuous flow in veins and **(F)** pulsatile intermittent systolic flow in arteries. Note the *red* and *blue* colors in the lumen of the vessels indicate flow away (*blue*) and toward (*red*) the US probe. **(E)** PWD sampling of the distal right IJV lumen in LAX shows a multiphasic trace with the systolic and diastolic flow away from the transducer and a small retrograde flow from atrial contraction. **(G)** PWD sampling of the proximal internal CA shows pulsatile flow toward the transducer with systolic prominence. *CA*, carotid artery; *Cd*, caudad; *Ce*, cephalad; *IJV*, internal jugular vein; *La*, lateral; *LAX*, long-axis; *Me*, medial; *PWD*, pulsed-wave Doppler; *SAX*, short-axis; *US*, ultrasound. See Video 2.

In the US-guided technique, the operator scans the IJV to determine the puncture site that provides a direct pathway to the vessel lumen and minimizes IJV-CA overlap and the risk for CA puncture (Figure 11). Most operators use the out-of-plane approach from a SAX view, as described in section 3.4., during IJV cannulation (Figure 9, Video 5).

Evidence. Several randomized controlled trials (RCTs) and meta-analyses comparing US-guided and landmark techniques for IJV access in diverse clinical settings establish higher first attempt success rates, higher overall success rates, reduced access time, lower rates of arterial puncture, and fewer insertion attempts with US guidance.[29,31,33-35] A meta-analysis in 2013 of 26 studies (4,185 patients) showed that US-guided IJV cannulation in adults had decreased cannulation failure and complications (arterial puncture, hematoma, and hemothorax).[34] A 2015 Cochrane analysis of 35 studies enrolling 5,108 patients noted, however, that the evidence for most outcomes is low in quality.[35]

An RCT comparing static US with a landmark approach for IJV insertion reported a higher first attempt success rate with static US but only equivocal evidence for improved overall success or impact on arterial puncture rates.[8]

Recommendation for IJV Cannulation. On the basis of evidence and expert consensus opinion, this writing group strongly recommends (grade 1A) that properly trained clinicians use US guidance during IJV cannulation, when possible, to improve cannulation success and reduce complication rates associated with catheter insertion. The writing group recognizes that static US is superior to a landmark technique and is useful in identifying vessel patency and anatomy by skin-marking the optimal entry site for vascular access.

4.3. Subclavian and Axillary Vein

Anatomic and US Considerations. The axillary vein forms at the inferior axillary border by the union of the brachial and basilic veins and becomes the SCV after passing above the first rib and under the subclavius muscle and the clavicle (Figure 13, Video 7). Importantly, the axillary vein is extrathoracic and lies medial to the axillary artery 1 to 4 cm below the skin. The SCV and subclavian artery (SCA) are at the junction of the intrathoracic cavity and the extrathoracic zone. The advantages of choosing the axillary vein or SCV for central venous access include consistent surface anatomic landmarks and vein location, patient comfort, and the potential for less infection compared with other central venous sites.[36] The proximal axillary vein is larger, more superficial, and positioned anterior to the axillary artery near the clavicle, though there are many anatomic variations (Figure 13, Video 7).

Ultrasound imaging of the SCV is challenging, as shadowing from the clavicle often obscures the vein (Figure 14, Video 8). Moving the probe laterally better images the axillary vein in the extrathoracic

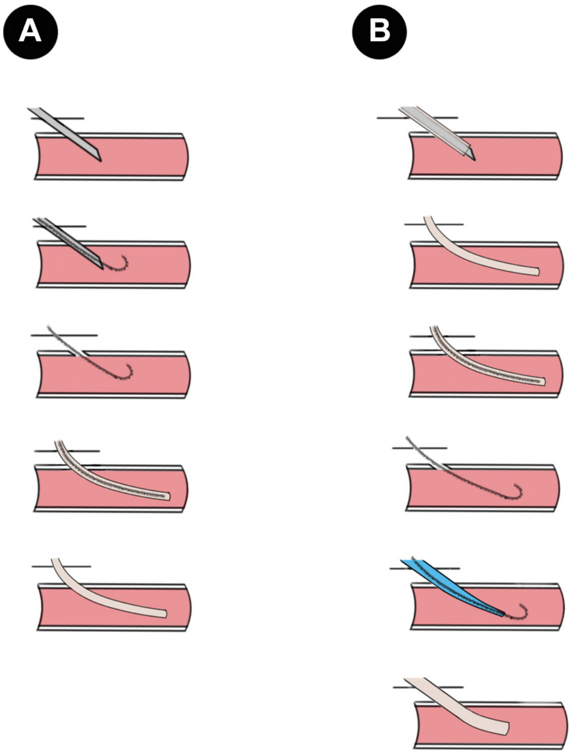

Figure 5 Seldinger techniques. **(A)** In the Seldinger technique, the operator inserts a beveled needle into a target vessel and, after aspirating blood, inserts a guidewire through the needle. After removing the needle, a catheter is then advanced over the guidewire into the vessel, followed by guidewire removal. **(B)** The modified Seldinger technique entails advancing a catheter over the needle into the target vessel and withdrawing the needle, leaving the catheter in the vessel. In either technique, a dilator (seen in the 5th image of **B**) can pass over the guidewire to dilate the extravascular tissue and vessel wall to accommodate a larger sized cannula.

region, improving this vessel as a target for US-guided vascular cannulation.[37] Baseline and postprocedural US imaging of the pleural line and lung sliding can help exclude the presence of a pneumothorax after vascular cannulation.

Cannulation Techniques. The supine position with the head neutral and slight shoulder retraction most effectively aligns the SCV for a landmark-based technique during cannulation.[38] Although many clinicians place the patient in the Trendelenburg position, there is less distension of the SCV than the IJV because the surrounding tissue fixes the SCV. Thus, the primary reason for the Trendelenburg position is to increase venous pressure in the SCV, thus reducing the risk for air embolism in spontaneously breathing patients.

The operator may cannulate the SCV using a supraclavicular or an infraclavicular approach. The infraclavicular approach is the most common and, hence, is the focus of this discussion. Clinicians have largely abandoned the "blind" supraclavicular approach (without US) because of a high incidence of pneumothorax.

Many clinicians consider the landmark technique for SCV cannulation to be the simplest method to access this vein. A typical approach is to insert the needle 1 cm inferior to the junction of the middle and medial third of the clavicle at the deltopectoral groove (Figure 13). The patient's anatomy influences the amount of lateral needle displacement. An increased angle to the skin or too anterior needle direction increases the risk for causing a pneumothorax. Caudal rotation of the needle bevel after venipuncture helps direct the guidewire toward the right atrium.

In US-guided SCV access, the probe position is perpendicular to the mid-clavicle near the first rib to identify the SCV, SCA, and pleura (Figure 14, Video 8). Relative to the SCA, the SCV is medial, superficial, and compressible. The operator may puncture the SCV in a SAX view or rotate the probe to attain a LAX view.[38] In LAX, the probe lies parallel to the vessel and preferably orientated to track the direction of blood flow toward the heart, so the needle puncture follows the direction of venous flow.

Proximal and distal approaches are two US-guided techniques to choose for axillary vein cannulation.[39] In the proximal approach, the probe position is near the middle third of the clavicle and images the distal axillary vein in SAX or LAX with needle entry closer to the clavicle. In the distal approach, needle entry is approximately a third of the distance between the clavicle and axilla. The probe orientation shows a LAX or SAX view of the axillary vein, which is centered on the screen display.[39,40] Skin puncture occurs at a 45° angle to the probe. Ultrasound probe manipulation tracks the needle tip from skin penetration to the vessel wall. Ultrasound can confirm the correct guidewire position in the axillary vein directed toward the heart, excluding malposition in the ipsilateral IJV and contralateral SCV.

Evidence. A few RCTs and meta-analyses compare US-guided vascular access of the SCV and axillary vein to landmark techniques.[41-44] For the SCV, RCTs with US guidance report fewer attempts and higher overall success rates but are equivocal for arterial puncture and hematoma.[43,44] The largest RCT involving 401 patients comparing US-guided and landmark SCV cannulation showed US improved cannulation rates by experienced operators using a LAX approach (100% vs 87.5%) with fewer mechanical complications.[41] A meta-analysis of 10 studies (2,168 patients) in 2015 concluded that US-guided SCV cannulation reduced the frequency of adverse events compared with the landmark technique.[43] A 2015 Cochrane analysis of 35 studies enrolling 5,108 participants suggested small gains in safety and quality with a slight reduction in complications when using US guidance for SCV access.[44] A meta-analysis in 2023 involving six studies (805 patients, 2017-2022) showed that US-guided SCV access is safer and more efficient with increased overall and first attempt success rates, reduced total number of attempts, access times and complication rates.[45]

Randomized controlled trials have shown US-guided axillary vein cannulation to be a safe alternative to IJV access, with fewer complications.[46,47] A meta-analysis of five studies (1,852 patients) in 2022 demonstrated that US-guided axillary vein cannulation reduces catheterization failures and mechanical complications compared with landmark-guided SCV puncture.[48]

Recommendations for SCV and Axillary Vein Cannulation. On the basis of expert consensus opinion and despite low-quality evidence, this writing group strongly recommends (grade

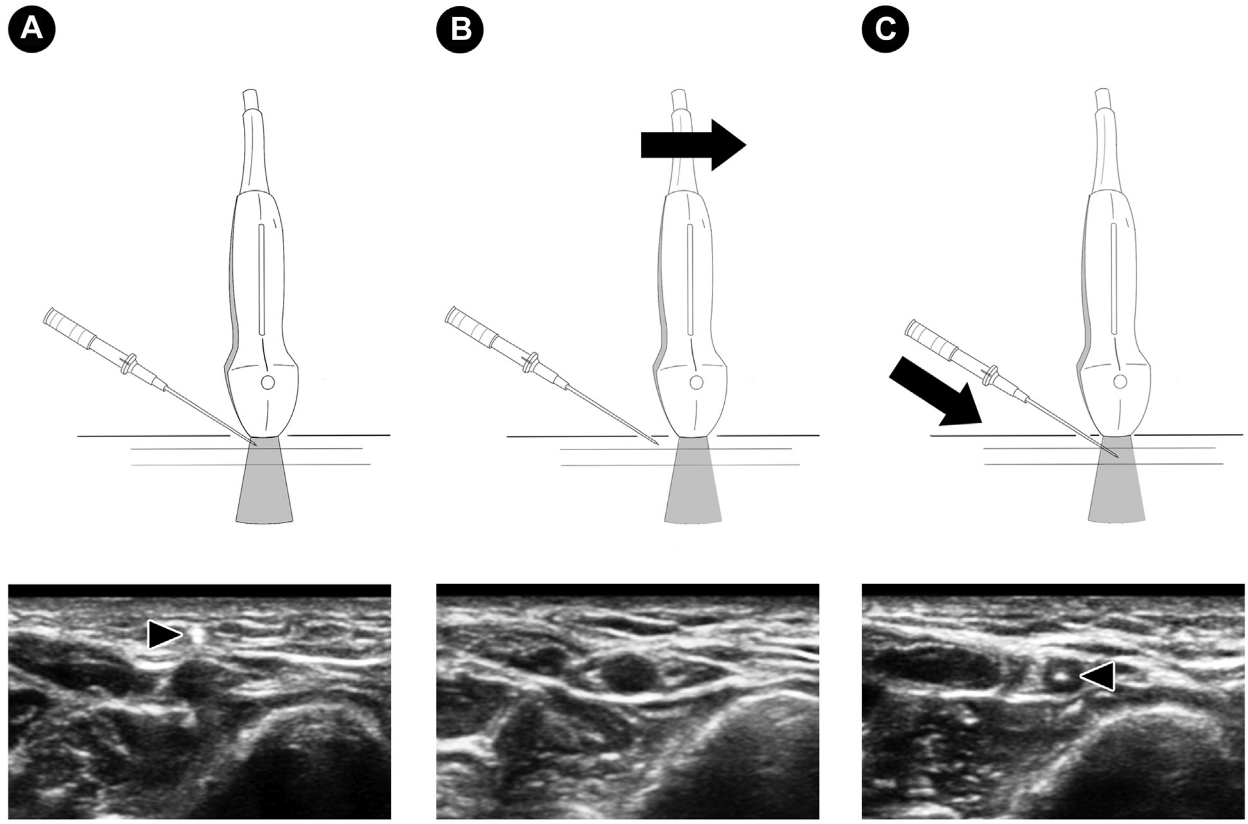

Figure 6 Out-of-plane cannulation approach. An out-of-plane approach using an SAX view of vessels does not continuously image needle tip advancement throughout its course. The US-guided DNTP technique uses the SAX view as shown here for the radial artery. The operator identifies **(A)** the needle tip as a bright echogenic spot (*arrow*) in the subcutaneous tissue and **(B)** then moves the probe without moving the needle until it disappears. **(C)** The operator advances the needle until it reappears and penetrates the anterior vessel wall. The term for the appearance of a needle tip in the center of the vessel is the "bull's eye" finding (Video 3). *DNTP*, dynamic needle tip positioning; *SAX*, short-axis; *US*, ultrasound.

1C) that trained clinicians use US guidance during SCV cannulation. On the basis of a few studies with high-quality evidence and expert consensus opinion, this writing group strongly recommends (grade 1B) that properly trained clinicians use US guidance during axillary vein cannulation, when possible, to improve cannulation success and reduce complication rates.

4.4. Common Femoral Vein

Anatomic and US Considerations. The common femoral vein (CFV) and common femoral artery (CFA) lie parallel within the femoral triangle in the inguinal region with the CFV medial to the CFA (Figure 15, Video 9). The femoral artery pulse is at the midpoint of the inguinal ligament connecting the anterior superior iliac spine to the pubic tubercle. The degree of overlap of the CFV by the CFA increases from 5% to 60% moving distal to the inguinal ligament.[49] In addition, the variable relationship between the inguinal ligament and the inguinal crease makes the latter a less useful surface landmark.

The femoral site has advantages for elective and emergency venous and arterial access, as it is a relatively safe and accessible location with predictable anatomic landmarks. Femoral vascular access avoids the risk for hemothorax and pneumothorax, which are notable in patients with severe coagulopathy or respiratory failure. Although the femoral site permits cannulation attempts without interruption of cardiopulmonary resuscitation during cardiac arrest, recent Advanced Cardiac Life Support guidelines recommend intraosseous access over femoral venous access in patients who lack intravenous access.[50] Interosseous access involves the insertion manually or by drill of a special intraosseous hollow-bore needle into the proximal tibia through the bone cortex into the medullary sinus to allow the administration of fluids and medications.

Ultrasound imaging of the inguinal region begins at the midpoint, close to the inguinal ligament.[16] The SAX view perpendicular to the vessels easily identifies the relative position and depth of the CFV and CFA (Figure 15). A more caudal US probe position shows the great saphenous vein entering the CFV and the bifurcation of the CFA into superficial and deep femoral arteries. The CFV may be pulsatile in patients with elevated central venous pressure, right heart dysfunction, and pulmonary hypertension.

Cannulation Techniques. Positioning the patient supine with the hip in the neutral position or with slight hip abduction and external rotation (frog-leg position) allows access to the femoral vessels (Figure 16). The frog-leg position improves the CFV accessibility from 70% to 83% in adults and increases the vessel diameter in

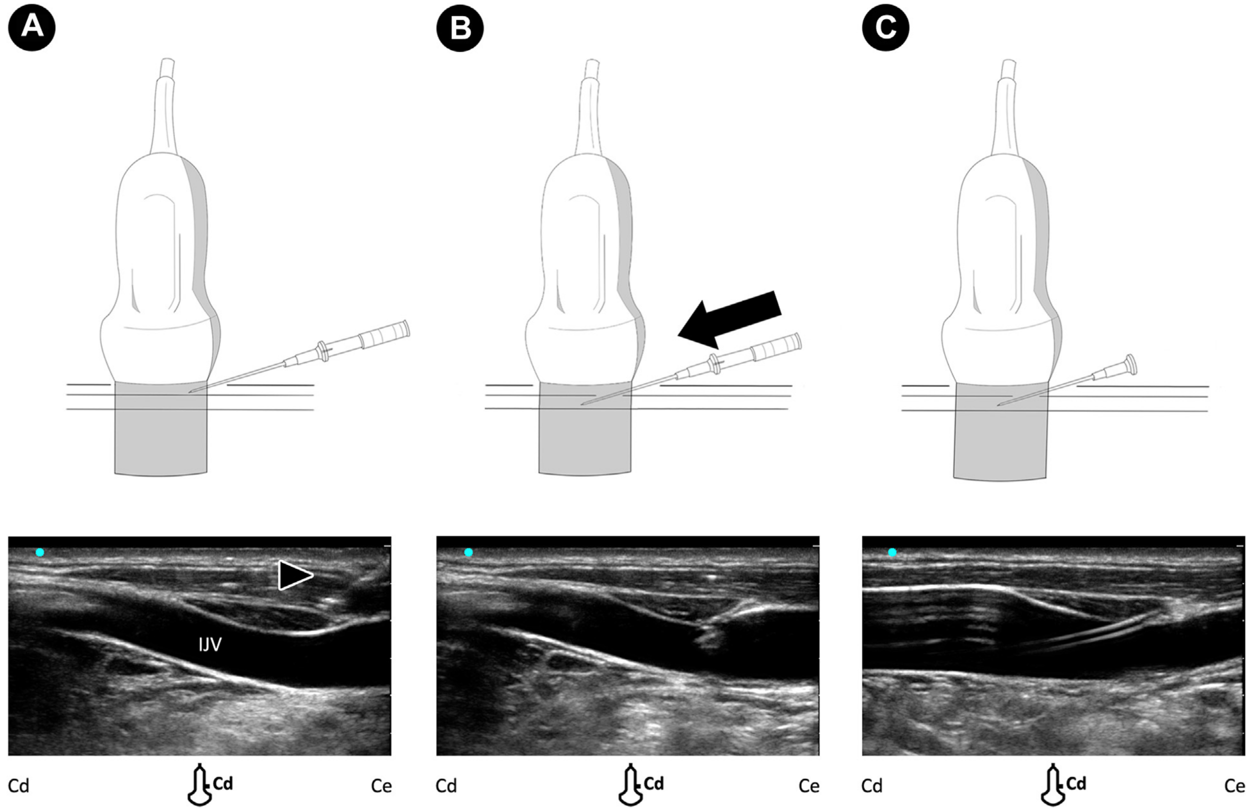

Figure 7 In-plane cannulation approach. An in-plane approach shows an LAX view of the vessel with direct visualization of the advancing needle shaft and tip without moving the probe. **(A)** The operator advances the needle in the soft tissue (*arrow*), **(B)** puncturing the anterior wall but not the posterior wall, in this example, the IJV, and **(C)** positions a cannula in the vessel. *Cd*, caudad; *Ce*, cephalad; *IJV*, internal jugular vein; *LAX*, long-axis. See Video 4.

children compared with a straight-leg approach.[51] The reverse Trendelenburg position increases CFV CSA by >50%.[52]

In the landmark technique, the operator locates the CFA by palpating the point of maximal pulsation 1 to 2 cm below the midpoint of the inguinal ligament. The CFV is found by inserting a needle at a 45° angle to the skin 1 cm medial to the maximal pulsation of the CFA with needle advancement in a cephalad and medial direction. In most adults, the CFV is 2 to 4 cm beneath the skin.

In the US-guided approach, the operator positions the US probe in the inguinal region perpendicular to the vessel orientation, thus displaying the vessels in a SAX view. Scanning the CFV evaluates the patency and caliber.[16] Cannulation involves placing the target vessel in the center of the screen and inserting the needle at a 45° angle to the skin (Figure 16). The operator manipulates the US probe to track the needle tip as it approaches the vessel. The LAX view may improve visualization of the needle tip path and entry into the vessel but is difficult to maintain depending on the depth of the vessel.

Evidence. There are RCTs, observational studies, and meta-analyses comparing US guidance to landmark techniques during CFV cannulation.[8,53-56] These RCTs report fewer insertion attempts with US guidance, higher overall success rates, and fewer complications.[53,54] A meta-analysis of seven studies (830 catheters) in 2011 concluded that US-guided CFV cannulation for hemodialysis catheters reduced the frequency of adverse events compared with the landmark technique.[55] A 2015 Cochrane meta-analysis that included four studies (311 patients) showed that US-guided CFV cannulation had greater first attempt success and a small increase in overall success but no difference in inadvertent arterial puncture or other complications.[44] A 2020 meta-analysis comparing US guidance to the landmark technique for CFV access in electrophysiology procedures included nine studies (8,232 patients) and showed the use of US was associated with fewer major vascular complications and inadvertent arterial puncture rates, shorter puncture time, and less procedure pain.[56]

Recommendation for CFV Cannulation. On the basis of evidence from RCTs, meta-analyses, and expert consensus opinion, this writing group strongly recommends (grade 1B) the routine use of US guidance during CFV cannulation, when possible, to improve cannulation success, and reduce cannulation time and complications.

4.5. Peripheral Intravenous Central Cannulation

Anatomic and US Considerations. A peripherally inserted central catheter (PICC) can provide central venous access from a peripheral vein puncture, avoiding the risks of central venous cannulation. The availability of multilumen catheters makes this suitable access for long-term infusions, administration of sclerosing drugs, and venous blood sampling in outpatient, inpatient, and intensive care unit settings.

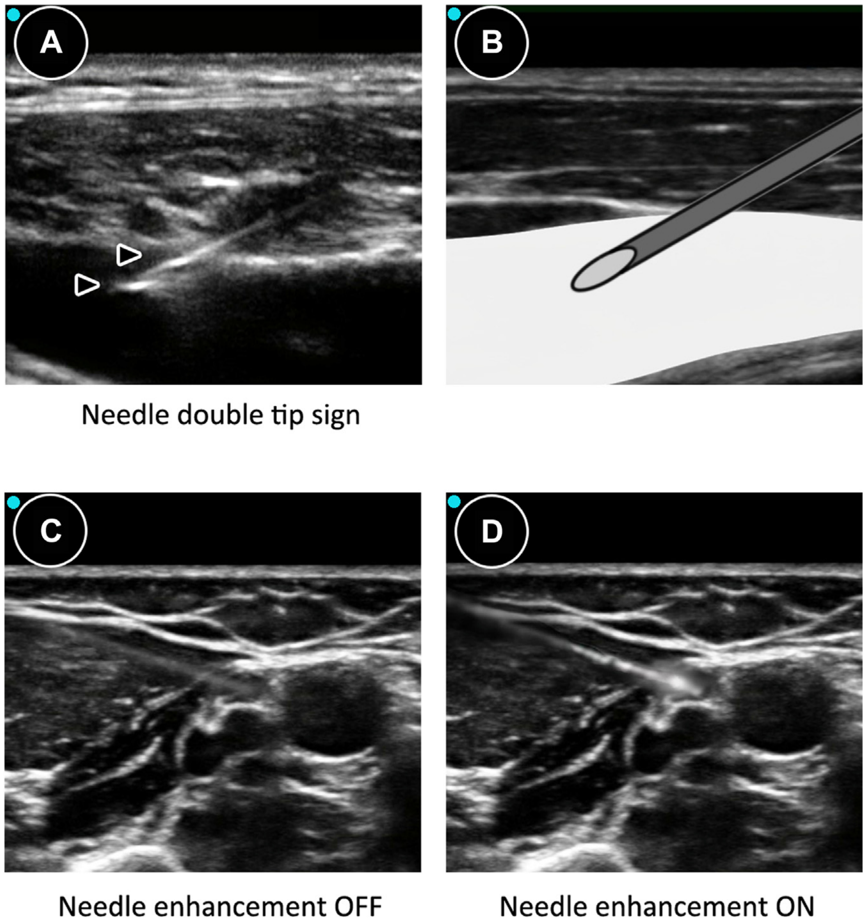

Figure 8 Needle tip visualization. An essential component of any US-guided approach is to visualize the needle tip and shaft, which best occurs when the US beam aligns at an orthogonal angle. **(A** and **B)** The LAX view of the needle best accomplishes this, as the needle tip appears as 2 echogenic lines, the so-called "double tip" sign. **(C** and **D)** US machine software may enable enhanced needle visualization using proprietary software shown **(C)** without (off) and **(D)** with (on) activation. The needle shaft is more visible near the vessel wall with this US machine feature activated. *LAX*, long-axis; *US*, ultrasound.

In most patients, the upper arm venous system drains into the SCV from three major veins, basilic, brachial, and cephalic, with some anatomic variability (Figure 17). There is no consensus on the best vessel for cannulation, although the more common is the basilic vein in the upper arm. The brachial vein is usually the last choice to minimize the risk for brachial artery puncture.

Using a portable US machine for US-guided cannulation of peripheral veins makes this a bedside procedure performed by trained clinicians and nurses.[57] The operator scans the arm from the antecubital fossa to the axillary vein to ensure vessel patency and facilitate the selection of the largest vein. The optimal puncture site in the arm is as high as possible.[58]

Cannulation Technique. The patient lies supine or with 45° head elevation to improve patient comfort. The supinated arm is at 75° of abduction and supported on a firm surface. The operator may apply an arm tourniquet and after skin antisepsis, positions a full body drape over the insertion site to create a sterile field. Venous puncture commonly uses an out-of-plane approach to imaging the vessel in SAX for the modified Seldinger technique (Figure 5). Current success rates of bedside US-guided PICC line insertion are >90%.

Evidence. Using US guidance for PICC placement enhances vein assessment and cannulation success while decreasing complications.[59-61]

Recommendations for Peripheral Intravenous Central Cannulation. On the basis of evidence from fewer studies and an evolving standard of care, this writing group strongly recommends (grade 1C) the routine use of US guidance to aid in PICC placement.

4.6. Peripheral Intravenous Cannulation

Anatomic and US Considerations. The cephalic vein travels near the radial vessels and the basilic vein is next to the ulnar vessels (Figure 17). The brachial and basilic veins continue into the axillary vein at the inferior border of the teres major. The cephalic vein runs laterally along the forearm and upper arm, then travels between the deltoid and pectoralis major to join the SCV.

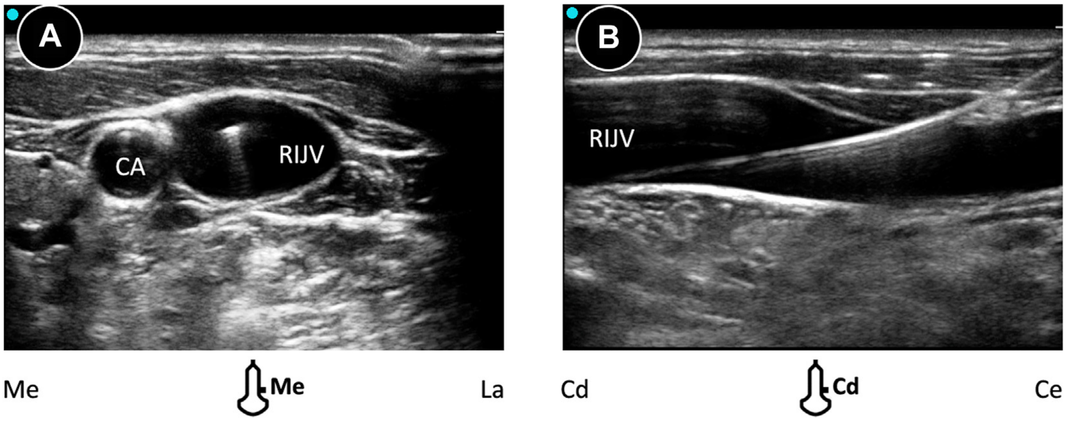

Figure 9 Guidewire identification. After the needle enters the vessel, a guidewire passes through the needle lumen, followed by withdrawal of the needle. Ultrasound should confirm the guidewire position in the correct vessel lumen. **(A)** In the SAX view, the guidewire appears as an echogenic dot, often with a reverberation artifact. **(B)** In the LAX view, the guidewire enters the vessel from the subcutaneous tissue, tracking distally into the vessel lumen. *CA*, carotid artery; *Cd*, caudad; *Ce*, cephalad; *La*, lateral; *LAX*, long-axis; *Me*, medial; *RIJV*, right internal jugular vein; *SAX*, short-axis. See Video 5.

The definition of difficult peripheral intravenous (PIV) access is the absence of easily visible or palpable veins in both arms after tourniquet placement.[62] Ultrasound scans of the antecubital fossa, forearm, and lower extremities can help identify veins. It is important to recall that pressure from the probe can compress the veins, making them difficult to visualize.

Cannulation Technique. During peripheral venous cannulation, skin asepsis is performed at the puncture site but depending on the technique the US probe and gel may or may not be sterile. Ultrasound-guided cannulation of peripheral veins follows the needle tip of the angiocatheter using an out-of-plane approach, visualizing the vessel in SAX. Smaller vessels may be tortuous and can be difficult to keep in a longitudinal view.

Evidence. Meta-analyses of RCTs and prospective observational studies showed that US-guided PIV cannulation is better than using landmarks when venous access is difficult and is of particular benefit in children.[63-67] A meta-analysis from 2018 involving eight studies (1,660 patients) using US-guided PIV access showed higher cannulation success rates, with a reduced number of punctures and time to cannulation.[65] Another meta-analysis in 2023, including seven studies (994 patients) involving children and adults using US guidance in different clinical settings showed higher first attempt and overall success rates.[66] Using US for PIV placement can reduce the time to gain venous access, improve patient satisfaction, and reduce the need for physician intervention.[68]

Recommendation for Peripheral Venous Cannulation. On the basis of limited evidence from studies and expert consensus opinion, this writing group strongly recommends (grade 1B) the use of US guidance for PIV cannulation in adults and children with moderate to difficult venous access, in both emergency and elective situations.

Key Points: Venous Cannulation

- The indications for venous cannulation include therapeutic, monitoring, and diagnostic reasons in hospital and outpatient settings.
- Venous access sites may involve central or peripheral vein cannulation.
- In the US-guided technique, the operator scans the vein to determine the puncture site that provides a direct pathway to the vessel lumen and minimizes the risk for arterial puncture.
- Evidence in diverse clinical settings shows higher first insertion attempt success rates, higher overall success rates, reduced access time, lower rates of arterial puncture, and fewer insertion attempts for US-guided access in different vessels.

5. ARTERIAL CANNULATION

5.1. Overview

Indications. The indications for arterial cannulation are expanding for monitoring, diagnostic, and therapeutic reasons in acute care, operating room, interventional radiology, and cardiac catheterization settings (Table 3). Diagnostic procedures, such as vascular and cardiac angiograms, use temporary arterial access. Increasingly large sheaths are necessary for arterial access to facilitate the delivery of therapeutic devices into the aorta and heart and for percutaneous therapeutic interventions, such as supporting the heart with an intra-aortic balloon or other forms of mechanical circulatory support.

Site Selection. Sites for arterial cannulation in the upper body include the radial, ulnar, brachial, axillary, and carotid arteries and in the lower body the CFA, posterior tibial artery (PTA), and dorsalis pedis artery (DPA). For monitoring, the common femoral and brachial

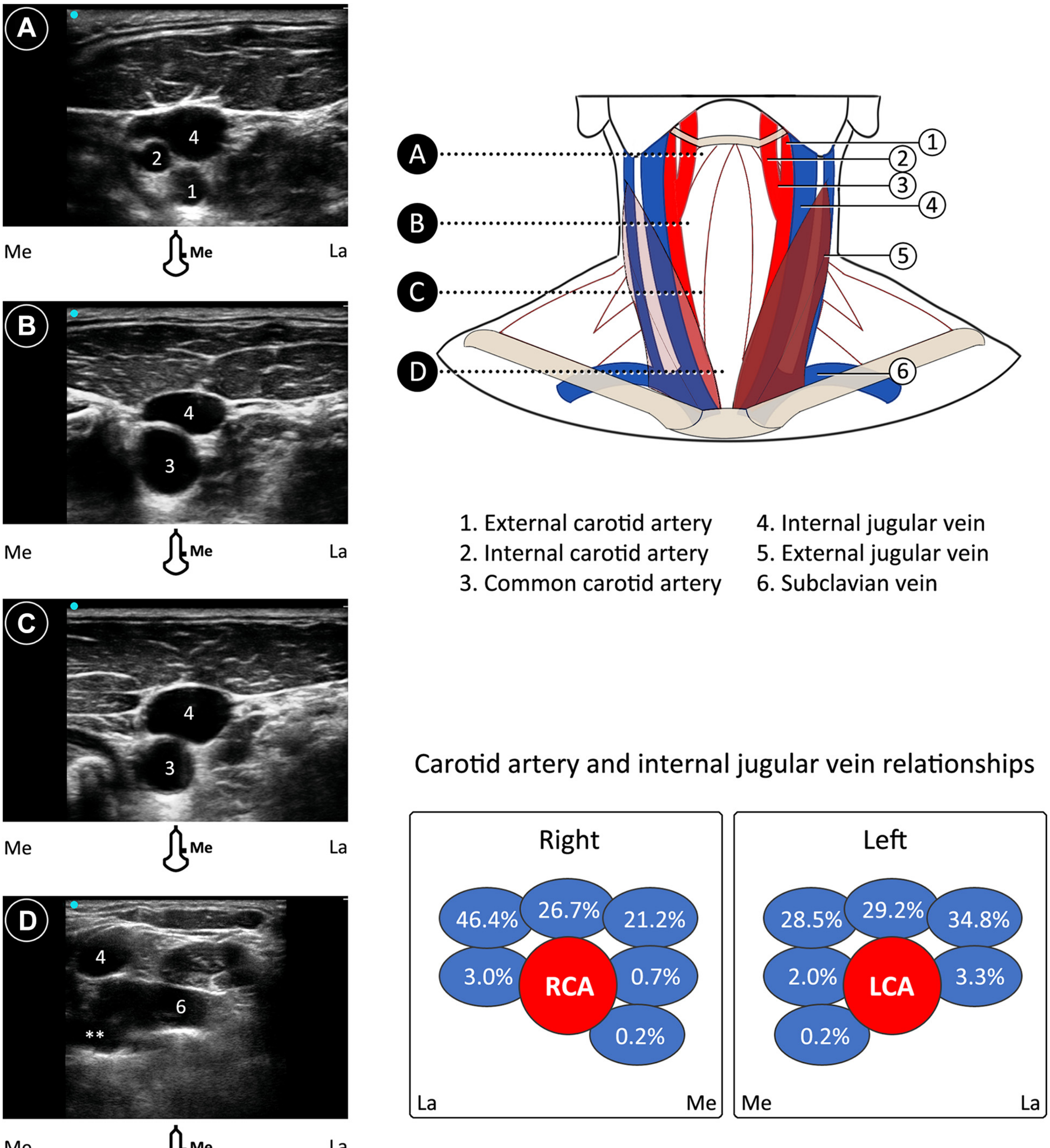

Figure 10 Internal jugular vein. The diagram shows the anatomy of both internal jugular veins with US images **(A-D)** of the RIJV in SAX at different levels. In the supraclavicular region **(D)**, the RIJV joins the right subclavian vein to form the right brachiocephalic vein (**). There is a variable relationship between the CA and the IJV, depending on the level of imaging. Note the probe marker is medial on the patient. The graphic shows the position (in percentage) of the IJV in relation to the common CA with the head in a neutral position (adapted from Hind *et al*.[33]). *CA*, carotid artery; *La*, lateral; *LCA*, left carotid artery; *Me*, medial; *RCA*, right carotid artery; *RIJV*, right internal jugular vein; *SAX*, short-axis. See Video 6.

arteries provide a better estimate of central arterial pressure compared with peripheral arteries.

The preferential site for peripheral arterial cannulation is the radial artery as it is superficial, easily accessible, and compressible with adequate collateral flow, thus minimizing complications.[69] The ulnar artery is an alternative cannulation site for invasively monitoring arterial blood pressure. The ulnar artery is less favorable compared with the radial artery because of the deeper anatomic position, location near a large nerve, and potential difficulty in achieving hemostasis after the procedure. Brachial artery cannulation as an alternative to radial or

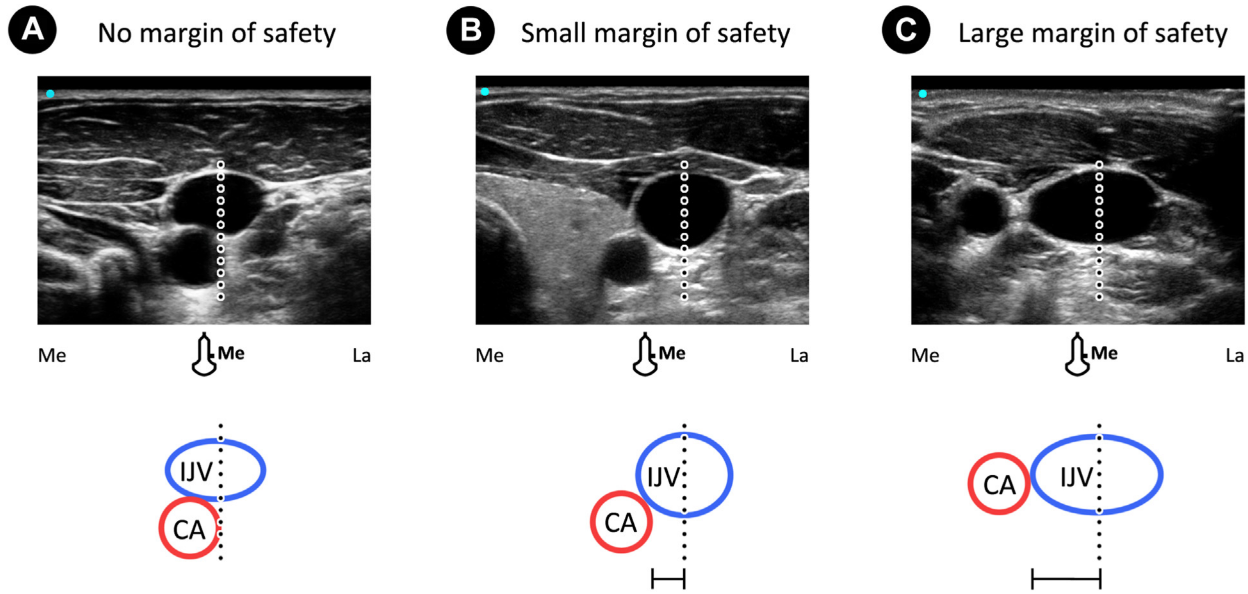

Figure 11 Margin of safety. The margin of safety is the distance between the midpoint of the IJV and the lateral border of the CA with examples showing **(A)** no, **(B)** small, and **(C)** large margins of safety. During cannulation of the IJV, the operator chooses the needle path (*dotted line*) to minimize the risk of CA puncture. *CA*, carotid artery; *IJV*, internal jugular vein; *La*, lateral; *Me*, medial.

ulnar artery access theoretically risks distal limb ischemia, though clinical experience, even in neonates and infants, does not support this.[70] The CFA is a frequent cannulation site for the delivery of endovascular stents and retrograde access to the heart for structural heart procedures. It may also be a favored site for arterial access during cardiac catheterization in children. The axillary artery and CA are alternative therapeutic large-bore percutaneous access sites in adults when femoral access is unavailable because of small vessel size, atherosclerotic disease, or tortuosity. Axillary artery cannulation may be preferable over other arterial sites in neonates and small infants for certain catheter-based interventions (e.g., stenting of the ductus arteriosus in congenital heart disease).

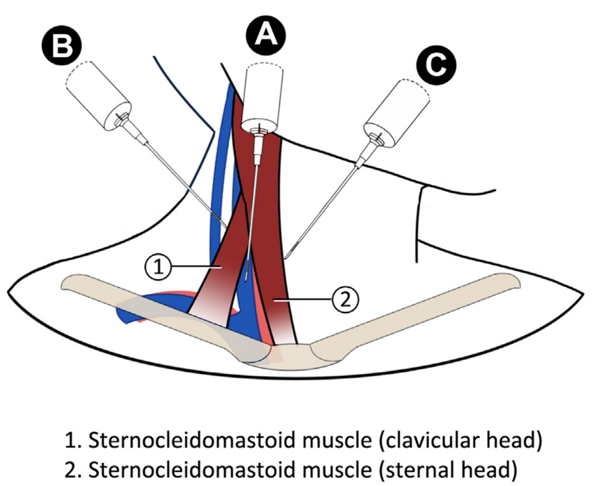

Figure 12 Internal jugular vein landmark technique. The landmark technique to access the internal jugular vein may use anterior, middle, or posterior approaches. **(A)** The most common is the middle approach with needle insertion at the apex of a triangle formed by the heads of the SCM and the clavicle directing it toward the ipsilateral nipple at a 30° angle to the skin. **(B)** In the posterior approach, the needle enters at the lateral border of the SCM, where the external jugular vein crosses, directing it toward the sternal notch. **(C)** In the anterior approach, after palpation of the carotid pulse and retraction of the artery medially, the needle enters at the medial margin of the SCM in a direction toward the ipsilateral nipple. *SCM*, sternocleidomastoid.

Ultrasound of Vessels. As previously discussed in section 3.3, US can identify arteries that should be distinguishable from veins (Figure 4). It is easy to obscure arteries and veins when imaging with US as even gentle probe pressure may compress the superficial vessels. The US examination of the target artery in SAX and LAX views should evaluate for depth, size, patency, tortuosity, and the presence of any calcium.[71,72]

Landmark Technique for Arterial Access. Clinicians use a similar approach to gain arterial access in any region of interest. The operator positions and immobilizes the area and palpates the point of maximal pulsation over the artery. After skin infiltration with a local anesthetic if needed, the application of skin antisepsis and sterile drapes creates a sterile area. The operator advances a needle or angiocatheter at a 30° to 45° angle to the vessel while watching for blood return using a Seldinger or modified Seldinger technique (Figure 5). A dilator over the guidewire may be necessary to create a subcutaneous tunnel that accommodates a large cannula or sheath. Fluoroscopy, if available, is often used before CFA access to confirm an appropriate puncture site over the femoral head.

US-Guided Arterial Access. Ultrasound guidance is most useful when the artery is difficult to palpate, small in diameter, in deep locations, has nonpulsatile blood flow, and after previous unsuccessful cannulation. Heavily calcified vessels can be challenging to access using US so fluoroscopy, if available, can be a substitute in this situation.

Under sterile conditions, imaging of the vessel is in SAX with cannulation using a Seldinger or modified Seldinger technique (Figure 5). After the initial vessel puncture in SAX, US imaging of the vessel in LAX can help the operator direct the guidewire through the lumen past a stenosis or plaque, if present.

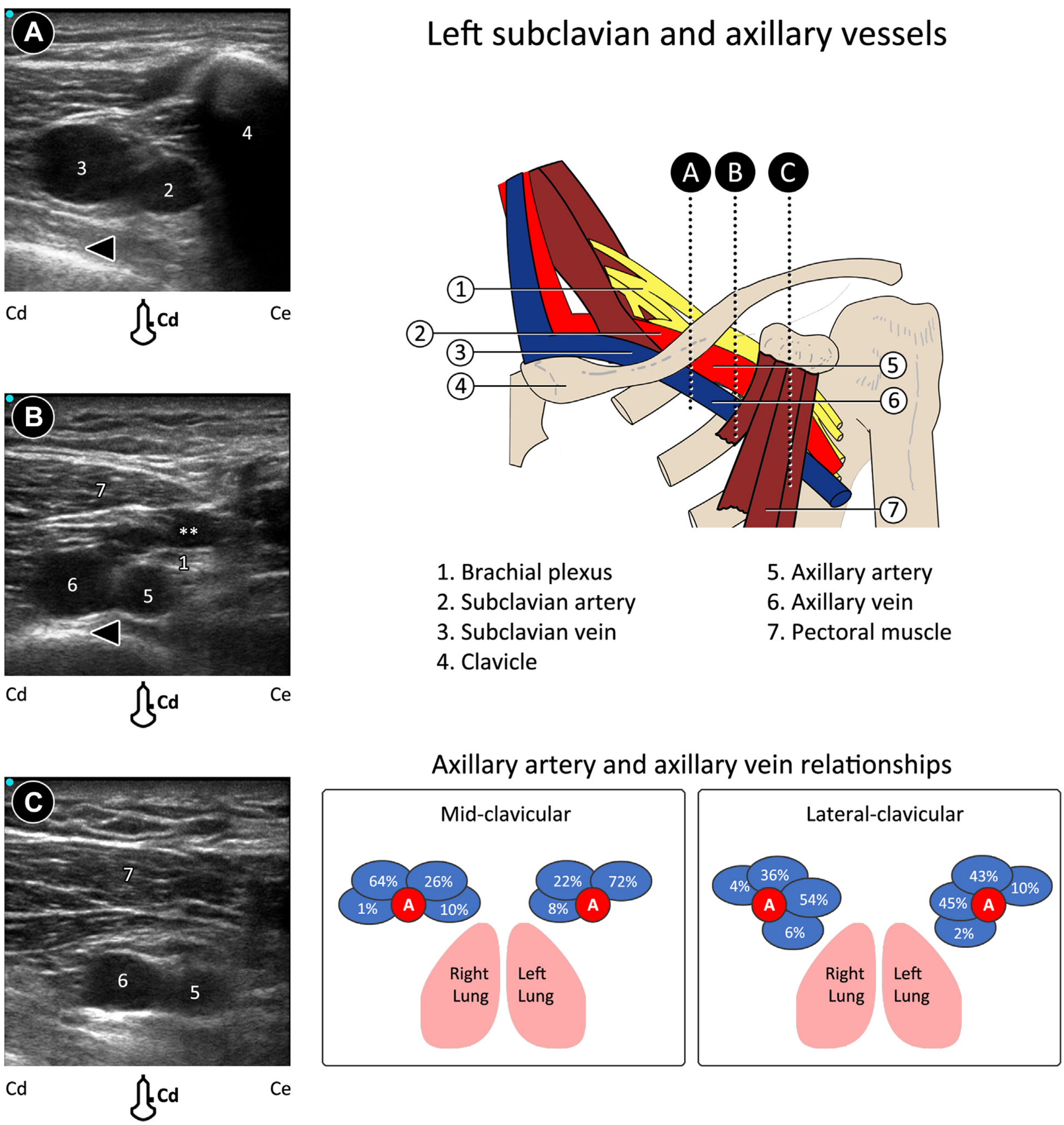

Figure 13 Subclavian and axillary veins. The diagram shows the anatomy of the left subclavian and axillary vessels. (A-C) The US images represent sagittal probe placement, probe marker caudad, at **(A)** mid, **(B)** lateral, and **(C)** far lateral positions of the clavicle showing the left axillary vessels and surrounding structures in SAX. The axillary vein appears smaller and is in a more medial position, further laterally along the clavicle. The graphic shows the position (in percentage) of the axillary vein relative to the axillary artery at the **(B)** mid and **(C)** lateral clavicular levels (Source: Lavallee et al.[37]). The *asterisks* in **(B)** represent the cephalic vein entering the axillary vein. The *arrow* in **(A** and **B)** represents the pleural line. *Cd*, caudad; *Ce*, cephalad; *SAX*, short-axis; *US*, ultrasound. See Video 7.

5.2. Radial Artery and Ulnar Artery

Anatomy and Access Considerations. The brachial artery bifurcates into the ulnar and radial arteries distal to the antecubital fossa (Figure 18). The radial artery runs laterally and the ulnar artery medially down the forearm to end at the wrist. Two veins accompany each artery at the wrist with the artery in the middle and a vein on each side. The radial and ulnar arteries connect through the superficial palmar and deep palmar arches, providing a dual blood supply to the hand. In adults, the average diameter of the radial artery is 2.2 to 2.3 $\pm$ 0.4 mm and the ulnar artery is 2.3 to 2.5 $\pm$ 0.5 mm at the wrist.[72]

The radial artery is a common cannulation site for monitoring and procedures involving interventional specialties, such as cardiology, neuroradiology, and radiology, even in patients with thrombocytopenia or coagulopathy.[73] Benefits of radial cannulation compared with femoral cannulation include lower risk for bleeding

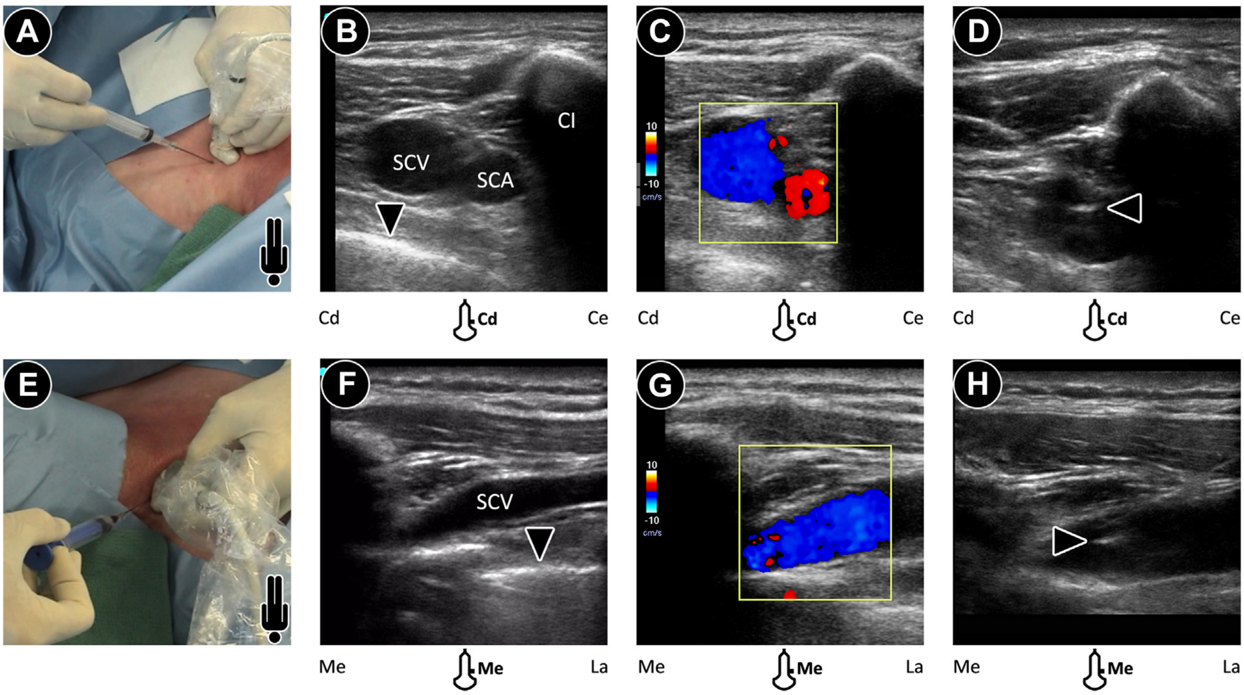

Figure 14 Subclavian vein cannulation. The operator can use either **(A-D)** an SAX out-of-plane needle approach or **(E-H)** an LAX in-plane needle approach to access the subclavian vein in the subclavicular area. It is important to distinguish the vein from the artery by using **(B** and **F)** 2D images and **(C** and **G)** color flow Doppler. The arrow in **(B** and **F)** represents the pleural line. **(F)** The LAX view shows compression of the vein. **(C** and **G)** The color flow Doppler images show low-velocity nonpulsatile flow in the vein from lateral to medial which is away from the probe (*blue*). **(D** and **H)** Ultrasound images should show the needle tip (*arrow*) in the vein lumen in the **(D)** SAX and in the **(H)** LAX views. *Cd*, caudad; *Ce*, cephalad; *Cl*, clavicle; *La*, lateral; *LAX*, long axis; *Me*, medial; *SAX*, short axis; *SCA*, subclavian artery; *SCV*, subclavian vein. See Video 8.

complications, shorter recovery time, and ability to ambulate immediately after the procedure.[74] It is advantageous in obese patients and has high patient satisfaction.[75] It is preferable to access the heart using the right radial artery to avoid crossing the aortic arch and left cerebral vessels. For peripheral interventions, the left radial artery is a better choice for the same reason as it avoids all cerebral vessels apart from the left vertebral artery. Distal radial artery cannulation within the snuff box is another safe alternative to traditional transradial artery access. The ulnar artery is a suitable alternative for patients with a contraindication to radial artery access.

Before radial or ulnar artery puncture, US can assess the vessel size. The modified Allen and Barbeau tests can assess the adequacy of collateral circulation in the hand when considering large-bore access.[11] In the modified Allen test, the patient elevates and clenches the hand for 30 seconds. The simultaneous occlusion of both the ulnar and radial arteries at the wrist blanches the hand. Upon release of the ulnar artery, the hand should regain color within 5 to 15 seconds, indicating a normal Allen test result. If color does not return, the Allen test is positive suggestive of insufficient ulnar collateral flow.

The Barbeau test uses a pulse oximeter on the thumb to observe the waveform during compression of the radial artery for 2 minutes. Possible oximeter waveform changes include (A) no damping, (B) damping, (C) loss but recovery within 120 seconds, and (D) loss without recovery within 120 seconds. A Barbeau test score of D and a small radial artery size (<1.7 mm) that cannot accommodate the 5-Fr (1.65 mm) radial vascular sheath are contraindications to radial artery access for cardiac catheterization or peripheral procedures.[76]

In adults, cannulation of a small radial artery (<1.8 mm) for monitoring purposes should be avoided, as it often gives a falsely low blood pressure measurement and increases the risk for pseudoradial hypotension during cardiac procedures.[77,78]

Cannulation Techniques. The operator positions a high-frequency linear US probe perpendicular to the radial or ulnar artery, visualizing the vessel in SAX (Figure 19, Video 3). In an awake adult patient, after lidocaine administration and skin antisepsis, a 21- or 22-G access needle or 20-G angiocatheter is continuously advanced into the vessel lumen under US guidance. It is preferable to use a single anterior wall puncture technique. If not proceeding under fluoroscopy, the operator should rotate the probe to image the vessel in LAX and watch the guidewire advancing during needle or angiocatheter access.

Evidence. Prospective RCTs of patients undergoing radial artery cannulation for monitoring or cardiac catheterization comparing US guidance to any other technique showed that US increased first attempt success and reduced the time to cannulation.[79-85]

Several meta-analyses have compared palpation with US-guided radial artery cannulation.[86-89] One in 2011 involving four RCTs (311 patients, 159 US guided) showed US guidance was associated with a 71% improvement in first attempt cannulation success.[86] Another in 2016 involving 11 RCTs (five pediatric, six adult) demonstrated high-level evidence that the use of US improved first attempt success rate in adults and pediatric patients.[87] In 2018, another included 12 RCTs (2,432 adult patients) and showed US guidance had higher first attempt success and lower failure rate, with no significant differences

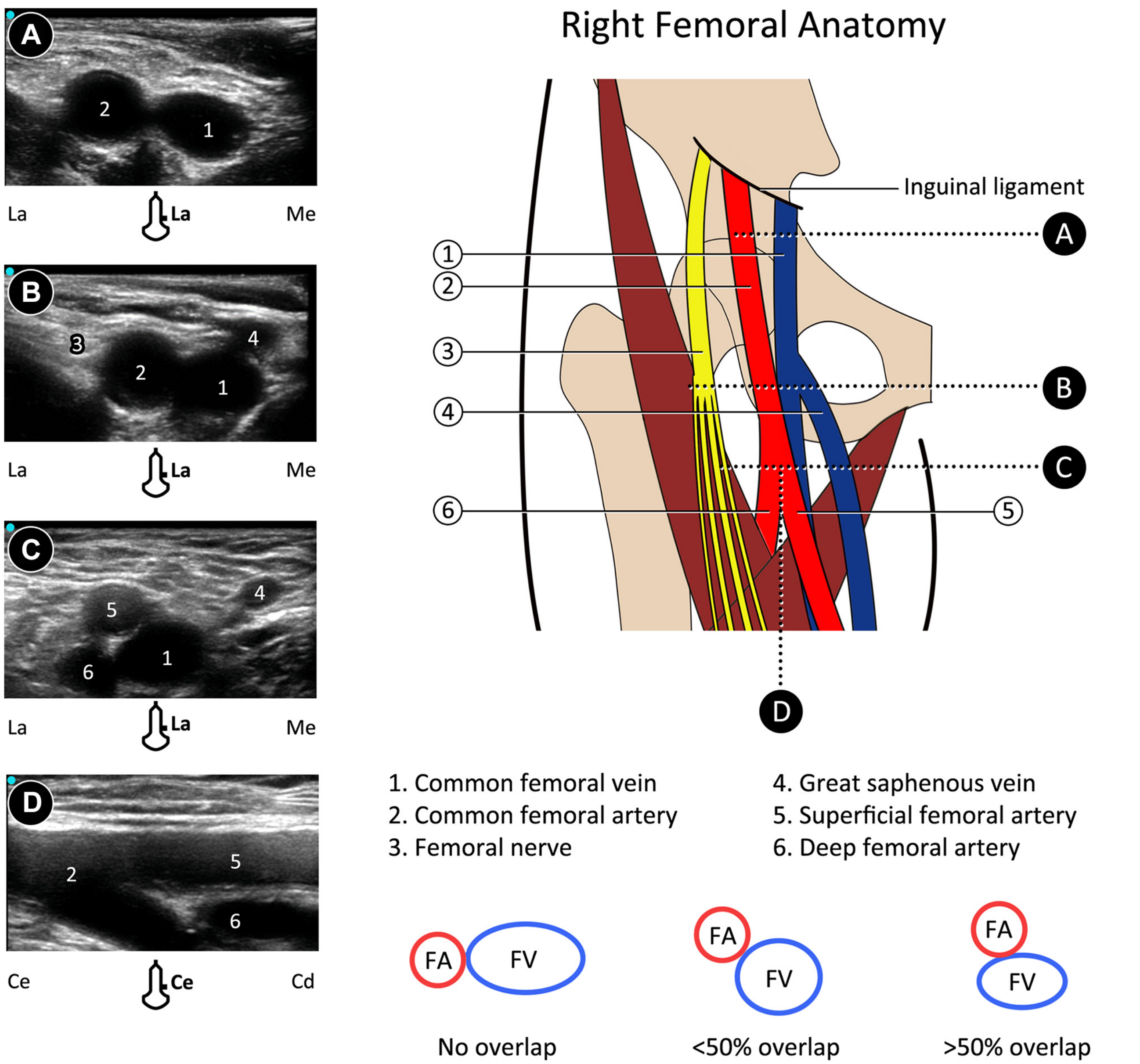

Figure 15 Femoral vessel anatomy and ultrasound. The diagram shows the anatomy of the right femoral triangle. The US images are of the right femoral vessels at various levels, with the probe marker lateral. **(A)** In the most superior position below the inguinal ligament, the CFV and common femoral artery appear in SAX with the vein medial to the artery. **(B)** Sliding the probe caudally shows the great saphenous vein as it enters the CFV. **(C, D)** Further caudal movement of the probe shows the bifurcation of the superficial femoral artery and the deep femoral artery in **(C)** SAX and **(D)** LAX. The graphic shows the variable amount of overlap of the femoral vessels, with greater overlap the more distal from the inguinal ligament. *Cd*, caudad; *Ce* cephalad; *CFV*, common femoral vein; *FA*, femoral artery; *FV*, femoral vein; *La*, lateral; *LAX*, long-axis; *Me*, medial; *SAX*, short-axis; *US*, ultrasound. See Video 9.

in access site hematoma or time to a successful attempt.[88] A 2021 meta-analysis that included 19 studies (3,220 patients) showed that US guidance has higher first attempt success as well as fewer attempts to success, shorter mean time to success, and a lower hematoma rate.[89] Ultrasound guidance can also minimize hematoma formation and patient discomfort during ulnar artery cannulation.[90]

Recommendation for Radial and Ulnar Artery Cannulation. On the basis of the evidence and expert consensus opinion, the writing group strongly recommends using US guidance during radial artery cannulation routinely (grade 1B) and in patients with a weak pulse and small artery or failed landmark attempt (grade 1A). Using US more effectively reduces complications, time to cannulation, and number of attempts, and increases the overall and first attempt success rates.

5.3. Brachial Artery

Anatomy and Access Considerations. The brachial artery is a continuation of the axillary artery after the inferior border of the teres major and courses medially down the ventral surface of the arm to the antecubital fossa (Figure 18). The median nerve accompanies the brachial artery and is susceptible to injury during vessel cannulation.

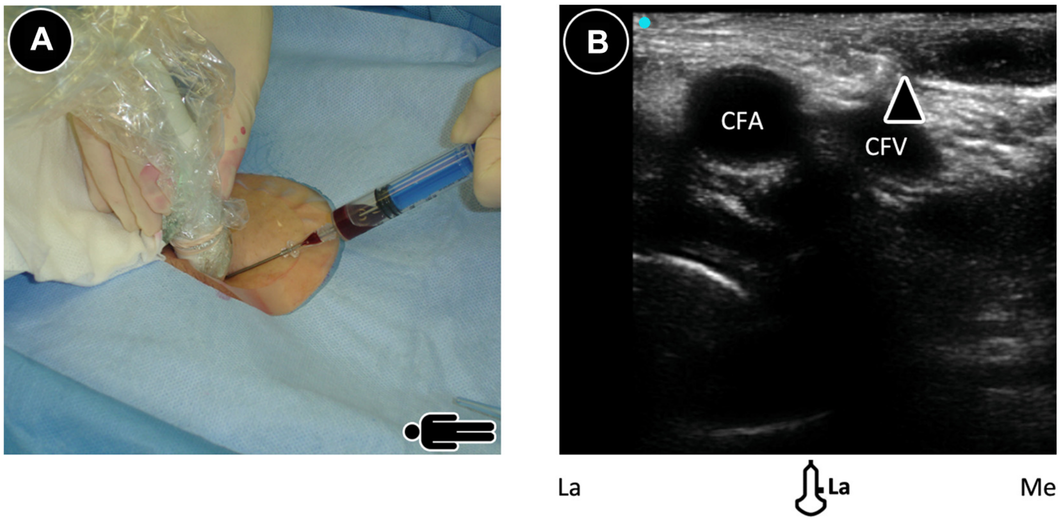

Figure 16 Femoral vessel access. **(A)** The patient is supine with the hip in a neutral position with the US probe in a transverse orientation to the vessels below the inguinal ligament. **(B)** The US image shows the CFA and CFV in SAX. The position of the target vessel, in this case, the CFV, should be in the center of the screen. **(A)** The insertion of the needle is at a 45° angle to the skin with manipulation of the probe **(B)** to track the needle tip (*black arrow*) in the soft tissue as it approaches, then enters the vessel. *CFA*, common femoral artery; *CFV*, common femoral vein; *La*, lateral; *Me*, medial; *SAX*, short-axis; *US*, ultrasound.

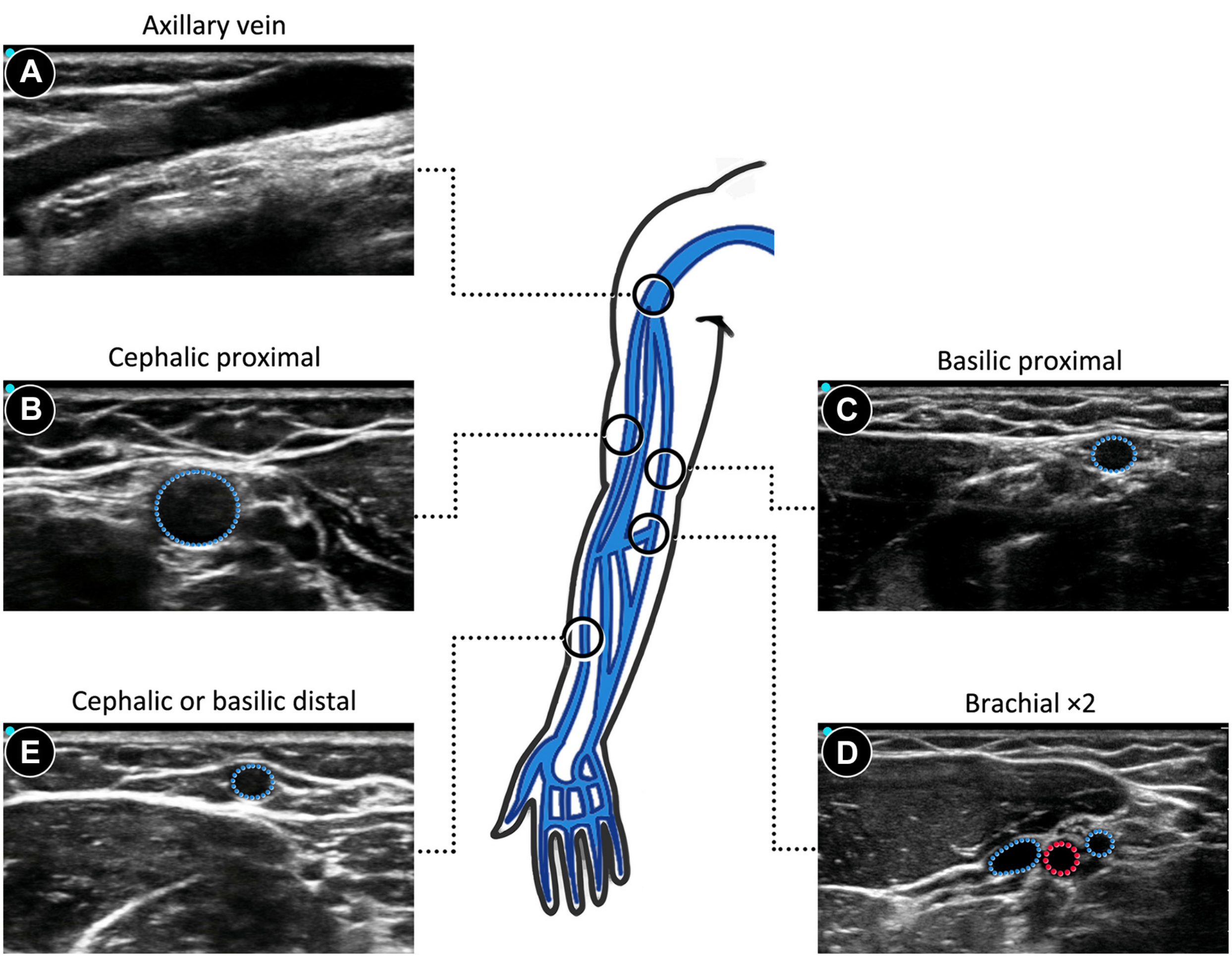

Figure 17 Peripheral venous access. The diagram shows the venous anatomy of the right arm. The cephalic vein traverses the lateral arm, the basilic vein is in the medial arm, and the brachial vein runs in the center of the arm, though with many variations. US imaging shows the veins are easily compressible and have continuous low-velocity blood flow. **(A)** Shown are US images of the axillary vein in LAX and SAX views with blue dotted circles indicating the **(B)** proximal cephalic vein in the lateral upper arm, **(C)** proximal basilic vein in the medial upper arm, and **(D)** 2 brachial veins in the antecubital fossa. **(E)** The superficial distal veins appear above the fascia and have a similar appearance, as shown for the distal cephalic vein. *LAX*, long-axis; *SAX*, short-axis; *US*, ultrasound.

Table 3 Common indications for arterial access

- Continuous invasive blood pressure monitoring
- Arterial blood sampling
- Facilitate diagnostic tests such as cardiac and vascular angiograms
- Therapeutic percutaneous endovascular procedures such as angioplasty or embolization
- Delivery of therapeutic devices such as stents and heart valves
- Provide access for mechanical support to the heart, intra-aortic balloon pump, ventricular support, extracorporeal membrane oxygenation
- Creation of endovascular arteriovenous fistula
- Thrombolysis or thrombectomy procedures

The average diameter of the brachial artery above the antecubital fossa is 3.9 ± 0.5 mm in adults.[72]

A brachial artery is an access option that accommodates large sheath sizes used for interventions such as stenting, complex endovascular aneurysm repairs, and visceral interventions when there is a contraindication to CFA access or a requirement for upper extremity access.[91] Brachial artery access may be an alternative site for pressure monitoring in adults, neonates, and children.

Cannulation Technique. The patient is in the supine position with the supinated arm extended laterally and supported on a firm surface. The brachial artery is easily palpable medial to the biceps tendon in the antecubital fossa. The operator positions the US probe to attain a transverse SAX view of the artery, which is confirmed using a lack of compression or CFD. Cannulation of the vessel is with a micropuncture 21-G needle or fine angiocatheter using US guidance (Figure 19, Video 10).

Evidence. There is no RCT comparing landmark to US-guided approaches for brachial artery cannulation. A single-center retrospective review of 265 US-guided brachial artery cannulation attempts reported a 98.9% success rate.[92] Another single institution retrospective study looking at US-guided brachial artery cannulation for interventional procedures demonstrated a 100% success rate with an 8% complication rate (5.3% minor and 2.7% major).[93]

Recommendation for Brachial Artery Cannulation. On the basis of the limited evidence and strong expert consensus opinion, the writing group strongly recommends (grade 1C) using US guidance during brachial artery cannulation. The clinician should choose this site only when radial, ulnar, or femoral artery access sites are less favorable.

5.4. Axillary Artery and CA Access

Anatomy and Access Considerations. The lateral edge of the first rib and the inferior margin of the teres minor defines the extent of the axillary artery. It is contiguous with the subclavian and brachial arteries and has multiple branches, including the lateral thoracic, anterior circumflex humeral, posterior circumflex humeral, thoracoacromial, and subscapularis arteries.[94]

Although less commonly performed, axillary artery cannulation may be useful in specific clinical scenarios. Axillary artery cannulation has a role in hemodynamic monitoring for critically ill patients in the setting of poor alternative choices. Axillary artery hemodynamic monitoring has the added benefit of monitoring central arterial pressures vs peripheral, which can benefit a select patient population where femoral or aortic access is not possible.[95] Additionally, percutaneous axillary artery cannulation is an alternative large-bore access when there is a contraindication to femoral access for transcatheter structural heart interventions, endovascular procedures, and percutaneous mechanical circulatory assist devices.[96]

Direct CA cannulation using a cutdown or percutaneous approach may be preferable in some neonates undergoing cardiac catheterization on the basis of the nature of the planned intervention. It is also an option in patients with contraindications to transfemoral access or challenging aortic arch anatomy for CA stenting or intracranial thrombectomy.

Cannulation Technique. For axillary artery cannulation, the patient is in the supine position with the arm abducted at 90°. Before cannulation, the operator should use US to gain a SAX view and identify the brachial plexus, which often drapes over the axillary artery. It is preferable to access the proximal portion where the artery lies cephalad to the vein with fewer adjacent structures and more compressibility.[94] The operator should cannulate the vessel under continuous US guidance using the Seldinger technique with a shallow angle (<30°) approach to allow large-bore cannulation.

Percutaneous CA cannulation uses US guidance at the base of the neck just above the clavicle with a micropuncture needle and a single wall puncture technique. The access is subsequently upsized after advancing the guidewire into the external CA.[97]

Evidence. Ultrasound-guided axillary artery cannulation is safe and effective according to the limited literature available. A retrospective study of 159 US-guided cannulations for hemodynamic monitoring in 155 patients showed a 97% success rate, 84% first attempt success rate, and a 20% complication rate.[95] A study of Impella devices (Abiomed) placed via the axillary artery reported a similar safety profile with 10 cases of bleeding or hematoma, one stroke, and three patients with brachial plexus symptoms among 102 patients.[98]

Recommendation for Axillary Artery and CA Cannulation. On the basis of limited evidence and strong expert consensus opinion, this writing group strongly recommends (grade 1C) using US guidance during axillary and CA cannulation.

5.5. Common Femoral Artery

Anatomy and Access Considerations. The common iliac artery divides into the internal iliac artery and the external iliac artery, which continues as the CFA for about 4 cm before bifurcating into the superficial femoral artery medially and the deep (or profunda) femoral artery laterally (Figure 20, Video 9).[99] The average diameter of the CFA in adults is 6.6 ± 1.2 mm.[72] The overlap between the CFV and CFA increases more distal to the inguinal ligament.

Common femoral artery vascular access is a mainstay for many endovascular procedures and therapeutic interventions, such as visceral or peripheral angiograms with or without intervention, an intra-aortic balloon pump catheter insertion, and peripheral extracorporeal membrane oxygenation. It is an alternative site if there are contraindications to or failed radial cannulation for adult cardiac catheterization. It is the standard arterial access for cardiac catheterization in pediatrics.

Cannulation Technique. Ultrasound-guided CFA cannulation has become an increasingly common practice, replacing the landmark technique. The operator positions the US probe perpendicular to the vessel, showing a SAX view of the artery.[100] Moving the probe proximally and distally identifies the bifurcation, branches that may cross anterior to the vessel, such as the inferior epigastric artery, as well as where the vessel dives deep into the retroperitoneum,

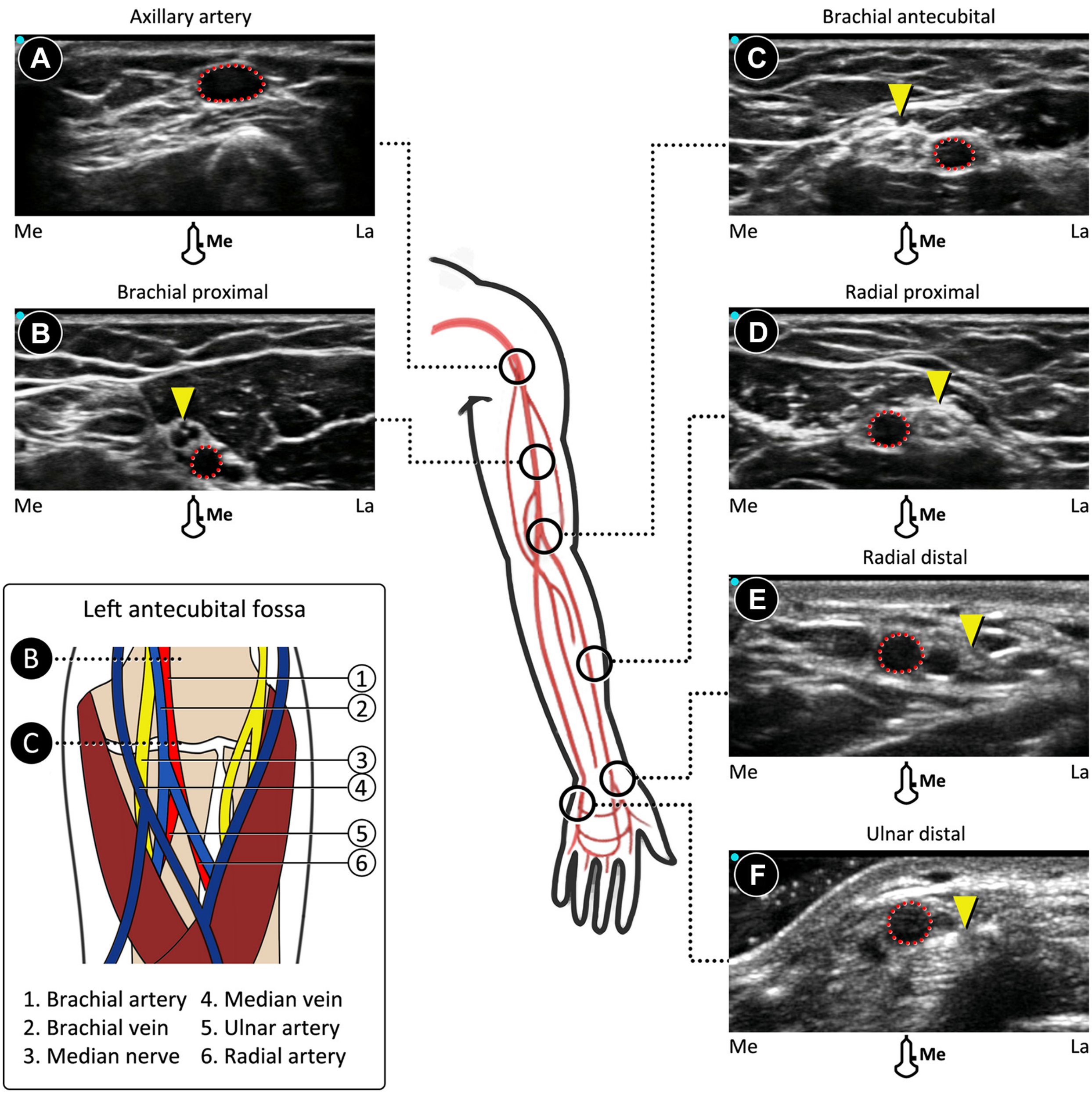

Figure 18 Upper limb arterial access. Diagrams of the arterial anatomy in the left arm and the antecubital fossa show the location of the brachial, radial, and ulnar arteries. Shown are US images in short-axis (SAX) of the left arm with *red dotted circles* indicating the **(A)** axillary artery, **(B)** proximal brachial artery in the upper arm, **(C)** brachial artery in the antecubital fossa, **(D)** proximal radial artery in the forearm, **(E)** distal radial artery, and **(F)** ulnar artery at the wrist. Note the 2 veins that accompany the distal radial and ulnar arteries, one on either side of the artery. When cannulating arteries, it is important to avoid injuring the nerves (*yellow arrow*) that accompany an artery. *La*, lateral; *Me*, medial; *US*, ultrasound.

becoming the external iliac artery. This helps the operator identify a safe location to puncture the vessel below the inguinal ligament. To reduce the risk for procedure-related vascular complications, the recommended puncture site is the middle segment of the CFA overlying the femoral head (Figure 15). Under sterile conditions and US guidance, the access needle (18 - 21 G) or angiocatheter advances into the vessel with a single wall puncture. The needle tip should always be clearly visible during advancement and centered within the vessel lumen before guidewire insertion.

Evidence. Several studies compared US-guided CFA cannulation to fluoroscopic guidance and palpation. A multicenter RCT, FAUST (Femoral Arterial Access With Ultrasound Trial), showed that routine US guidance improved CFA cannulation only in patients with high CFA bifurcations but did reduce the number of attempts, time to access, risk for venipunctures, and vascular complications.[101] Other prospective RCTs in patients undergoing CFA access for vascular and interventional procedures revealed a significantly higher first attempt success rate and quicker access time with fewer complications using US guidance.[102-105]

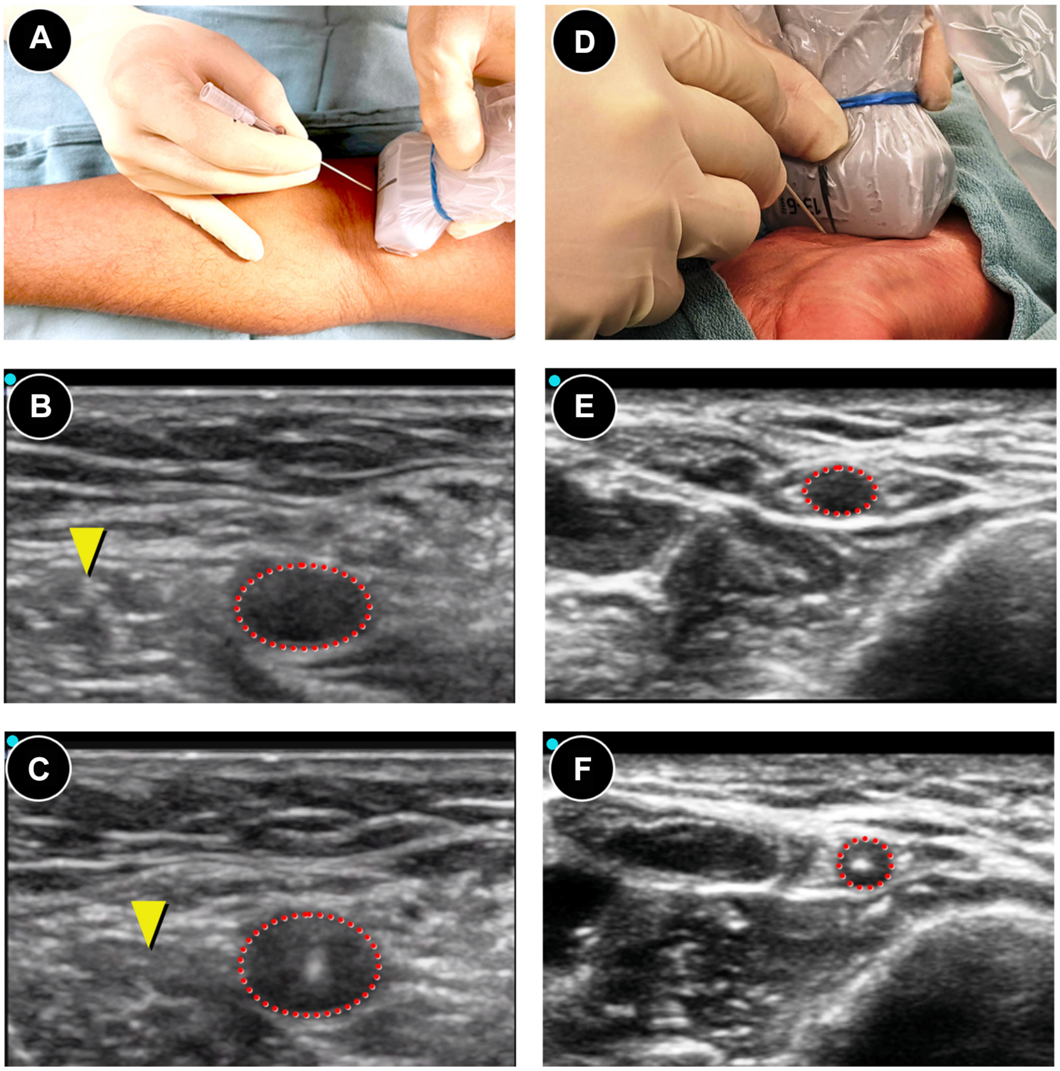

Figure 19 Peripheral artery cannulation. **(A)** The position of the abducted arm is on a firm surface with the location of the US probe perpendicular to the left brachial artery in the antecubital fossa. **(B)** The US image shows a short-axis (SAX) view of the brachial artery in the screen center. **(C)** The operator advances the needle in the soft tissue into the vessel lumen using an out-of-plane approach. **(D)** To cannulate the distal radial artery, a roll placed under the wrist extends the region. **(E)** The US image shows the superficial radial artery in SAX, and **(F)** using the out-of-plane technique, the operator cannulates the radial artery. The *yellow arrows* in **(B and C)** represent the median nerve. *SAX*, short-axis; *US*, ultrasound. See Video 10.

An RCT of 635 patients undergoing CFA cannulation for coronary angiography or intervention showed US-guided access had higher first attempt success with fewer attempts and reduced venipuncture but did not reduce bleeding or vascular complications.[104] A meta-analysis in 2019 including five RCTs (1,553 patients, 784 US guided) showed US guidance reduced bleeding events, venipuncture, and multiple puncture attempts, though the rates of successful CFA cannulation were the same in both groups.[106]

Recommendation for CFA Cannulation. On the basis of the growing evidence and strong expert consensus opinion, the writing group strongly recommends (grade 1B) using US guidance during CFA cannulation in all patients. Using US more effectively reduces major and minor complications as well as time to cannulation and increases the overall and first attempt success rates.

5.6. Posterior Tibial And Dorsalis Pedis Arteries

Anatomy and Access Considerations. After exiting the adductor canal, the superficial femoral artery becomes the popliteal artery and divides into the anterior tibial artery and tibioperoneal trunk, which then divides into the PTA medially and the peroneal artery laterally. At the ankle, the anterior tibial artery continues into the DPA, which the deep peroneal nerve accompanies.[100] In adults, the diameter of the PTA is 3.1 ± 0.4 mm, and the DPA is 3.0 to 3.6 ± 1.2 mm.[107]

Tibial artery cannulation is increasingly a site for percutaneous interventions of the lower extremities. It is effective for retrograde access and crossing chronic total occlusions. The DPA on the dorsum of the foot can provide access for invasive pressure monitoring and below-the-knee interventions.

Cannulation Technique. Percutaneous cannulation of the tibial vessels should occur distally where the vessels are most superficial. Compression and CFD can help distinguish the artery from the adjacent paired veins. The operator typically cannulates the vessel with a 21-G needle, followed by a guidewire. Dedicated DPA access sheaths (4 Fr) are available from multiple manufacturers for use, if needed, though some interventionalists prefer the micropuncture kit. To cannulate the PTA, the foot position is in dorsiflexion with eversion, while for the DPA and anterior tibial artery, the foot is in plantar flexion.[108]

Evidence. A 2023 RCT comparing palpation to US-guided PTA cannulation in 76 adults showed US reduced cannulation time with a comparable first attempt success rate.[109] A 2021 RCT in 140 pediatric patients undergoing cardiac surgery compared palpation to US guidance for DPA and PTA cannulation. This study showed higher cannulation success with US vs palpation for first attempt (DPA 85.7% vs 25.7% and PTA 82.9% vs 22.9%) and overall (DPA 91.4% vs 54.3% and PTA 85.7% vs 40%) with a shorter time and fewer attempts.[110] A 2023 RCT using US-guided techniques comparing DPA and PTA cannulation in 90 adult patients showed similar success rates in both groups (73.3% DPA, 80% PTA) though in the DPA group there were longer cannulation and procedure times.[111] In 2015, a retrospective review of 75 patients undergoing DPA access for managing peripheral artery disease showed a 99% successful cannulation with US guidance.[112] A 2019 RCT in 60 adults comparing US-guided vs palpation techniques for the DPA showed similar first attempt success rate, total number of cannulation attempts, and total procedure time in both groups.[113]

Recommendations for PTA and DPA Cannulation. On the basis of evidence and expert consensus opinion, this writing group strongly recommends (grade 1C) using US guidance during PTA cannulation and weakly recommends (grade 2C) using US guidance during DPA cannulation.

Key Points: Arterial Cannulation

- The indications for arterial cannulation are expanding, with an increasing need for large sheaths to deliver therapeutic devices.
- The preferential site for peripheral arterial cannulation is the radial artery. CFA vascular access is a mainstay for many endovascular image-guided procedures and therapeutic interventions.
- US guidance is particularly valuable in patients with a weak pulse and small artery or after a failed landmark attempt.

6. VASCULAR CANNULATION COMPLICATIONS

6.1. Overview

Complications associated with vascular cannulation may directly involve the vessels or surrounding vessel structures or relate to the technique (arrhythmias, catheter malposition, guidewire).[114] Common vascular cannulation complications related to vessel puncture include hematoma, abscess, seroma, lymphocele, thrombosis, stenosis, vasospasm, and major bleeding (Figure 21, Video 11). Additional arterial cannulation complications include arterial dissection, pseudoaneurysm, and arteriovenous fistula. Complications may also relate to the specific site of cannulation with injury to surrounding structures, such as lung (pneumothorax), nerves, or lymphatics (chylothorax). A report of 12,667 central venous catheter insertions in 8,586 patients, of which 93% were US guided, showed a 7.7% incidence of mechanical complications.[115]

Risk factors for central venous cannulation complications, regardless of using US guidance, are operator inexperience, number of needle passes, body mass index > 30 or <20 kg/m^2, and catheter size.[114] Factors influencing failure to cannulate are inexperience, previous cannulations, and previous local surgery or radiotherapy. Identification of risk factors before vascular cannulation may decrease complication rates by altering the approach to include US guidance. Experienced physicians rather than novices should attempt cannulation in the presence of risk factors or in patients at risk for failed cannulation.

6.2. Common Vascular Complications

Hematoma, Abscess, Seroma, and Lymphocele. Hematoma, abscess, seroma, and lymphocele are all complications from vascular access that occur outside of the artery and vein. These complications may have a similar sonographic appearance, making it difficult to distinguish among these entities. Structures can appear as a cystic mass, or a heterogeneous and/or hypoechoic lesion beside the vessel. Hematoma can have mixed echoes compared with a more anechoic cystic-like appearance of a seroma. An abscess can have a more complex appearance, and with a little pressure, there may be movement within the structure.

These structures are avascular and can have posterior acoustic enhancement with increased echoes deep to the structure. A low CFD scale can evaluate for blood flow within the lesion. Depending on the vessel accessed, such as in the groin or pelvis, it may be necessary to use a curvilinear probe (<5 MHz) to provide adequate penetration to visualize these anomalies.

Thrombosis and Embolization. Deep vein thrombosis (DVT) may involve the IJV, SCV, axillary vein, brachial vein, and CFV, while superficial vein thrombosis may affect the cephalic, basilic, and other superficial veins. Compression of the vein is vital when evaluating for a DVT. The vein will not compress or only partially compress if thrombosis is present, particularly in the early stages when clot formation may not be visible on 2D imaging. Depending on the stage of the thrombosis (acute or chronic) the vessel lumen may show a lack of flow by CFD or no respiratory variation by spectral Doppler with mixed echoes seen in the vein lumen on 2D imaging.[116] A thrombus may often attach to an indwelling catheter. The catheter appears as two echogenic lines in the vessel; the vessel is compressible, whereas the thrombus is less compressible.

Embolization can occur when mobile debris or a clot from either the vein or artery becomes detached from its source. The sonographic image shows an echogenic mobile structure attached to the wall of the vessel, as well as the presence of thrombus (vein) or plaque (artery).

Stenosis. Stenosis in arteries alters blood flow in segments proximal, at, and distal to the narrowing.[18] In severe arterial stenosis (>75%) the narrowed segment shows turbulent mosaic flow with CFD and the spectral Doppler is a monophasic pattern with an increase in peak systolic velocity. There is a reduction in flow distal to the stenosed segment. This changes the spectral Doppler waveform to show monophasic flow with a delayed and dampened upstroke, termed tardus parvus, and low peak systolic velocity.[18,117]

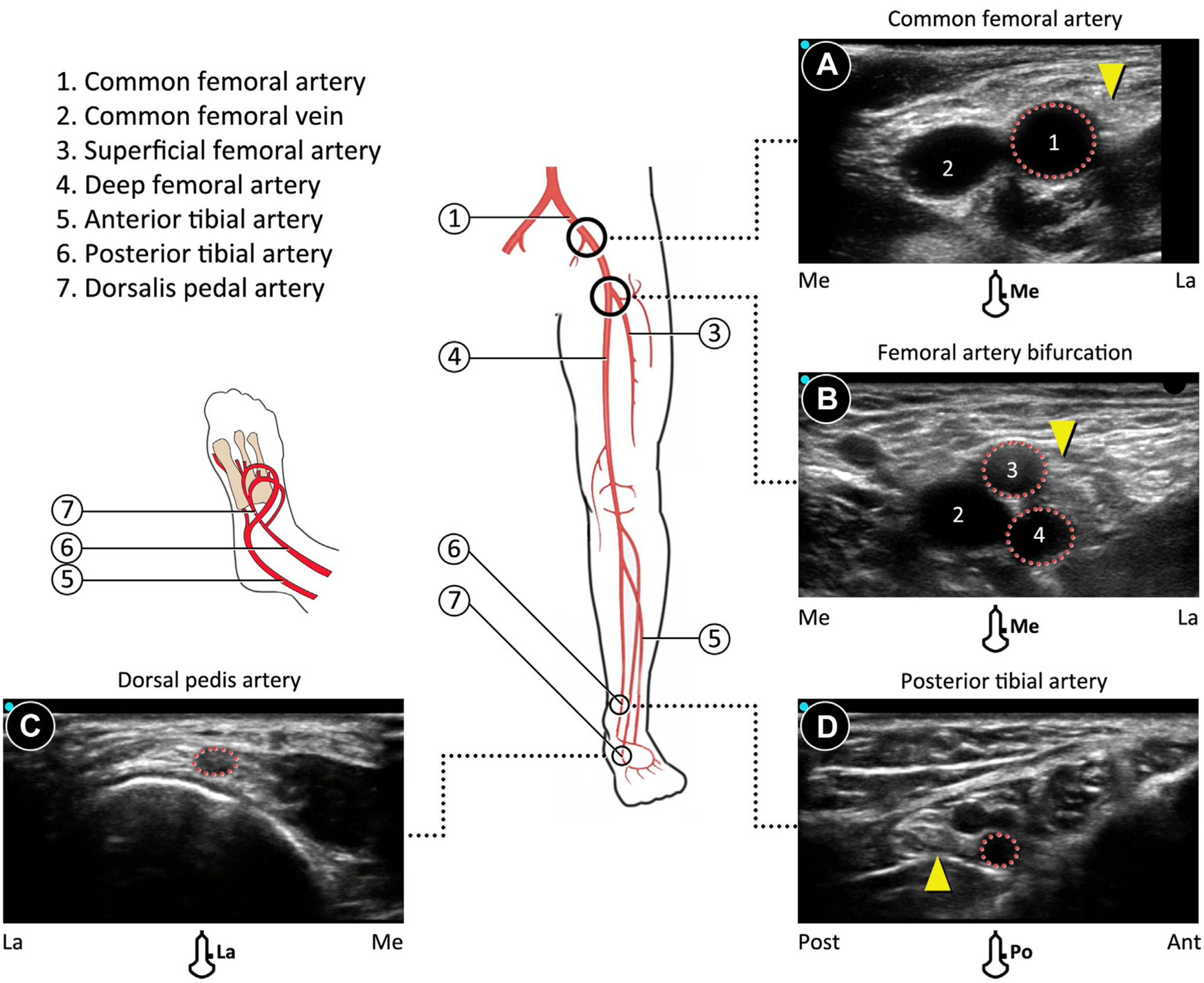

Figure 20 Lower limb arterial access. The diagrams show the arterial anatomy of the left leg, including the location of the femoral artery, posterior tibial artery, and dorsalis pedis artery. Shown are US images in SAX of the left leg, with *red dotted circles* indicating the **(A)** common femoral artery, **(B)** femoral artery bifurcation into the superficial femoral artery and deep femoral artery, **(C)** dorsalis pedis artery, and **(D)** posterior tibial artery. Note the veins and nerves (*yellow triangles*) that accompany the arteries. *Ant*, anterior; *La*, lateral; *Me*, medial; *Post*, posterior; *SAX*, short-axis; *US*, ultrasound.

Venous stenosis shows a narrowed segment of the vein with turbulent flow by CFD and monophasic spectral Doppler trace without respiratory variation.

Vasospasm. Vasospasm is the temporary reduction in lumen size in response to the presence of a needle, catheter, or guidewire in a vessel and more commonly affects arteries. This may cause difficulties with needle or guidewire advancement. The vessel wall can relax with time and possibly the administration of vasodilators, or it may be necessary to choose an alternative access site.

6.3. Specific Arterial Access Complications

Arterial Dissection. Dissections occur when a wire or catheter enters the subintimal layer and creates a space between the media and the intima walls of the artery, forming a false lumen.[118] The intimal flap can have a linear echogenic appearance seen in the arterial lumen (Figure 21A). Color Doppler can show two different directions of blood flow, one going through the false lumen and the other through the true lumen. Blood flow is not always present in the false lumen. Flow through the false lumen can create an aneurysm, thrombus, or rupture in the future.

Pseudoaneurysm. A pseudoaneurysm or false aneurysm is a collection of blood that forms between one or two outer arterial layers. It can be asymptomatic or present as a painful palpable pulsatile mass. The sonographic appearance is an anechoic or hypoechoic structure (or sac) connected to an artery by a neck with blood flow (Figure 21D). Color and spectral Doppler show "to-and-fro" flow into and out of the sac, helping differentiate a pseudoaneurysm from a simple hematoma (Figure 21E).[119] A variable amount of thrombus may be present in the sac.

Arteriovenous Fistula. An arteriovenous fistula can occur when the needle pierces both the artery and vein, creating a connection between the two.[120] As a result, the vein becomes exposed to the higher arterial pressure. Over time the vein wall will thicken making the vessel lumen more difficult to compress. Color flow Doppler images show turbulent blood flow between the artery and vein, seen best in the SAX view. The spectral Doppler trace shows pulsatile flow in both vessels.

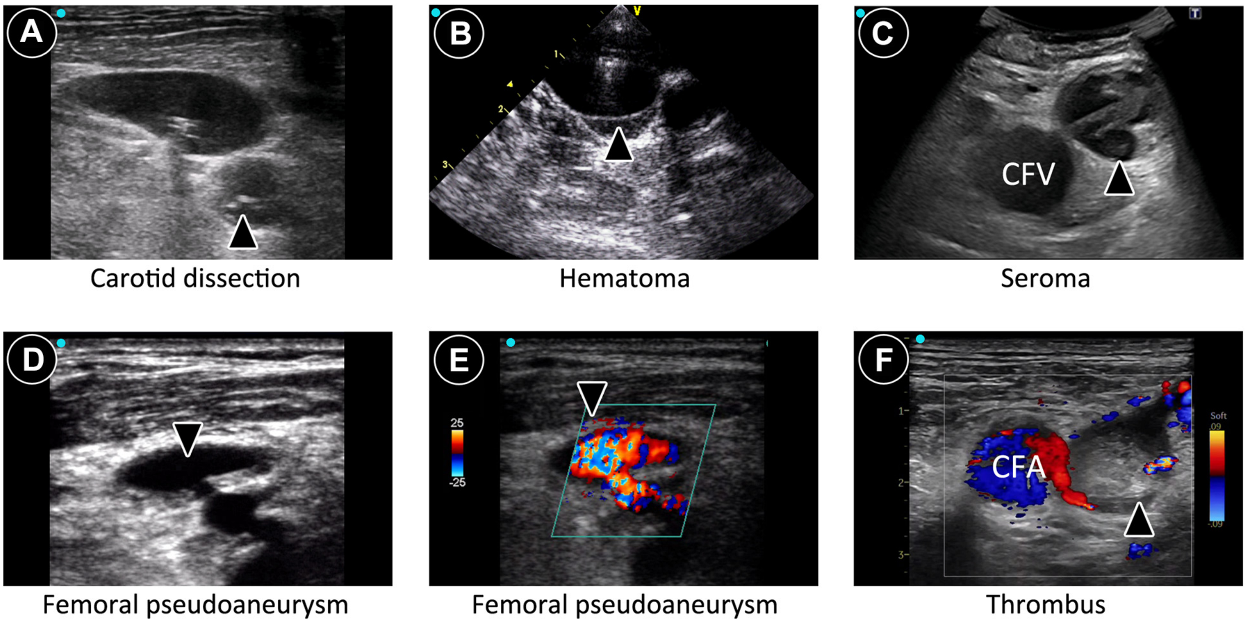

Figure 21 Vascular access complications. The US images show evidence of complications involving vascular access. **(A)** Dissection of the carotid artery with a mobile intraluminal flap and a cannula in the right internal jugular vein. **(B)** Hematoma surrounding a vessel. **(C)** A complex collection adjacent to femoral vessels represents a seroma. **(D** and **E)** Pseudoaneurysm of the femoral artery appears **(D)** without and **(E)** with color flow Doppler. **(F)** Intraluminal thrombus of the CFV presents as a mass in the lumen. *CFA*, common femoral artery; *CFV*, common femoral vein; *US*, ultrasound. See Video 11.

6.4. Site-Specific Complications

IJV Cannulation. Complications for IJV access are infrequent. However, hematoma, arteriovenous fistula, hemothorax, and pneumothorax can occur particularly when an inexperienced operator performs the cannulation. Carotid artery puncture can occur even when using US guidance to monitor the SAX view, if the posterior wall of the IJV is accidentally punctured. During needle advancement, a low-pressure IJV may compress, resulting in puncture of both the anterior and posterior walls. In this case blood will not be aspirated into the syringe.[121] The degree of contralateral rotation of the patient's head decreases the margin of safety (Figure 11) and increases vessel overlap of the IJV with the CA. The vessel overlap is from 29% to 42% to 72% with turning of the head from 0° (neutral) to 45° to 90°, respectively, and is most apparent among patients with body surface area > 1.87 m^2 and body mass index > 25 kg/m^2.[27,122] Injury to the SCA is more common on the right than the left, as the subclavian-jugular venous junction overlies the right SCA.

Pneumothorax can occur with a low approach to IJV cannulation in the neck. Brachial plexus injury of the upper trunk (C5-C6) may occur from injection of local anesthetic, needle or catheter cannulation or hematoma formation manifesting as shoulder weakness and arm paresthesia. Rarely there may be injury to the sympathetic trunk causing Horner's syndrome with partial ptosis, miosis, and facial anhidrosis.

SCV and Axillary Vein Cannulation. Mechanical complications associated with SCV cannulation are higher using the landmark technique and include SCA puncture and hematoma (5.4%), hemothorax (4.4%), pneumothorax (4.9%), brachial plexus injury (2.9%), phrenic nerve injury (1.5%), and cardiac tamponade (0.5%).[39,115,116] The SCV enters the innominate vein at a sharper angle on the right, making the right SCV more vulnerable to perforation during cannulation.[115,116]

Chest radiography or lung US is mandatory to exclude pneumothorax and confirm proper line placement.[123]

Femoral Vessel Cannulation. Femoral vessel cannulation is associated with complications including vascular injury such as pseudoaneurysms, arteriovenous fistulas, local and retroperitoneal bleeding, and nerve injury.[124] A thrombus may develop within the femoral vein or iliac vein in up to 21.5% of patients from the presence of the catheter or during compression upon removal.[120] Ultrasound guidance better defines the anatomy and most likely reduces the incidence of complications during femoral vessel cannulation.[124] A meta-analysis showed that US guidance for hemodialysis catheter placement decreased arterial punctures, risk for placement failure, and risk for failed first attempt access.[54]

Injury to the femoral nerve can cause femoral neuralgia because of direct compression by vascular complications, such as hematoma or aneurysm formation or traumatic injury during cannulation.

PICC Cannulation. The most common complications for PICC placement are thrombosis, bleeding, tip malposition, arm discomfort, and line malfunction. There is a comparable incidence of central line and PICC line–associated bloodstream infections (5.2%) and a higher incidence of catheter-related DVT at the site of PICC insertion (13.9%).[125,126] These complications occur independently of where the PICC line insertion was US-guided. Careful consideration should be given to the number of lumens as this directly relates to the occurrence of complications.[127]

6.5. Other Complications

Arrhythmias. Arrhythmias may occur during palpation of the vessel, cannulation, or more commonly, with guidewire or catheter insertion into the heart. Withdrawing the offending stimulus should terminate the arrythmia.

Catheter Malposition. Recommendations suggest the catheter tip of a central line or PICC placed in the upper body should reside at the caval-right atrial junction above the pericardial reflection.[128] In addition, the angle of the catheter tip against the vessel wall should be <40° to reduce the risk for perforation. In SCV insertions, the catheter tip may travel to the ipsilateral IJV or the contralateral SCV, US may examine these locations during cannulation to exclude malposition.

Guidewire Problems. The operator may lose control of the guidewire during cannulation with the potential for embolization in the vessel. Guidewire retrieval is necessary to avoid any further complications. The guidewire may knot or kink during insertion, making removal more difficult. Kinking of the guidewire may misdirect the dilator or cannula to lie outside the vessel. US imaging of the guidewire from skin to as distal as possible in the vessel lumen can help verify safe guidewire placement.

Key Points: Vascular Cannulation Complications

- Complications associated with vascular cannulation may involve the arteries and veins themselves or the structures surrounding those vessels.
- Complications may also relate to the specific site of cannulation or insertion technique.
- Two-dimensional and color Doppler US imaging may identify early and late complications.

7. PEDIATRIC VASCULAR ACCESS

7.1. Overview

Access in the Pediatric Age-Group. There is an extensive body of literature mostly addressing venous rather than arterial vascular access in children.[129,130] To date, no organization representing the professionals who care for infants, children, and adolescents has provided evidence-based clinical practice guidelines or formalized recommendations regarding arterial access for this patient population. This section reviews published data on vascular access in pediatrics and the role of US guidance.

Indications. The indications for arterial and venous cannulation in children are the same as in adults. The threshold to institute invasive arterial monitoring varies depending on the clinical condition of the patient. Specific catheter-based diagnostic or interventional procedures may dictate the access site. Vascular cannulation in the pediatric age group is technically challenging because of the small vessel caliber (Table 4), potentially variable and anomalous anatomy (Figure 22), and prior vessel cannulation, which often leads to multiple and failed attempts.[131] Pediatric patients may be uncooperative requiring the use of restraints, liberal infiltration of local anesthesia to the area, and judicious sedation. In patients undergoing general anesthesia, intravenous access may be obtained after the patient is asleep following induction of anesthesia.

7.2. Pediatric Venous Cannulation

IJV. The most frequently accessed central vein using US in pediatric patients is the right IJV. US scanning allows easy visualization of the vessel, demonstrating its position, patency, and thrombus when present. This is important, as there is a high incidence (28%) of DVT in children from short-term central venous line placement, which may impact the site for subsequent central venous access.[132]

The cannulation technique follows that previously described for adults in terms of patient positioning and US guidance. In pediatric patients, the supine position with Trendelenburg, liver compression, or simulated Valsalva maneuver may increase IJV size. Shorter needles and a superior entry point may reduce the risk for pleural or great vessel puncture. Avoiding compression of small veins by the US probe takes experience.

A meta-analysis of 23 studies (3,995 procedures) in pediatric patients undergoing IJV and CFV cannulation revealed that US guidance significantly reduced the risk for cannulation failure and the incidence of arterial punctures.[133] Compared with the landmark approach, studies using US guidance show a shorter time to successful first attempt cannulation, and overall time to cannulation with fewer complications.[134-136] An RCT of 60 neonates and infants weighing <7.5 kg comparing US guidance with a surface-marking technique showed a reduction in cannulation time and fewer needle passes necessary for right IJV cannulation.[137]

CFV. Various studies have explored the anatomic relationship between the femoral vessel in children with respect to leg positioning and a suitable site for CFV cannulation. A significant number of children have femoral vessel overlap that may vary between straight and frog leg positions and distance from the inguinal ligament.[138] The specific angle of leg abduction with external hip rotation is also known to affect the extent of this overlap.

The optimal site for CFV cannulation in pediatric patients has been reported to be at the level of the inguinal crease, with 60° leg abduction and external hip rotation.[139] Given the variable data, the clinical applications of leg positioning during femoral venous cannulation in children remains unclear.

Several maneuvers can improve visualization of the CFV in neonates, including placing a towel under the child's buttock, the

Table 4 Vessel size in pediatric patients in millimeters*

Age	IJV	CA	CFV	CFA	SCV	SCA
0-1 mo	5.5 (0.8)	3.0 (0.5)	3.8 (0.6)	2.8 (0.3)	5.6 (0.9)	3.5 (0.3)
1 mo to 2 y	8.9 (1.6)	4.3 (0.5)	4.5 (0.9)	3.1 (0.5)	5.5 (0.9)	4.1 (0.7)
2-6 y	10.5 (1.6)	5.3 (0.5)	7.3 (0.8)	5.0 (0.6)	6.9 (1.0)	4.4 (0.5)
6-12 y	11.9 (1.8)	6.0 (0.6)	7.7 (1.3)	5.9 (0.8)	8.5 (1.4)	5.6 (1.2)
12-18 y	11.3 (1.9)	6.9 (0.7)	8.9 (1.2)	7.4 (0.7)	11.0 (2.0)	6.6 (0.8)

CA, carotid artery; *CFA*, common femoral artery; *CFV*, common femoral vein; *IJV*, internal jugular vein; *SCA*, subclavian artery; *SCV*, subclavian vein; *mo*, months; *y*, years.
Source: Souza Neto *et al*.[131]
*Mean of bilateral cross-sectional internal diameters of the central vessel expressed in millimeters ([right side + left side]/2). Values in parentheses are the median absolute deviation.

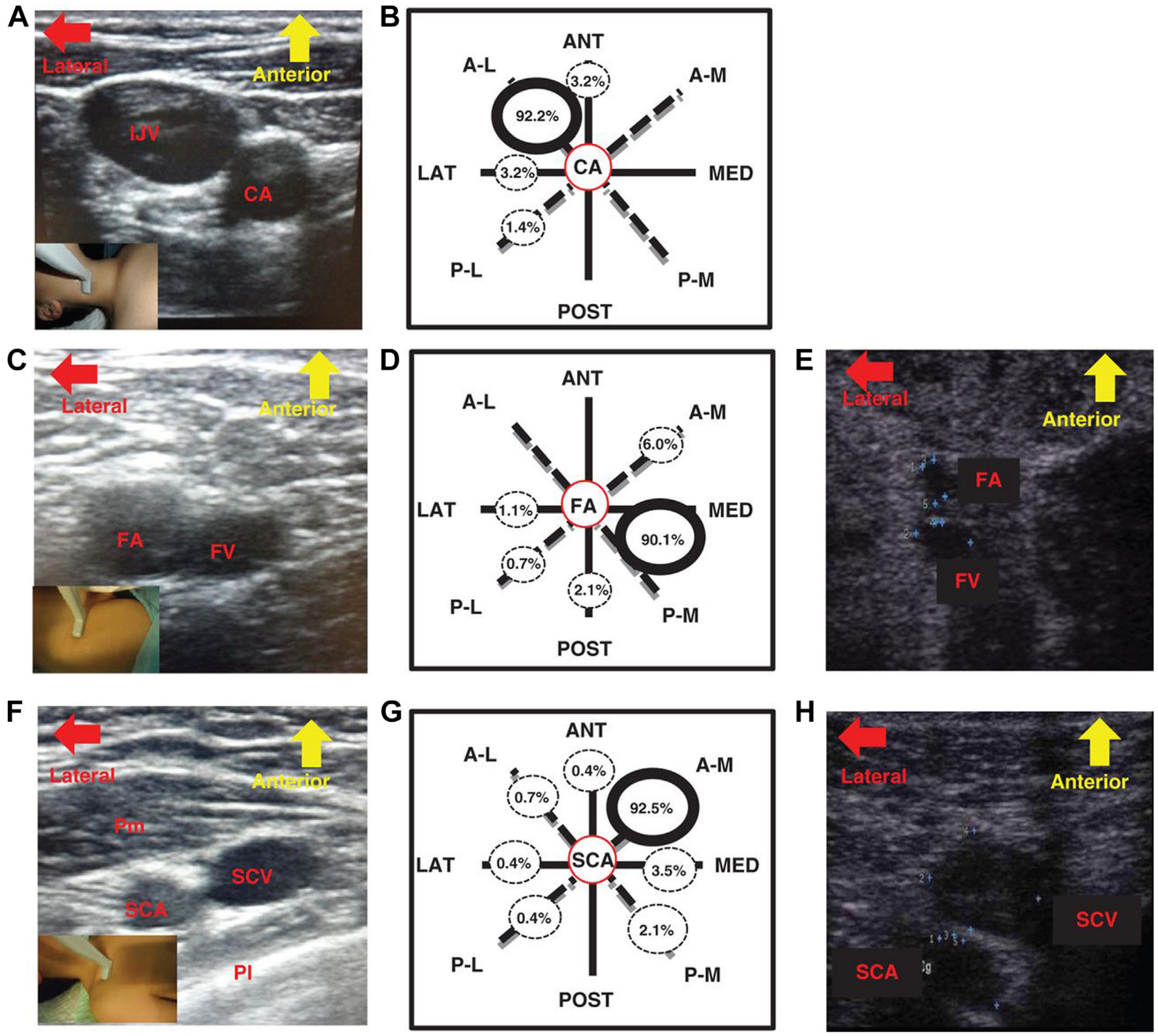

Figure 22 Pediatric vessel variations. Ultrasound of the IJV, femoral vessels, and subclavian vessels showing anatomic variations in the location of the vessels. **(A)** SAX view of the IJV at the level of the cricoid cartilage. **(B)** The diagram shows the variations in IJV location relative to the CA. The typical IJV position is anterolateral to the CA. **(C)** SAX view of the femoral vessels just below the inguinal ligament. **(D)** The diagram shows variations in the location of the FV relative to the FA. The typical FV position is posteromedial or medial to the FA. **(E)** An example of a variation of femoral vessels with the FV posterior to the FA. **(F)** SAX view of the subclavian vessels at the infraclavicular level. **(G)** The diagram shows variations in the location of the SCV relative to the SCA. The typical SCV position is anteromedial to the SCA. **(H)** An example of variation of subclavian vessels with the SCV anterior to the SCA. *A-L*, anterolateral; *A-M*, anteromedial; *ANT*, anterior; *CA*, carotid artery; *FA*, femoral artery; *FV*, femoral vein; *IJV*, internal jugular vein; *LAT*, lateral; *MED*, medial; *Pl*, pleura; *Pm*, pectoral muscles; *P-L*, posterolateral; *P-M*, posteromedial; *POST*, posterior; *SAX*, short axis; *SCA*, subclavian artery; *SCV*, subclavian vein; *US*, ultrasound. Figure reproduced with permission from Souza Neto.[131]

reverse Trendelenburg position, and gentle abdominal compression. There is a one in five chance of failure to locate the CFV by landmark technique in children.[140] Because the vein is superficial in children, it is important to direct the needle at a <30° angle with the skin during vessel cannulation.

Randomize control trials in children have shown that US-guided CFV cannulation is marginally more effective than landmark and/or other techniques. An RCT of 48 pediatric patients undergoing CFV cannulation comparing US-guided and landmark techniques showed a shorter time (155 vs 370 seconds, $P = .02$), greater first attempt success (75% vs 25%, $P = .001$), and fewer needle passes (one vs three, $P = .001$) needed to complete cannulation using US.[141] The overall success rate was similar in both groups (95.8%), and the incidence of femoral artery puncture was comparable.[141] In general, RCTs in the pediatric cardiac catheterization setting have shown no difference in overall rate of successful vascular cannulation and time to access with US guidance, but conflicting results regarding a reduction of complications. US guidance may be of greatest benefit in small patients (weight < 10 kg).[142]

Peripheral Veins. Peripheral vein cannulation can be challenging in children, especially in small infants or children with poorly visible or palpable peripheral veins. An RCT comparing US-guided and palpation techniques showed a longer time for cannulation using

US but a significantly higher success rate in patients with difficult access.[143] A systematic review and meta-analysis of RCTs addressing US-guided vs conventional techniques for PIV insertion in pediatric patients (1,312 total patients in high-quality studies) supported using US, demonstrating a higher success rate, reduced procedure time, and fewer attempts at cannulation.[144]

Recommendations for US-Guided Venous Access in Children. On the basis of evidence and expert consensus opinion, this writing group strongly recommends that trained clinicians use US guidance during IJV cannulation (grade IA) and CFV cannulation (grade IC), when possible, to improve cannulation success, reduce the time to successful cannulation, and lower the incidence of complications associated with the insertion of relatively large-bore catheters in pediatric patients.

Because of the paucity of large well-conducted studies, this writing group weakly recommends (grade 2B) using US guidance for PIV cannulation in pediatric patients. Some evidence suggests that an experienced operator using US improves the success rate of difficult PIV cannulation in children. As this practice has evolved, many clinicians with ready access to US equipment routinely use it for PIV cannulation, whether potentially easy or difficult.

7.3. Pediatric Arterial Cannulation

Sites of Cannulation. Arterial access in infants and children most often involves radial and femoral artery cannulation, with similar alternative sites to adults.[145] The radial artery is the preferred site in children. The CFA is the vessel of choice in children over other peripheral arteries when there are concerns about the reliability of arterial pressure monitoring from other sites or when both lower and upper body arterial monitoring is necessary. The femoral route is also the primary route for retrograde arterial cardiac catheterization in the pediatric age group.

In the newborn, umbilical artery catheterization permits reliable hemodynamic monitoring and blood sampling in the first few days of life. There are no guidelines standardizing the use of umbilical catheters in neonates, which may vary according to institutional or professional organization preferences. Percutaneous cannulation of peripheral arteries is an option in sick neonates and premature infants, with reports of fewer complications than with umbilical artery catheterization.[146,147] Temporal artery cannulation, once an option in neonates, is now rare because of potential sequelae and serious neurologic morbidity.[148]

Cannulation Techniques. Ultrasound-guided arterial cannulation techniques used in children are the same as in adults and include those previously described in section 3.4, the SAX out-of-plane and LAX in-plane approaches incorporating DNTP.[149]

Factors that significantly increase the difficulty of US-guided radial artery cannulation in children <2 years of age include a vessel CSA of <1 mm^2 and the presence of an anomalous branch.[150] The subcutaneous vessel depth is important as the shortest insertion time and most reliable cannulation occurs with US guidance when the vessel is relatively shallow, 2 to 4 mm below the skin surface.[151] Children with Down syndrome often have an abnormal vascular pattern and present challenges in achieving successful vascular cannulation.[152]

Evidence. Ultrasound guidance, in most investigations with rare exceptions, improves the success rate of arterial cannulation compared with traditional anatomic landmarks or palpation methods, reduces the need for surgical interventions to gain arterial access, shortens procedural time, and decreases complication rates.[88,153-157]

An RCT comparing SAX and LAX approaches in anesthetized infants and children showed no major differences in the total time to successful cannulation but noted a significantly longer imaging time for the LAX view (46.5 ± 39.2 vs 16.0 ± 17.6 seconds), whereas posterior wall vessel puncture rate was much more likely to occur with SAX imaging (95.7% vs. 18.0%).[158] A meta-analysis of six studies (725 patients) in 2023 comparing US-guided SAX out-of-plane vs LAX in-plane radial artery cannulation in infants showed similar success rates, first attempt success rates, and incidence of hematoma.[159]

In a retrospective review of consecutive patients undergoing cardiac surgery, US-guided arterial access substantially reduced the need for surgical cutdown in all pediatric age groups.[160] For cannulation of deep radial arteries (depth of ≥4 mm relative to the skin), US guidance improves the first attempt success rate and cannulation time.[161] Modification using the DNTP technique for radial artery cannulation in neonates improves first attempt and total success rates and decreases the total procedural time and complications compared with the traditional palpation technique.[162] In an RCT, the DNTP technique compared with conventional palpation reduced the number of insertion attempts for accessing the radial artery, PTA, or DPA.[163]

In a prospective RCT, the addition of acoustic shadowing as a technique to overcome the limitations of 2D imaging improved the success rate of US-guided radial artery cannulation in young children.[164] This technique modifies the US image by placing strands from x-ray-detectable gauze perpendicular to the face of the probe using a sterile membrane. When positioned to show a SAX view of the radial artery, the strands produce two parallel dark lines of acoustic shadowing in the soft tissue. The operator can position these dark lines on either side of the radial artery to facilitate cannulation.

A prospective RCT in infants and children undergoing cardiac surgery reported that, when performed by trainees, US-guided femoral artery cannulation was superior to palpation, with a reduction in vessel cannulation time, success at first attempt, and fewer attempts.[165] A 2023 Cochrane systematic review of US-guided arterial cannulation in the pediatric population included nine RCTs (748 patients, 2006-2021).[166] The study aimed to evaluate the benefits of US guidance compared with traditional techniques used in children, such as palpation and Doppler auditory assistance. The latter, also referred as audio Doppler, typically uses a small-caliber 10-MHz nonimaging probe to identify the respective pulsatile arterial sound and the low-pitched venous hum. This review concluded that evidence of US guidance compared with traditional techniques probably improves the cannulation success rate on the first attempt, within two attempts, and overall. US guidance probably also reduces the incidence of hematoma, the number of attempts to successful cannulation, and the time to cannulation. The authors suggest that further studies are needed to determine if these benefits are more significant in the younger age vs older age groups.

7.4. Pediatric Vascular Access Complications

Complications of arterial access in pediatric patients can be minor or major; frequencies depend on the cannulation site. These are rare and include bleeding, hematoma, arteriovenous fistula, nerve injury, thrombosis, occlusion, digital ischemia, limb shortening, air embolism, and others.[167] Transient vascular insufficiency manifesting as a decrease in limb perfusion after arterial cannulation is a finding more common in children than in adults.[168] Although not always a reason for catheter removal, this finding requires ongoing careful surveillance of distal arterial bed perfusion. Most clinical manifestations of vascular compromise resolve with restoration of normal flow after catheter removal.

Cardiac catheterization via the femoral artery in children can lead to the acute loss of the arterial pulse (6.8% incidence), requiring treatment using institutional protocols, which may include anticoagulation.[169] A femoral artery diameter of <3 mm represents an independent risk factor for this complication.[169] The evaluation of vessel size by US can help minimize arterial complications in infants undergoing these procedures.[170] In children, arterial catheters can cause thrombosis and damage to the distal vascular supply with an overall incidence of nearly 3%, and a higher incidence of 11% in children undergoing cardiac catheterization procedures.[171] Thrombosis most often involves the femoral artery with risk factors of younger age, lower body weight, low cardiac output, and increased hematocrit.

Key Points: Pediatric Vascular Access

- Indications for vascular access in children are the same as those in adults.
- Vascular access in the pediatric age group is technically challenging, related to small vessel size, anatomic variation of structures, and potential prior vessel cannulation.
- In general, US-guided vascular cannulation techniques used in children are the same as in adults.
- US guidance offers major advantages for arterial access over techniques that rely on landmarks, palpation, and audio Doppler. This is of particular benefit in neonates, infants, and small children, permitting an increase in first attempt success rates while reducing the number of failed attempts and decreasing the rate of complications.
- Transient vascular insufficiency is a common finding associated with arterial cannulation in children compared with adults.

Recommendations for US-Guided Arterial Access in Children. On the basis of the evidence and expert consensus opinion, this writing group strongly recommends (grade 1B) using US guidance during arterial cannulation in most children, particularly in those at the younger end of the age spectrum, with known challenging vascular access, and previously instrumented vessels.

8. TRAINING

As the role of US has expanded in clinical practice, many educational efforts are addressing the need for adequate training. Formal training in US-guided cannulation is necessary to realize the clinical outcomes supported by the literature and ultimately improve patient safety.[172] Importantly, the operator must possess an appreciation of the US anatomy surrounding the target vessel, the ability to identify the optimal entry site and needle angulation, and an understanding of the limitations of the US-guided technique. The clinician should recognize that US guidance enhances procedural safety compared with the landmark-guided cannulation technique.

An international evidence-based consensus task force established through the World Congress of Vascular Access provided recommendations for the training on insertion of central venous lines.[173] These experts suggest that training in US-guided vascular cannulation includes three components: (1) knowledge acquired through review of didactic and web-based material, (2) simulation training using models, and (3) supervised practice with clinical experts.[174] Proper training should impart the cognitive knowledge and technical skills necessary to perform US-guided cannulation, as outlined in Table 5.

A simulated environment that allows the trainee to develop the dexterity needed for simultaneous probe manipulation and needle insertion can help with training.[175] The 2020 European Anesthesia Society perioperative use of US-guided vascular access guidelines requires successful completion of simulation training before supervised clinical practice.[11] Simulation-based education for vascular cannulation may improve overall success rates, but it is unclear whether it can reduce adverse events, including mechanical complications.[176]

Ultrasound-guided training with an experienced instructor must include image acquisition, interpretation, vessel puncture and cannulation, with a demonstration to the trainee of how to translate 2D imaging to perform a 3D task. It is preferable that training occurs at one vascular site to reenforce learning the US-guided technique. However, after mastering the technique, the trainee can use the

Table 5 Recommended training objectives for US-guided vascular cannulation

Cognitive skills	Technical skills
• Knowledge of the physical principles of US • Knowledge of US equipment operation, including the controls affecting the imaging display • Knowledge of infection control standards for performing vascular access and sterile preparation of the US probe for real-time use • Knowledge of the surface anatomy specific to the access site and US anatomy that identifies the target vessel and structures that are to be avoided • Ability to recognize the location and patency of the target vessel • Ability to recognize atypical vessel location and redirect needle entry to minimize complications • Knowledge of the color flow and spectral Doppler flow patterns that identify arterial and venous flow characteristics • Knowledge of potential vascular access complications and their management	• Ability to operate the US equipment and controls to produce quality information to identify the target vessel • Dexterity to coordinate needle guidance in the desired direction and depth on the basis of the imaging data • Use of needle guides for coordination of needle insertion with imaging data when operator dexterity is lacking or clinical conditions make dexterity coordination challenging • Ability to insert the catheter into the target vessel using US information • Ability to confirm catheter placement into the target vessel and the absence of the catheter in unintended vessels and structures

US, ultrasound.

principles of US guidance to access vessels at other sites independently or under appropriate supervision.

There are limited studies regarding the number of procedures needed to establish competency in vascular cannulation. Previous ASE guidelines recommend that individuals perform a minimum of 10 US-guided vascular cannulation procedures under supervision to show competence to practice independently.[2,26] Other experts suggest the determination of clinical competence should use an objective global rating scale during clinical practice rather than just by the number of procedures performed. European Anesthesia Society perioperative use of US-guided vascular access guidelines recommend the performance of at least 30 successful procedures within 12 months after concluding the theoretical-practical course and with a low complication rate to establish competency.[11] Procedural volume is a key factor in reducing complications, developing and maintaining clinical competence, and reducing complications.

Peripheral cannulation of vascular structures in pediatric patients is an essential skill among providers from different specialties, including neonatologists, pediatricians, cardiologists, critical care physicians, surgeons, anesthesiologists, and radiologists that care for these patients. The skills and experience of the operator significantly influence the successful use of US for vascular cannulation in the pediatric age group. In recent years, educational efforts have focused on learning and improving technical skills through simulation training programs and realistic models aimed at lessening the learning curve.

Key Points: Training

- The expanding use of US in clinical practice has been associated with the need for increasing educational efforts.
- Training in US-guided vascular cannulation includes 3 components: (1) knowledge acquisition, (2) simulation training, and (3) supervised practice.
- There are limited studies regarding the number of procedures needed to establish competency in vascular cannulation.
- Procedural volume is a key factor in developing and maintaining clinical competence and in reducing complications.

9. EVIDENCE GAPS AND FUTURE RESEARCH

Ultrasound-guided vascular access has gained traction in clinical practice, as studies show a better success rate with reduced attempts and fewer complications compared with landmark techniques. Although adopted as a standard of practice for IJV cannulation, the use of US guidance is not routine in other vascular access sites. This is because the quality of the evidence to base recommendations on for US-guided vascular access remains moderate to weak. Large-scale studies comparing US-guided with landmark techniques for vascular access may become impractical as more clinicians become adept at using US. Many studies now compare different US techniques, though ultimately the clinician will adopt the technique they are most familiar with to achieve the best success.

Many trainees now receive education about US-guided vascular access early in their training and thus incorporate its use throughout their clinical practice. However, there are no hard data or RCTs on how best to train and educate trainees, so further studies may better clarify the training options.

10. CONCLUSIONS

The use of US for diagnostic and procedural purposes is becoming a standard in daily clinical practice. The major roles of US during vascular access can include: (1) precannulation vessel assessment, (2) dynamic US guidance during cannulation, and (3) identification of local complications. There is an increasing body of literature that US-guided vascular access improves success rates and reduces complications, but the quality of the evidence on which to base recommendations remains moderate to weak (Table 6). The known benefits of US-guided vascular access and expert opinion based on clinical practice cannot be ignored despite limited existing high-quality data. It seems likely that the ready availability of US equipment and clinician proficiency will influence the routine use of US for all vascular access procedures more than future research studies.

NOTICE AND DISCLAIMER

ACKNOWLEDGMENTS

This document was reviewed by members of the 2024-2025 ASE Guidelines and Standards Committee, ASE Board of Directors, and the ASE Executive Committee.

The writing committee would like to thank Dr. Catalin-Julian Efrimescu (Consultant Mater Misericordiae University Hospital, Dublin, Ireland) and Albert Fung (Toronto General Hospital, Toronto, Ontario, Canada) for their contributions in preparing the graphic content for this document.

SUPPLEMENTARY DATA

Supplementary data related to this article can be found at https://doi.org/10.1016/j.echo.2024.12.004.

Table 6 Summary of recommendations and benefits for US-guided vascular access in adults and pediatric patients

Location	Grade of recommendation	Increase overall success	Increase first success	Reduce time to cannulation	Reduce Complications
Adults					
Internal Jugular vein	1A	+	+	+	+
Subclavian vein	1C	+	+	+	+
Axillary vein	1B	+	–	–	+
Femoral vein	1B	+	+	+	+
PICC	1C	Ø	Ø	Ø	Ø
Peripheral vein	1B	+	+	+	+
Radial artery	1B or 1A*	+	+	+	+
Brachial artery	1C	+	Ø	Ø	Ø
Axillary artery	1C	+	+	Ø	Ø
Femoral artery	1B	+	+	+	+
Posterior Tibial artery	1C	+	–	+	Ø
Dorsalis Pedis artery	2C	+	–	–	Ø
Pediatrics†					
Internal Jugular vein	1A	+	–	–	+
Femoral vein	1C	+	–	Ø	Ø
Peripheral vein	2B	+	+	+	Ø
Radial artery	1B	+	+	+	+
Femoral artery	1B	+	+	+	+

PICC, peripheral intravenous central cannulation.
+, Supported by randomized control trials and studies; –, not supported by randomized control trials and studies; Ø, no evidence from randomized control trials and studies.
*(Grade 1B) routinely or (GRADE 1A) for a weak pulse and small artery or failed landmark attempt.
†There is a wide spectrum of recommendations for the pediatric age group, such that one recommendation may be stronger for neonates and young children and less so for the older child.

REFERENCES

1. Rothschild JM. Ultrasound guidance of central vein catheterization. In: Making health care safer: a critical analysis of patient safety practices. Rockville, MD: Agency for Healthcare Research and Quality publication; 2001. pp. 245-53.
2. Troianos CA, Hartman GS, Glas KE, et al. Guidelines for performing ultrasound guided vascular cannulation: recommendations of the American Society of Echocardiography and the Society of Cardiovascular Anesthesiologists. J Am Soc Echocardiogr 2011;24:1291-318.
3. Guyatt G, Gutterman D, Baumann MH, et al. Grading strength of recommendations and quality of evidence in clinical guidelines: report from an American College of Chest Physicians task force. Chest 2006;129:174-81.
4. McGee DC, Gould MK. Preventing complications of central venous catheterization. N Engl J Med 2003;348:1123-33.
5. Ezaru CS, Mangione MP, Oravitz TM, et al. Eliminating arterial injury during central venous catheterization using manometry. Anesth Analg 2009;109:130-4.
6. Sznajder JI, Zveibil FR, Bitterman H, et al. Central vein catheterization. Failure and complication rates by three percutaneous approaches. Arch Intern Med 1986;146:259-61.
7. Milling TJ, Rose J, Briggs WM, et al. Randomized, controlled clinical trial of point-of-care limited ultrasonography assistance of central venous cannulation: the Third Sonography Outcomes Assessment Program (SOAP-3) Trial. Crit Care Med 2005;33:1764-9.
8. Airapetian N, Maizel J, Langelle F, et al. Ultrasound-guided central venous cannulation is superior to quick-look ultrasound and landmark methods among inexperienced operators: a prospective randomized study. Intensive Care Med 2013;39:1938-44.
9. Lamperti M, Bodenham AR, Pittiruti M, et al. International evidence-based recommendations on ultrasound-guided vascular access. Intensive Care Med 2012;38:1105-17.
10. Franco-Sadud R, Schnobrich D, Mathews BK, et al. Recommendations on the use of ultrasound guidance for central and peripheral vascular access in adults: a position statement of the Society of Hospital Medicine. J Hosp Med 2019;14:E1-22.
11. Lamperti M, Biasucci DG, Disma N, et al. European Society of Anaesthesiology guidelines on peri-operative use of ultrasound-guided for vascular access (PERSEUS vascular access). Eur J Anaesthesiol 2020;37:344-76.
12. Timsit JF, Baleine J, Bernard L, et al. Expert consensus-based clinical practice guidelines management of intravascular catheters in the intensive care unit. Ann Intensive Care 2020;10:118.
13. Practice guidelines for central venous access 2020: an updated report by the American Society of Anesthesiologists task force on central venous access. Anesthesiology 2020;132:8-43.
14. Dowling M, Jlala HA, Hardman JG, et al. Real-time three-dimensional ultrasound-guided central venous catheter placement. Anesth Analg 2011;112:378-81.
15. Spencer TR, Pittiruti M. Rapid Central Vein Assessment (RaCeVA): a systematic, standardized approach for ultrasound assessment before central venous catheterization. J Vasc Access 2019;20:239-49.
16. Brescia F, Pittiruti M, Ostroff M, et al. Rapid Femoral Vein Assessment (RaFeVA): a systematic protocol for ultrasound evaluation of the veins of the lower limb, so to optimize the insertion of femorally inserted central catheters. J Vasc Access 2021;22:863-72.
17. Armstrong PJ, Sutherland R, Scott DH. The effect of position and different manoeuvres on internal jugular vein diameter size. Acta Anaesthesiol Scand 1994;38:229-31.

18. Kim ES, Sharma AM, Scissons R, et al. Interpretation of peripheral arterial and venous Doppler waveforms: a consensus statement from the Society for Vascular Medicine and Society for Vascular Ultrasound. Vasc Med 2020;25:484-506.
19. Taute BM, Schmidt H, Bach AG, et al. Spectral Doppler waveform analysis of common femoral veins for the detection of right ventricular dysfunction in acute pulmonary embolism. J Cardiovas Dis Diagn 2015;03.
20. Seldinger SI. Catheter replacement of the needle in percutaneous arteriography; a new technique. Acta radiol 1953;39:368-76.
21. Stone MB, Moon C, Sutijono D, et al. Needle tip visualization during ultrasound-guided vascular access: short-axis vs long-axis approach. Am J Emerg Med 2010;28:343-7.
22. Phelan M, Hagerty D. The oblique view: an alternative approach for ultrasound-guided central line placement. J Emerg Med 2009;37:403-8.
23. Galvez JA, Lin EE, Schwartz AJ, et al. Ultrasound-guided vascular access: visualizing the tip of the needle. Anesthesiology 2016;125:396.
24. Gillman LM, Blaivas M, Lord J, et al. Ultrasound confirmation of guidewire position may eliminate accidental arterial dilatation during central venous cannulation. Scand J Trauma Resusc Emerg Med 2010;18:39.
25. Denys BG, Uretsky BF. Anatomical variations of internal jugular vein location: impact on central venous access. Crit Care Med 1991;19:1516-9.
26. Troianos CA, Kuwik RJ, Pasqual JR, et al. Internal jugular vein and carotid artery anatomic relation as determined by ultrasonography. Anesthesiology 1996;85:43-8.
27. Maecken T, Marcon C, Bomas S, et al. Relationship of the internal jugular vein to the common carotid artery: implications for ultrasound-guided vascular access. Eur J Anaesthesiol 2011;28:351-5.
28. Lichtenstein D, Saifi R, Augarde R, et al. The internal jugular veins are asymmetric. Usefulness of ultrasound before catheterization. Intensive Care Med 2001;27:301-5.
29. Mey U, Glasmacher A, Hahn C, et al. Evaluation of an ultrasound-guided technique for central venous access via the internal jugular vein in 493 patients. Support Care Cancer 2003;11:148-55.
30. Suarez T, Baerwald JP, Kraus C. Central venous access: the effects of approach, position, and head rotation on internal jugular vein cross-sectional area. Anesth Analg 2002;95:1519-24.
31. Augoustides JG, Horak J, Ochroch AE, et al. A randomized controlled clinical trial of real-time needle-guided ultrasound for internal jugular venous cannulation in a large university anesthesia department. J Cardiothorac Vasc Anesth 2005;19:310-5.
32. Nassar B, Deol GRS, Ashby A, et al. Trendelenburg position does not increase cross-sectional area of the internal jugular vein predictably. Chest 2013;144:177-82.
33. Hind D, Calvert N, McWilliams R, et al. Ultrasonic locating devices for central venous cannulation: meta-analysis. BMJ 2003;327:361.
34. Wu SY, Ling Q, Cao LH, et al. Real-time two-dimensional ultrasound guidance for central venous cannulation: a meta-analysis. Anesthesiology 2013;118:361-75.
35. Brass P, Hellmich M, Kolodziej L, et al. Ultrasound guidance versus anatomical landmarks for internal jugular vein catheterization. Cochrane Database Syst Rev 2015;1:CD006962.
36. Goetz AM, Wagener MM, Miller JM, et al. Risk of infection due to central venous catheters: effect of site of placement and catheter type. Infect Control Hosp Epidemiol 1998;19:842-5.
37. Lavallee C, Ayoub C, Mansour A, et al. Subclavian and axillary vessel anatomy: a prospective observational ultrasound study. Can J Anaesth 2018;65:350-9.
38. Saini V, Vamsidhar A, Samra T, et al. Comparative evaluation of ultrasound guided supraclavicular and infraclavicular subclavian venous catheterizations in adult patients. J Anaesthesiol Clin Pharmacol 2022;38:411-6.
39. Su Y, Hou JY, Ma GG, et al. Comparison of the proximal and distal approaches for axillary vein catheterization under ultrasound guidance (PANDA) in cardiac surgery patients susceptible to bleeding: a randomized controlled trial. Ann Intensive Care 2020;10:90.
40. O'Leary R, Ahmed SM, McLure H, et al. Ultrasound-guided infraclavicular axillary vein cannulation: a useful alternative to the internal jugular vein. Br J Anaesth 2012;109:762-8.
41. Fragou M, Gravvanis A, Dimitriou V, et al. Real-time ultrasound-guided subclavian vein cannulation versus the landmark method in critical care patients: a prospective randomized study. Crit Care Med 2011;39:1607-12.
42. Oh AY, Jeon YT, Choi EJ, et al. The influence of the direction of J-tip on the placement of a subclavian catheter: real time ultrasound-guided cannulation versus landmark method, a randomized controlled trial. BMC Anesthesiol 2014;14:11.
43. Lalu MM, Fayad A, Ahmed O, et al. Ultrasound-guided subclavian vein catheterization: a systematic review and meta-analysis. Crit Care Med 2015;43:1498-507.
44. Brass P, Hellmich M, Kolodziej L, et al. Ultrasound guidance versus anatomical landmarks for subclavian or femoral vein catheterization. Cochrane Database Syst Rev 2015;1:CD011447.
45. Zawadka M, La Via L, Wong A, et al. Real-time ultrasound guidance as compared with landmark technique for subclavian central venous cannulation: a systematic review and meta-analysis with trial sequential analysis. Crit Care Med 2023;51:642-52.
46. Liccardo M, Nocerino P, Gaia S, et al. Efficacy of ultrasound-guided axillary/subclavian venous approaches for pacemaker and defibrillator lead implantation: a randomized study. J Interv Card Electrophysiol 2018;51:153-60.
47. Shinde PD, Jasapara A, Bansode K, et al. A comparative study of safety and efficacy of ultrasound-guided infra-clavicular axillary vein cannulation versus ultrasound-guided internal jugular vein cannulation in adult cardiac surgical patients. Ann Card Anaesth 2019;22:177-86.
48. Zhou J, Wu L, Zhang C, et al. Ultrasound guided axillary vein catheterization versus subclavian vein cannulation with landmark technique: a PRISMA-compliant systematic review and meta-analysis. Medicine (Baltimore) 2022;101:e31509.
49. Hughes P, Scott C, Bodenham A. Ultrasonography of the femoral vessels in the groin: implications for vascular access. Anaesthesia 2000;55:1198-202.
50. Merchant RM, Topjian AA, Panchal AR, et al. Part 1: Executive summary: 2020 American Heart Association guidelines for cardiopulmonary resuscitation and emergency cardiovascular care. Circulation 2020;142:S337-57.
51. Werner SL, Jones RA, Emerman CL. Effect of hip abduction and external rotation on femoral vein exposure for possible cannulation. J Emerg Med 2008;35:73-5.
52. Stone MB, Price DD, Anderson BS. Ultrasonographic investigation of the effect of reverse Trendelenburg on the cross-sectional area of the femoral vein. J Emerg Med 2006;30:211-3.
53. Prabhu MV, Juneja D, Gopal PB, et al. Ultrasound-guided femoral dialysis access placement: a single-center randomized trial. Clin J Am Soc Nephrol 2010;5:235-9.
54. Powell JT, Mink JT, Nomura JT, et al. Ultrasound-guidance can reduce adverse events during femoral central venous cannulation. J Emerg Med 2014;46:519-24.
55. Rabindranath KS, Kumar E, Shail R, et al. Use of real-time ultrasound guidance for the placement of hemodialysis catheters: a systematic review and meta-analysis of randomized controlled trials. Am J Kidney Dis 2011;58:964-70.
56. Kupo P, Pap R, Saghy L, et al. Ultrasound guidance for femoral venous access in electrophysiology procedures-systematic review and meta-analysis. J Interv Card Electrophysiol 2020;59:407-14.
57. Alexandrou E, Spencer TR, Frost SA, et al. Central venous catheter placement by advanced practice nurses demonstrates low procedural complication and infection rates–a report from 13 years of service. Crit Care Med 2014;42:536-43.
58. Dawson RB. PICC Zone Insertion MethodTM (ZIMTM): a systematic approach to determine the ideal insertion site for PICCs in the upper arm. J Vasc Access 2011;16:156-65.
59. Cardella JF, Cardella K, Bacci N, et al. Cumulative experience with 1,273 peripherally inserted central catheters at a single institution. J Vasc Interv Radiol 1996;7:5-13.

60. Stokowski G, Steele D, Wilson D. The use of ultrasound to improve practice and reduce complication rates in peripherally inserted central catheter insertions: final report of investigation. J Infus Nurs 2009;32:145-55.
61. Hughes ME. PICC-related thrombosis: pathophysiology, incidence, morbidity and the effect of ultrasound-guided placement technique on occurrence in cancer patients. J Vasc Access 2011;16:8-18.
62. Kerforne T, Petitpas F, Frasca D, et al. Ultrasound-guided peripheral venous access in severely ill patients with suspected difficult vascular puncture. Chest 2012;141:279-80.
63. Egan G, Healy D, O'Neill H, et al. Ultrasound guidance for difficult peripheral venous access: systematic review and meta-analysis. Emerg Med J 2013;30:521-6.
64. Stolz LA, Stolz U, Howe C, et al. Ultrasound-guided peripheral venous access: a meta-analysis and systematic review. J Vasc Access 2015;16:321-6.
65. van Loon FHJ, Buise MP, Claassen JJF, et al. Comparison of ultrasound guidance with palpation and direct visualisation for peripheral vein cannulation in adult patients: a systematic review and meta-analysis. Br J Anaesth 2018;121:358-66.
66. Poulsen E, Aagaard R, Bisgaard J, et al. The effects of ultrasound guidance on first-attempt success for difficult peripheral intravenous catheterization: a systematic review and meta-analysis. Eur J Emerg Med 2023;30:70-7.
67. Mahler SA, Wang H, Lester C, et al. Ultrasound-guided peripheral intravenous access in the emergency department using a modified Seldinger technique. J Emerg Med 2010;39:325-9.
68. Bauman M, Braude D, Crandall C. Ultrasound-guidance vs. standard technique in difficult vascular access patients by ED technicians. Am J Emerg Med 2009;27:135-40.
69. Brzezinski M, Luisetti T, London MJ. Radial artery cannulation: a comprehensive review of recent anatomic and physiologic investigations. Anesth Analg 2009;109:1763-81.
70. Handlogten KS, Wilson GA, Clifford L, et al. Brachial artery catheterization: an assessment of use patterns and associated complications. Anesth Analg 2014;118:288-95.
71. Vallespin J, Meola M, Ibeas J. Upper limb anatomy and preoperative mapping. J Vasc Access 2021;22:9-17.
72. Cho SA, Jang YE, Ji SH, et al. Ultrasound-guided arterial catheterization. Anesth Pain Med (Seoul) 2021;16:119-32.
73. Posham R, Biederman DM, Patel RS, et al. Transradial approach for noncoronary interventions: a single-center review of safety and feasibility in the first 1,500 cases. J Vasc Interv Radiol 2016;27:159-66.
74. Di Santo P, Simard T, Wells GA, et al. Transradial versus transfemoral access for percutaneous coronary intervention in ST-segment-elevation myocardial infarction: a systematic review and meta-analysis. Circ Cardiovasc Interv 2021;14:e009994.
75. Mason PJ, Shah B, Tamis-Holland JE, et al. An update on radial Aatery access and best practices for transradial artery coronary angiography and intervention in acute coronary syndrome: a scientific statement from the American Heart Association. Circ Cardiovasc Interv 2018;11:e000035.
76. Gayed A, Yamada R, Bhatia S, et al. Society of interventional radiology quality improvement standards on radial artery access. J Vasc Interv Radiol 2021;32:761.e1-21.
77. Fuda G, Denault A, Deschamps A, et al. Risk factors involved in central-to-radial arterial pressure gradient during cardiac surgery. Anesth Analg 2016;122:624-32.
78. Bouchard-Dechene V, Kontar L, Couture P, et al. Radial-to-femoral pressure gradient quantification in cardiac surgery. JTCVS Open 2021;8:446-60.
79. Bobbia X, Grandpierre RG, Claret PG, et al. Ultrasound guidance for radial arterial puncture: a randomized controlled trial. Am J Emerg Med 2013;31:810-5.
80. Hansen MA, Juhl-Olsen P, Thorn S, et al. Ultrasonography-guided radial artery catheterization is superior compared with the traditional palpation technique: a prospective, randomized, blinded, crossover study. Acta Anaesthesiol Scand 2014;58:446-52.
81. Seto AH, Roberts JS, Abu-Fadel MS, et al. Real-time ultrasound guidance facilitates transradial access: RAUST (radial artery access with ultrasound trial). JACC Cardiovasc Interv 2015;8:283-91.
82. Ueda K, Bayman EO, Johnson C, et al. A randomised controlled trial of radial artery cannulation guided by Doppler vs. palpation vs. ultrasound. Anaesthesia 2015;70:1039-44.
83. Li X, Fang G, Yang D, et al. Ultrasonic technology improves radial artery puncture and cannulation in intensive care unit (ICU) shock patients. Med Sci Monit 2016;22:2409-16.
84. Burad J, Date R, Kodange S, et al. Comparison of conventional and ultrasound guided techniques of radial artery cannulation in different haemodynamic subsets: a randomised controlled study. Intensive Care Med 2017;43:140-1.
85. Tangwiwat S, Pankla W, Rushatamukayanunt P, et al. Comparing the success rate of radial artery cannulation under ultrasound guidance and palpation technique in adults. J Med Assoc Thai 2016;99:505-10.
86. Shiloh AL, Savel RH, Paulin LM, et al. Ultrasound-guided catheterization of the radial artery: a systematic review and meta-analysis of randomized controlled trials. Chest 2011;139:524-9.
87. White L, Halpin A, Turner M, et al. Ultrasound-guided radial artery cannulation in adult and paediatric populations: a systematic review and meta-analysis. Br J Anaesth 2016;116:610-7.
88. Moussa Pacha H, Alahdab F, Al-Khadra Y, et al. Ultrasound-guided versus palpation-guided radial artery catheterization in adult population: a systematic review and meta-analysis of randomized controlled trials. Am Heart J 2018;204:1-8.
89. Zhao W, Peng H, Li H, et al. Effects of ultrasound-guided techniques for radial arterial catheterization: a meta-analysis of randomized controlled trials. Am J Emerg Med 2021;46:1-9.
90. Bi X, Wang Q, Liu D, et al. Is the complication rate of ulnar and radial approaches for coronary artery intervention the same? Angiology 2017;68:919-25.
91. Watkinson AF, Hartnell GG. Complications of direct brachial artery puncture for arteriography: a comparison of techniques. Clin Radiol 1991;44:189-91.
92. Franz RW, Tanga CF, Herrmann JW. Treatment of peripheral arterial disease via percutaneous brachial artery access. J Vasc Surg 2017;66:461-5.
93. Appelt K, Takes M, Zech CJ, et al. Complication rates of percutaneous brachial artery puncture: effect of live ultrasound guidance. CVIR Endovasc 2021;4:74.
94. Dawson K, Jones TL, Kearney KE, et al. Emerging role of large-bore percutaneous axillary vascular access: a step-by-step guide. Interv Cardiol 2020;15:e07.
95. Htet N, Vaughn J, Adigopula S, et al. Needle-guided ultrasound technique for axillary artery catheter placement in critically ill patients: a case series and technique description. J Crit Care 2017;41:194-7.
96. Dahle TG, Kaneko T, McCabe JM. Outcomes following subclavian and axillary artery access for transcatheter aortic valve replacement: Society of the Thoracic Surgeons/American College of Cardiology TVT Registry report. JACC Cardiovasc Interv 2019;12:662-9.
97. Bergeron P. Direct percutaneous carotid access for carotid angioplasty and stenting. J Endovasc Ther 2015;22:135-8.
98. McCabe JM, Kaki AA, Pinto DS, et al. Percutaneous axillary access for placement of microaxial ventricular support devices: the axillary access registry to monitor safety (ARMS). Circ Cardiovasc Interv 2021;14:e009657.
99. Seto AH, Tyler J, Suh WM, et al. Defining the common femoral artery: Insights from the femoral arterial access with ultrasound trial. Catheter Cardiovasc Interv 2017;89:1185-92.
100. Hwang JY. Doppler ultrasonography of the lower extremity arteries: anatomy and scanning guidelines. Ultrasonography 2017;36:111-9.
101. Seto AH, Abu-Fadel MS, Sparling JM, et al. Real-time ultrasound guidance facilitates femoral arterial access and reduces vascular complications: FAUST (Femoral Arterial Access with Ultrasound Trial). JACC Cardiovasc Interv 2010;3:751-8.

102. Tuna Katırcıbaşı M, Güneş H, Çağrı Aykan A, et al. Comparison of ultrasound guidance and conventional method for common femoral artery cannulation: a prospective study of 939 patients. Acta Cardiol Sin 2018;34:394-8.
103. Marquis-Gravel G, Tremblay-Gravel M, Levesque J, et al. Ultrasound guidance versus anatomical landmark approach for femoral artery access in coronary angiography: a randomized controlled trial and a meta-analysis. J Interv Cardiol 2018;31:496-503.
104. Stone P, Campbell J, Thompson S, et al. A prospective, randomized study comparing ultrasound versus fluoroscopic guided femoral arterial access in noncardiac vascular patients. J Vasc Surg 2020;72:259-67.
105. Jolly SS, AlRashidi S, d'Entremont MA, et al. Routine ultrasonography guidance for femoral vascular access for cardiac procedures: the UNIVERSAL randomized clinical trial. JAMA Cardiol 2022;7:1110-8.
106. Rashid MK, Sahami N, Singh K, et al. Ultrasound guidance in femoral artery catheterization: a systematic review and a meta-analysis of randomized controlled trials. J Invasive Cardiol 2019;31:E192-8.
107. Khan Z, Khan M, Mohammednouraltaf F, et al. Diameter of the dorsalis pedis artery and its clinical relevance. J Med Dent Sci 2016;15:129-33.
108. El-Sayed HF. Retrograde pedal/tibial artery access for treatment of infragenicular arterial occlusive disease. Methodist Debakey Cardiovasc J 2013;9:73-8.
109. Sharma A, Goyal S, Kumari K, et al. A randomized controlled trial comparing ultrasound-guided versus traditional palpatory methods of posterior tibial artery cannulation in adult patients. J Vasc Access 2023; 25:1140-5.
110. Takeshita J, Tachibana K, Nakayama Y, et al. Ultrasound-guided dynamic needle tip positioning versus conventional palpation approach for catheterisation of posterior tibial or dorsalis pedis artery in infants and small children. Br J Anaesth 2021;126:e140-2.
111. Kaushal A, Ramakumar N, Talawar P, et al. A randomized trial to compare ultrasound-guided dorsalis pedis versus posterior tibial artery cannulation in neurosurgical patients. Cureus 2023;15:e33514.
112. Kwan TW, Shah S, Amoroso N, et al. Feasibility and safety of routine transpedal arterial access for treatment of peripheral artery disease. J Invasive Cardiol 2015;27:327-30.
113. Anand RK, Maitra S, Ray BR, et al. Comparison of ultrasound-guided versus conventional palpatory method of dorsalis pedis artery cannulation: a randomized controlled trial. Saudi J Anaesth 2019;13:295-8.
114. Kusminsky RE. Complications of central venous catheterization. J Am Coll Surg 2007;204:681-96.
115. Adrian M, Borgquist O, Kroger T, et al. Mechanical complications after central venous catheterisation in the ultrasound-guided era: a prospective multicentre cohort study. Br J Anaesth 2022;129:843-50.
116. Karande GY, Hedgire SS, Sanchez Y, et al. Advanced imaging in acute and chronic deep vein thrombosis. Cardiovasc Diagn Ther 2016;6: 493-507.
117. Roter E, Denault AY. Radial artery reliability using arterial Doppler assessment prior to arterial cannulation. Can J Anaesth 2019;66:1272-3.
118. Costa F, van Leeuwen MA, Daemen J, et al. The Rotterdam radial access research: ultrasound-based radial artery evaluation for diagnostic and therapeutic coronary procedures. Circ Cardiovasc Interv 2016;9: 1110-8.
119. Mahmoud MZ, Al-Saadi M, Abuderman A, et al. "To-and-fro" waveform in the diagnosis of arterial pseudoaneurysms. World J Radiol 2015;7: 89-99.
120. Altin RS, Flicker S, Naidech HJ. Pseudoaneurysm and arteriovenous fistula after femoral artery catheterization: association with low femoral punctures. Am J Roentgenol 1989;152:629-31.
121. Blaivas M, Adhikari S. An unseen danger: frequency of posterior vessel wall penetration by needles during attempts to place internal jugular vein central catheters using ultrasound guidance. Crit Care Med 2009; 37:2345-9.
122. Wang R, Snoey ER, Clements RC, et al. Effect of head rotation on vascular anatomy of the neck: an ultrasound study. J Emerg Med 2006;31:283-6.
123. Weekes AJ, Keller SM, Efune B, et al. Prospective comparison of ultrasound and CXR for confirmation of central vascular catheter placement. Emerg Med J 2016;33:176-80.
124. Kolluri R, Fowler B, Nandish S. Vascular access complications: diagnosis and management. Curr Treat Options Cardiovasc Med 2013;15:173-87.
125. Mermel LA, Allon M, Bouza E, et al. Clinical practice guidelines for the diagnosis and management of intravascular catheter-related infection: 2009 update by the infectious diseases Society of America. Clin Infect Dis 2009;49:1-45.
126. Chopra V, Anand S, Hickner A, et al. Risk of venous thromboembolism associated with peripherally inserted central catheters: a systematic review and meta-analysis. Lancet 2013;382:311-25.
127. O'Brien J, Paquet F, Lindsay R, et al. Insertion of PICCs with minimum number of lumens reduces complications and costs. J Am Coll Radiol 2013;10:864-8.
128. Fletcher SJ, Bodenham AR. Safe placement of central venous catheters: where should the tip of the catheter lie? Br J Anaesth 2000;85:188-91.
129. Heinrichs J, Fritze Z, Klassen T, et al. A systematic review and meta-analysis of new interventions for peripheral intravenous cannulation of children. Pediatr Emerg Care 2013;29:858-66.
130. AIUM practice parameter for the use of ultrasound to guide vascular access procedures. J Ultrasound Med 2019;38:E4-18.
131. Souza Neto E, Grousson S, Duflo F, et al. Ultrasonographic anatomic variations of the major veins in paediatric patients. Br J Anaesth 2014;112: 879-84.
132. Hanslik A, Thom K, Haumer M, et al. Incidence and diagnosis of thrombosis in children with short-term central venous lines of the upper venous system. Pediatrics 2008;122:1284-91.
133. de Souza TH, Brandao MB, Nadal JAH, et al. Ultrasound guidance for pediatric central venous catheterization: a meta-analysis. Pediatrics 2018; 142:e20181719.
134. Froehlich CD, Rigby MR, Rosenberg ES, et al. Ultrasound-guided central venous catheter placement decreases complications and decreases placement attempts compared with the landmark technique in patients in a pediatric intensive care unit. Crit Care Med 2009;37:1090-6.
135. Bruzoni M, Slater BJ, Wall J, et al. A prospective randomized trial of ultrasound- vs landmark-guided central venous access in the pediatric population. J Am Coll Surg 2013;216:939-43.
136. Oulego-Erroz I, Gonzalez-Cortes R, Garcia-Soler P, et al. Ultrasound-guided or landmark techniques for central venous catheter placement in critically ill children. Intensive Care Med 2018;44:61-72.
137. Hosokawa K, Shime N, Kato Y, et al. A randomized trial of ultrasound image-based skin surface marking versus real-time ultrasound-guided internal jugular vein catheterization in infants. Anesthesiology 2007;107: 720-4.
138. Hopkins JW, Warkentine F, Gracely E, et al. The anatomic relationship between the common femoral artery and common femoral vein in frog leg position versus straight leg position in pediatric patients. Acad Emerg Med 2009;16:579-84.
139. Suk EH, Lee KY, Kweon TD, et al. Ultrasonographic evaluation of the femoral vein in anaesthetised infants and young children. Anaesthesia 2010;65:895-8.
140. Bhatia N, Sivaprakasam J, Allford M, et al. The relative position of femoral artery and vein in children under general anesthesia–an ultrasound-guided observational study. Paediatr Anaesth 2014;24:1164-8.
141. Aouad MT, Kanazi GE, Abdallah FW, et al. Femoral vein cannulation performed by residents: a comparison between ultrasound-guided and landmark technique in infants and children undergoing cardiac surgery. Anesth Analg 2010;111:724-8.
142. Law MA, Borasino S, McMahon WS, et al. Ultrasound- versus landmark-guided femoral catheterization in the pediatric catheterization laboratory: a randomized-controlled trial. Pediatr Cardiol 2014;35:1246-52.
143. Oakley E, Wong AM. Ultrasound-assisted peripheral vascular access in a paediatric ED. Emerg Med Australas 2010;22:166-70.
144. Ye X, Li M. Comparison of ultrasound guided and conventional techniques for peripheral venous catheter insertion in pediatric patients: a

systematic review and meta-analysis of randomized controlled trials. Front Pediatr 2021;9:797705.
145. Schindler E, Kowald B, Suess H, et al. Catheterization of the radial or brachial artery in neonates and infants. Paediatr Anaesth 2005;15:677-82.
146. Spahr RC, MacDonald HM, Holzman IR. Catheterization of the posterior tibial artery in the neonate. Am J Dis Child 1979;133:945-6.
147. Sellden H, Nilsson K, Larsson LE, et al. Radial arterial catheters in children and neonates: a prospective study. Crit Care Med 1987;15:1106-9.
148. Bull MJ, Schreiner RL, Garg BP, et al. Neurologic complications following temporal artery catheterization. J Pediatr 1980;96:1071-3.
149. Nakayama Y, Takeshita J, Nakajima Y, et al. Ultrasound-guided peripheral vascular catheterization in pediatric patients: a narrative review. Crit Care 2020;24:592.
150. Jung OE, Jin MJ, Su KC, et al. Evaluation of the factors related to difficult ultrasound-guided radial artery catheterization in small children: a prospective observational study. Acta Anaesthesiol Scand 2021;65:203-12.
151. Nakayama Y, Nakajima Y, Sessler DI, et al. A novel method for ultrasound-guided radial arterial catheterization in pediatric patients. Anesth Analg 2014;118:1019-26.
152. Sulemanji DS, Donmez A, Akpek EA, et al. Vascular catheterization is difficult in infants with Down syndrome. Acta Anaesthesiol Scand 2009;53:98-100.
153. Gu WJ, Tie HT, Liu JC, et al. Efficacy of ultrasound-guided radial artery catheterization: a systematic review and meta-analysis of randomized controlled trials. Crit Care 2014;18:R93.
154. Aouad-Maroun M, Raphael CK, Sayyid SK, et al. Ultrasound-guided arterial cannulation for paediatrics. Cochrane Database Syst Rev 2016;9:CD011364.
155. Zhang W, Li K, Xu H, et al. Efficacy of ultrasound-guided technique for radial artery catheterization in pediatric populations: a systematic review and meta-analysis of randomized controlled trials. Crit Care 2020;24:197.
156. Ganesh A, Kaye R, Cahill AM, et al. Evaluation of ultrasound-guided radial artery cannulation in children. Pediatr Crit Care Med 2009;10:45-8.
157. Tan TY, Petersen JAK, Zhao X, et al. Randomized controlled trial of ultrasound versus palpation method for arterial cannulation in infants less than 24 months of age. SOJ Anesthesiol Pain Manag 2015;2:1-3.
158. Song IK, Choi JY, Lee JH, et al. Short-axis/out-of-plane or long-axis/in-plane ultrasound-guided arterial cannulation in children: a randomised controlled trial. Eur J Anaesthesiol 2016;33:522-7.
159. Wang Z, Guo H, Shi S, et al. Long-axis in-plane combined with short-axis out-of-plane technique in ultrasound-guided arterial catheterization in infants: a randomized controlled trial. J Clin Anesth 2023;85:111038.
160. Staudt GE, Eagle SS, Hughes AK, et al. Evaluation of dynamic ultrasound for arterial access in children undergoing cardiac surgery. J Cardiothorac Vasc Anesth 2019;33:1926-9.
161. Takeshita J, Yoshida T, Nakajima Y, et al. Dynamic needle tip positioning for ultrasound-guided arterial catheterization in infants and small children with deep arteries: a randomized controlled trial. J Cardiothorac Vasc Anesth 2019;33:1919-25.
162. Liu L, Tan Y, Li S, et al. "Modified dynamic needle tip positioning" short-axis, out-of-plane, ultrasound-guided radial artery cannulation in neonates: a randomized controlled trial. Anesth Analg 2019;129:178-83.
163. Takeshita J, Nakayama Y, Tachibana K, et al. Ultrasound-guided short-axis out-of-plane approach with or without dynamic needle tip positioning for arterial line insertion in children: a systematic review with network meta-analysis. Anaesth Crit Care Pain Med 2023;42:101206.
164. Quan Z, Zhang L, Zhou C, et al. Acoustic shadowing facilitates ultrasound-guided radial artery cannulation in young children. Anesthesiology 2019;131:1018-24.
165. Siddik-Sayyid SM, Aouad MT, Ibrahim MH, et al. Femoral arterial cannulation performed by residents: a comparison between ultrasound-guided and palpation technique in infants and children undergoing cardiac surgery. Paediatr Anaesth 2016;26:823-30.
166. Raphael CK, El Hage Chehade NA, Khabsa J, et al. Ultrasound-guided arterial cannulation in the paediatric population. Cochrane Database Syst Rev 2023;3:CD011364.
167. Schults JA, Long D, Pearson K, et al. Insertion, management, and complications associated with arterial catheters in paediatric intensive care: a clinical audit. Aust Crit Care 2020;33:326-32.
168. Graves PW, Davis AL, Maggi JC, et al. Femoral artery cannulation for monitoring in critically ill children: prospective study. Crit Care Med 1990;18:1363-6.
169. Alexander J, Yohannan T, Abutineh I, et al. Ultrasound-guided femoral arterial access in pediatric cardiac catheterizations: a prospective evaluation of the prevalence, risk factors, and mechanism for acute loss of arterial pulse. Catheter Cardiovasc Interv 2016;88:1098-107.
170. Tadphale S, Yohannan T, Kauffmann T, et al. Accessing femoral arteries less than 3 mm in diameter is associated with increased incidence of loss of pulse following cardiac catheterization in infants. Pediatr Cardiol 2020;41:1058-66.
171. Brotschi B, Hug MI, Kretschmar O, et al. Incidence and predictors of cardiac catheterisation-related arterial thrombosis in children. Heart 2015;101:948-53.
172. Loon FHV, Scholten HJ, Erp IV, et al. Establishing the required components for training in ultrasoundguided peripheral intravenous cannulation: a systematic review of available evidence. Med Ultrason 2019;21:464-73.
173. Moureau N, Lamperti M, Kelly LJ, et al. Evidence-based consensus on the insertion of central venous access devices: definition of minimal requirements for training. Br J Anaesth 2013;110:347-56.
174. Chenkin J, Lee S, Huynh T, et al. Procedures can be learned on the Web: a randomized study of ultrasound-guided vascular access training. Acad Emerg Med 2008;15:949-54.
175. Ballard HA, Tsao M, Robles A, et al. Use of a simulation-based mastery learning curriculum to improve ultrasound-guided vascular access skills of pediatric anesthesiologists. Paediatr Anaesth 2020;30:1204-10.
176. Okano H, Mayumi T, Kataoka Y, et al. Outcomes of simulation-based education for vascular access: a systematic review and meta-nalysis. Cureus 2021;13:e17188.