GUIDELINES AND STANDARDS

Guidelines for Performing Ultrasound Guided Vascular Cannulation: Recommendations of the American Society of Echocardiography and the Society of Cardiovascular Anesthesiologists

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1. INTRODUCTION

The Agency for Healthcare Research and Quality, in its 2001 report *Making Health Care Safer: A Critical Analysis of Patient Safety*

Abbreviations

ASE = American Society of Echocardiography

CA = Carotid artery

CI = Confidence interval

FV = Femoral vein

IJ = Internal jugular

LAX = Long-axis

PICC = Percutaneous intravenous central catheterization

SAX = Short-axis

SC = Subclavian

3D = Three-dimensional

2D = Two-dimensional

Practices, recommended the use of ultrasound for the placement of all central venous catheters as one of its 11 practices aimed at improving patient care.[1,2] The purpose of this document is to provide comprehensive practice guidelines on the use of ultrasound for vascular cannulation. Recommendations are made for ultrasound-guided central venous access of the internal jugular (IJ) vein, subclavian (SC) vein, and femoral vein (FV) on the basis of the strength of the scientific evidence present in the literature (Table 1). The role of ultrasound for vascular cannulation of pediatric patients is discussed specifically, and the use of ultrasound to facilitate arterial cannulation and peripheral venous access is also discussed. Recommendations are made for training, including the role of simulation.

2. METHODOLOGY AND EVIDENCE REVIEW

The writing committee conducted a comprehensive search of medical and scientific literature in the English language through the use of PubMed and MEDLINE. Original research studies relevant to ultrasound-guided vascular access published in peer-reviewed scientific journals from 1990 to 2011 were reviewed using the Medical Subject Headings terms "ultrasonography," "catheterization-central venous/adverse effects/methods," "catheterization-peripheral," "jugular veins," "subclavian vein," "femoral vein," "artery," "adult," "pediatric," "randomized controlled trials," and "meta-analysis." The committee reviewed the scientific evidence for the strength of the recommendation (i.e., risk/benefit ratio) as supportive evidence (category A), suggestive evidence (category B), equivocal evidence (category C), or insufficient evidence (category D). The weight or "level" of evidence was assigned within each category (Table 1). Recommendations for the use of ultrasound were based on supportive literature (category A) with a level 1 weight of scientific evidence (multiple randomized controlled trials with the aggregated findings supported by meta-analysis). The document was reviewed by 10 reviewers nominated by the American Society of Echocardiography (ASE) and the Society of Cardiovascular Anesthesiologists and approved for publication by the governing bodies of these organizations.

3. ULTRASOUND-GUIDED VASCULAR CANNULATION

Ultrasonography was introduced into clinical practice in the early 1970s and is currently used for a variety of clinical indications. Miniaturization and advancements in computer technology have made ultrasound affordable, portable, and capable of high-resolution imaging of both tissue and blood flow.

Cannulation of veins and arteries is an important aspect of patient care for the administration of fluids and medications and for monitoring purposes. The practice of using surface anatomy and palpation to identify target vessels before cannulation attempts ("landmark technique") is based on the presumed location of the vessel, the identification of surface or skin anatomic landmarks, and blind insertion of the needle until blood is aspirated. Confirmation of successful cannulation of the intended vascular structure relies on blood aspiration of a certain character and color (i.e., the lack of pulsation and "dark" color when cannulating a vein or pulsation and a "bright" red color when cannulating an artery), pressure measurement with a fluid column or pressure transducer, or observation of the intraluminal pressure waveform on a monitor. Although vascular catheters are commonly inserted over a wire or metal introducer, some clinicians initially cannulate the vessel with a small caliber ("finder") needle before the insertion of a larger bore needle. This technique is most beneficial for nonultrasound techniques, because a smaller needle may minimize the magnitude of an unintended injury to surrounding structures. The vessel is then cannulated with a larger bore 16-gauge or 18-gauge catheter, a guide wire is passed through it, and a larger catheter is inserted over the wire. The catheter–over–guide wire process is termed the Seldinger technique.[3]

Although frequently performed and an inherent part of medical training and practice, the insertion of vascular catheters is associated with complications. Depending on the site and patient population, landmark techniques for vascular cannulation are associated with a 60% to 95% success rate. A 2003 estimate cited the insertion of >5 million central venous catheters (in the IJ, SC, and FV) annually in the United States alone, with a mechanical complication rate of 5% to 19%.[4] These complications may occur more often with less experienced operators, challenging patient anatomy (obesity, cachexia, distorted, tortuous or thrombosed vascular anatomy, congenital anomalies such as persistent left superior vena cava), compromised procedural settings (mechanical ventilation or emergency), and the presence of comorbidity (coagulopathy, emphysema). Central venous catheter mechanical complications include arterial puncture, hematoma, hemothorax, pneumothorax, arterial-venous fistula, venous air embolism, nerve injury, thoracic duct injury (left side only), intraluminal dissection, and puncture of the aorta. The most common complications of IJ vein cannulation are arterial puncture and hematoma. The most common complication of SC vein cannulation is pneumothorax.[4] The incidence of mechanical complications increases sixfold when more than three attempts are made by the same operator.[4] The use of ultrasound imaging before or during vascular cannulation greatly improves first-pass success and reduces complications. Practice recommendations for the use of ultrasound for vascular cannulation have emerged from numerous specialties, governmental agencies such as the National Institute for Health and Clinical Excellence[5] and the Agency for Healthcare Research and Quality's evidence report.[2]

4. ULTRASOUND PRINCIPLES FOR NEEDLE-GUIDED CATHETER PLACEMENT

Ultrasound modalities used for imaging vascular structures and surrounding anatomy include two-dimensional (2D) ultrasound, Doppler color flow, and spectral Doppler interrogation. The operator must have an understanding of probe orientation, image display, the physics of ultrasound, and mechanisms of image generation and

Table 1 Categories of support from scientific evidence

Category A: supportive literature
Randomized controlled trials report statistically significant ($P < .01$) differences between clinical interventions for a specified clinical outcome.
Level 1: The literature contains multiple randomized controlled trials, and the aggregated findings are supported by meta-analysis.
Level 2: The literature contains multiple randomized controlled trials, but there is an insufficient number of studies to conduct a viable meta-analysis for the purpose of these guidelines.
Level 3: The literature contains a single randomized controlled trial.
Category B: suggestive literature
Information from observational studies permits inference of beneficial or harmful relationships among clinical interventions and clinical outcomes.
Level 1: The literature contains observational comparisons (e.g., cohort and case-control research designs) of two or more clinical interventions or conditions and indicates statistically significant differences between clinical interventions for a specified clinical outcome.
Level 2: The literature contains noncomparative observational studies with associative (e.g., relative risk, correlation) or descriptive statistics.
Level 3: The literature contains case reports.
Category C: equivocal literature
The literature cannot determine whether there are beneficial or harmful relationships among clinical interventions and clinical outcomes.
Level 1: Meta-analysis did not find significant differences among groups or conditions.
Level 2: There is an insufficient number of studies to conduct meta-analysis, and (1) randomized controlled trials have not found significant differences among groups or conditions, or (2) randomized controlled trials report inconsistent findings.
Level 3: Observational studies report inconsistent findings or do not permit inference of beneficial or harmful relationships.
Category D: insufficient evidence from literature
The lack of scientific evidence in the literature is described by the following conditions:
1. No identified studies address the specified relationships among interventions and outcomes.
2. The available literature cannot be used to assess the relationships among clinical interventions and clinical outcomes. The literature either does not meet the criteria for content as defined in the "focus" of the guidelines or does not permit a clear interpretation of findings because of methodologic concerns (e.g., confounding in study design or implementation).

Source: American Society of Anesthesiologists and Society of Cardiovascular Anesthesiologists Task Force on Transesophageal Echocardiography. Practice guidelines for perioperative transesophageal echocardiography. An updated report by the American Society of Anesthesiologists and the Society of Cardiovascular Anesthesiologists Task Force on Transesophageal Echocardiography. Anesthesiology 2010;112:1084–96.

artifacts and be able to interpret 2D images of vascular lumens of interest and surrounding structures. The technique also requires the acquisition of the necessary hand-eye coordination to direct probe and needle manipulation according to the image display. The supplemental use of color flow Doppler to confirm presence and direction of blood flow requires an understanding of the mechanisms and limitations of Doppler color flow analysis and display. This skill set must then be paired with manual dexterity to perform the three-dimensional (3D) task of placing a catheter into the target vessel while using and interpreting 2D images. Two-dimensional images commonly display either the short axis (SAX) or long axis (LAX) of the target vessel, each with its advantage or disadvantage in terms of directing the cannulating needle at the correct entry angle and depth. Three-dimensional ultrasound may circumvent the spatial limitations of 2D imaging by providing simultaneous real-time SAX and LAX views along with volume perspective without altering transducer location, allowing simultaneous views of neck anatomy in three orthogonal planes.[6] Detailed knowledge of vascular anatomy in the region of interest is similarly vital to both achieving success and avoiding complications from cannulation of incorrect vessels.

Ultrasound probes used for vascular access vary in size and shape. Probes with smaller footprints are preferred in pediatric patients. Higher frequency probes (≥7 MHz) are preferred over lower frequency probes (<5 MHz) because they provide better resolution of superficial structures in close proximity to the skin surface. The poorer penetration of the high-frequency probes is not typically a hindrance, because most target vascular structures intended for cannulation are <8 to 10 cm from the skin surface.

It is important to appreciate how probe orientation relates to the image display. Conventions established by the ASE for performing transthoracic imaging of the heart, and more recently epicardial imaging, established that the probe indicator and right side of the display should be oriented toward the patient's left side or cephalad.[7] In these settings, projected images correlate best with those visualized by the sonographer positioned on the patient's left side and facing the patient's right shoulder. In contrast, the operator's position during ultrasound-guided vascular access varies according to the target vessel. For example, the operator is typically positioned superior to the patient's head and faces caudally during cannulation of the IJ vein. The left side of the screen displays structures toward the patient's left side (Figure 1). In contrast, during cannulation of the FVs, the operator is typically positioned inferiorly and faces cephalad, so that the left side of the screen displays structures toward the patient's right side (see section 9, "Femoral Vein Cannulation"). For SC vein cannulation, the left and right sides of the screen display cephalad and caudad structures, depending on laterality (right or left). The changing image orientation is an important distinction from typical transthoracic, epicardial, or transesophageal imaging. For ultrasound-guided vascular access cannulation, the probe and screen display are best oriented to display the anatomic cross-section that would be visible from the same vantage point. Therefore, screen left and right will not follow standard conventions but rather vary with site and needle insertion orientation. What is common for all vascular access sites is that it is essential for the operator to orient the probe so that structures beneath the left aspect of the probe appear on the left side of the imaging screen. Although probes usually have markings that distinguishes one particular side of the transducer, the operator must identify which aspect of the screen corresponds to the marking on the probe. These markings may be obscure, and a recommended practice is to move the probe toward one direction or another while observing the screen

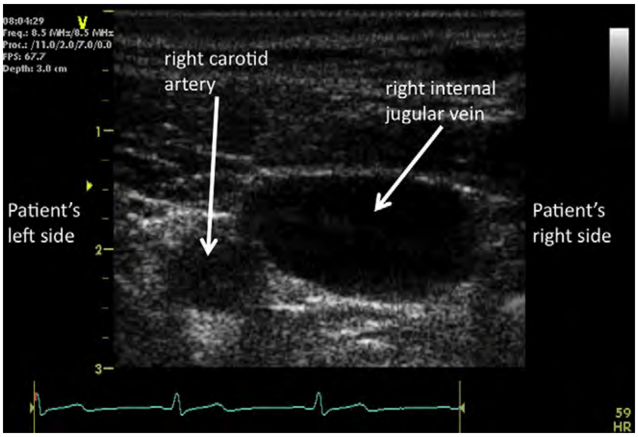

Figure 1 Right neck central vein cannulation. The ultrasound probe is held so that each side of the screen displays ipsilateral structures. With the probe mark placed on the upper left corner of the image, the displayed structures will move in the same direction with the probe.

or apply modest external surface pressure on one side of the transducer to demonstrate proper alignment of left-right probe orientation with image display.

The probe used ultimately depends on its availability, operator experience, ease of use, and patient characteristics (e.g., smaller patients benefit from smaller probes). Some probes allow the use of a needle guide, which directs the needle into the imaging plane and defined depth as viewed on the display screen (Figure 2). Needle guides are not available from every ultrasound probe manufacturer, but a needle guide may be a useful feature for the beginner who has not yet developed the manual dexterity of using a 2D image display to perform a 3D task. One study that evaluated ultrasound-guided cannulation of the IJ vein with and without a needle guide showed that its use significantly enhanced cannulation success after first (68.9%–80.9%, $P = .0054$) and second (80.0%–93.1%, $P = .0001$) needle passes.[8] Cumulative cannulation success after seven needle passes was 100%, regardless of technique. The needle guide specifically improved first-pass success among more junior operators (65.6%–79.8%, $P = .0144$), while arterial puncture averaged 4.2%, regardless of technique ($P > .05$) or operator ($P > .05$). A limitation of the needle guide is that the needle trajectory is limited to orthogonal orientations from the SAX imaging plane. Although helpful in limiting lateral diversion of the needle path, sometimes oblique angulation of the needle path may facilitate target vessel cannulation. In addition, there may be considerable costs associated with the use of needle guides. Depending on the manufacturer, they may cost as little as several dollars to >$100 each. Importantly, although the needle guide facilitated prompt cannulation with ultrasound in the novice operator, it offered no additional protection against arterial puncture.[8] However, one in vitro simulation study has refuted these in vivo results.[9]

Arterial puncture during attempted venous cannulation with ultrasound generally occurs because of a misalignment between the needle and imaging screen. It may also occur as a result of a through-and-through puncture of the vein into a posteriorly positioned artery. The first scenario is due to improper direction of the needle, while the latter occurs because of a lack of needle depth control. Needle depth control is also an important consideration because the anatomy may change as the needle is advanced deeper within the site of vascular access. The ideal probe should have a guide that not only directs the needle to the center of the probe but also directs the needle at the appropriate angle beneath the probe (Figure 2). This type of guide compensates for the limitation of using 2D ultrasound to perform a 3D task of vascular access. The more experienced operator with a better understanding of these principles and better manual dexterity may find the needle guide cumbersome, choosing instead the "maneuverability" of a freehand technique. Although the routine use of a needle guide requires further study, novice operators are more likely to improve their first-pass success.

Vascular structures can be imaged in SAX, LAX, or oblique orientation (Figures 3A, 3B, and 3C). The advantage of the SAX view is better visualization of surrounding structures and their relative positions to the needle. There is usually an artery in close anatomic proximity to most central veins. Identification of both vascular structures is paramount to avoid unintentional cannulation of the artery. In addition, it may be easier to direct the cannulating needle toward the target vessel and coincidentally away from surrounding structures when both are clearly imaged simultaneously. The advantage of the LAX view is better visualization of the needle throughout its course and depth of insertion, because more of the needle shaft and tip are imaged within the ultrasound image plane throughout its advancement, thereby avoiding insertion of the needle beyond the target vessel. A prospective, randomized observational study of emergency medicine residents evaluated whether the SAX or LAX ultrasound approach resulted in faster vascular access for novice ultrasound users.[10] The SAX approach yielded a faster cannulation time compared with the LAX approach, and the novice operators perceived the SAX approach as easier to use than the LAX approach. The operator's hand-eye coordination skill in aligning the ultrasound probe and needle is probably the most important variable influencing needle and target visibility. Imaging in the SAX view enables the simultaneous visualization of the needle shaft and adjacent structures, but this view does not image the entire needle pathway or provide an appreciation of insertion depth. Although novice users may find ultrasound guidance easier to adopt using SAX imaging, ultrasound guidance with LAX imaging should be promoted, because it enables visualization of the entire needle and depth of insertion, thereby considering anatomic variations along the needle trajectory as the needle is advanced deeper within the site of vascular access. The oblique axis is another option that may allow better visualization of the needle shaft and tip and offers the safety of imaging surrounding structures in the same view, thus capitalizing on the strengths of both the SAX and LAX approaches.[11]

5. REAL-TIME IMAGING VERSUS STATIC IMAGING

Ultrasound guidance for vascular access is most effective when used in real time (during needle advancement) with a sterile technique that includes sterile gel and sterile probe covers. The needle is observed on the image display and simultaneously directed toward the target vessel, away from surrounding structures, and advanced to an appropriate depth. Static ultrasound imaging uses ultrasound imaging to identify the site of needle entry on the skin over the underlying vessel and offers the appeal of nonsterile imaging, which obviates the need for sterile probe coverings, sterile ultrasound gels, and needle guides. If ultrasound is used to mark the skin for subsequent cannulation without real-time (dynamic) use, ultrasound becomes a vessel locator

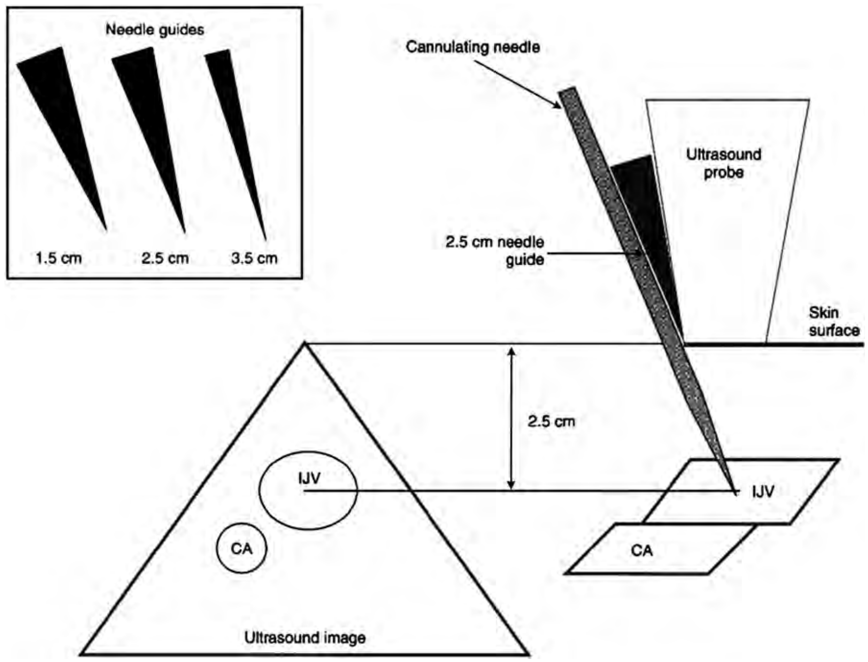

Figure 2 Various needle guides, used to direct the needle at the center of the probe (and image) and at an appropriate angle and depth beneath the probe. *IJV*, IJ vein. From Troianos CA. Intraoperative monitoring. In: Troianos CA, ed. Anesthesia for the Cardiac Patient. New York: Mosby; 2002.

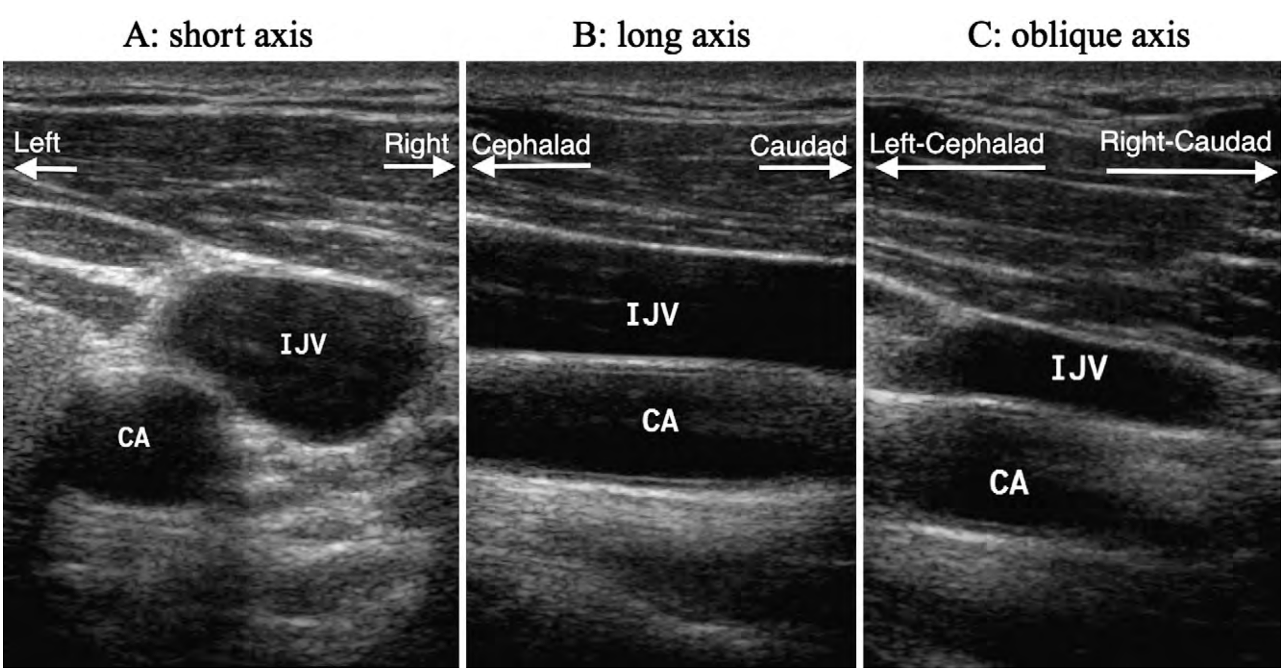

Figure 3 Two-dimensional imaging of the right IJ vein (IJV) and CA from the head of the patient over their right shoulder. **(A)** SAX, **(B)** LAX, **(C)** oblique axis. SAX imaging displays the lateral-right side of the patient on the right aspect of the display screen and the medial structures on the left aspect of the display screen. LAX imaging displays the caudad structures on the right aspect of the display screen and cephalad structures on the left aspect of the display screen. If the transducer is rotated counterclockwise about 30-40 degrees, oblique imaging displays more lateral-right caudad structures on the right aspect of the display screen, while more medial-left cephalad structures are on the left aspect of the display screen.

technique that enhances external landmarks rather than a technique that guides the needle into the vessel. Both static and real-time ultrasound-guided approaches are superior to a traditional landmark-guided approach. Although the real-time ultrasound guidance outperforms the static skin-marking ultrasound approach, complication rates are similar.[12]

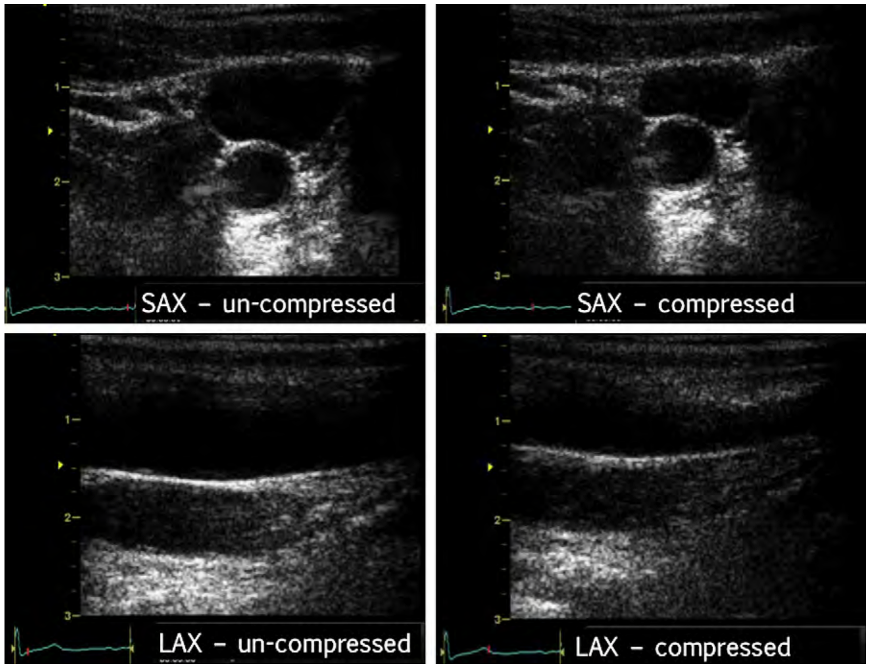

Figure 4 Vessel identification. Right IJ vein (*top*) and CA (*bottom*) in SAX and LAX orientation. Slight external pressure compresses the oval-shaped vein but not the round-shaped artery.

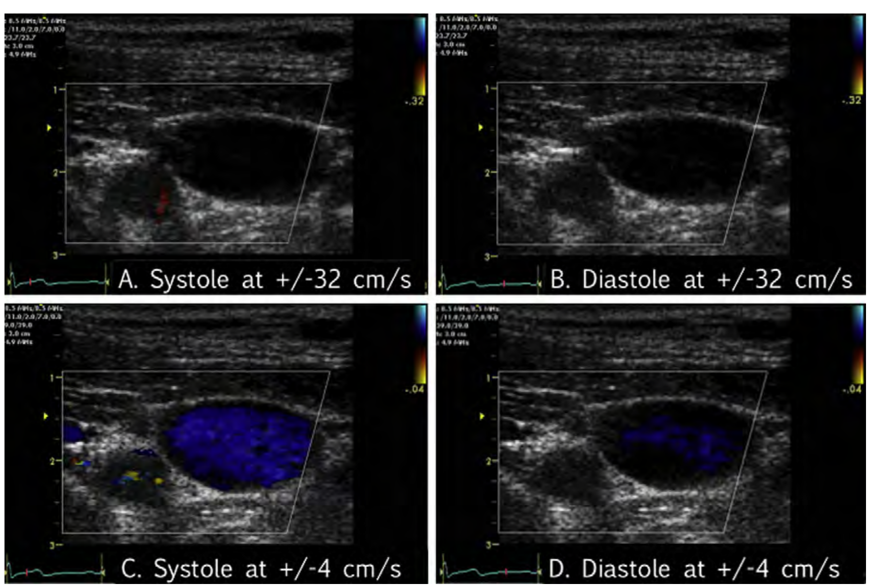

Figure 5 Vessel identification with color flow Doppler. Arterial flow is visible in systole only, irrespective of Nyquist limit. Venous flow is visible in systole and diastole, but only if the Nyquist limit is sufficiently decreased.

Venous puncture using real-time ultrasound was faster and required fewer needle passes among neonates and infants randomly assigned to real-time ultrasound-assisted IJ venous catheterization versus ultrasound-guided skin marking.[13] Fewer than three attempts were made in 100% of patients in the real-time group, compared with 74% of patients in the skin-marking group ($P < .01$). In this study, a hematoma and an arterial puncture occurred in one patient each in the skin-marking group.[13]

One operator can usually perform real-time ultrasound-guided cannulation. The nondominant hand holds the ultrasound probe while the dominant hand controls the needle. Successful cannulation of the vessel is confirmed by direct vision of the needle entering the vessel and with blood entering the attached syringe during aspiration. The probe is set aside on the sterile field, the syringe removed, and the wire is inserted through the needle. Further confirmation of successful cannulation occurs with ultrasound visualization of the guide wire in

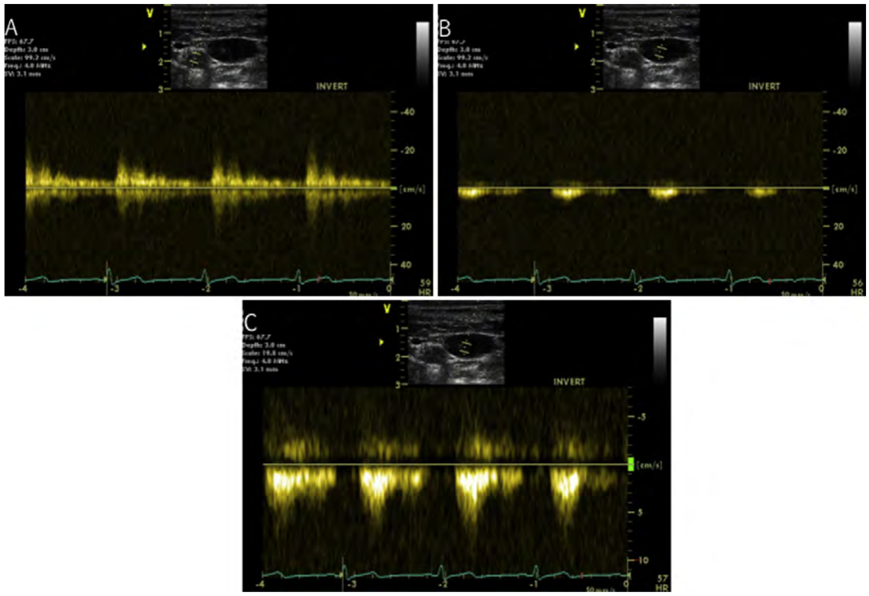

Figure 6 Vessel identification with pulsed-wave Doppler will distinguish artery **(A)** from vein **(B)** at a Nyquist limit of ±50 cm/sec. Arterial blood flow has a predominately systolic component and higher velocity **(A)** compared with venous blood flow **(B,C)**, which has systolic and diastolic components and much lower velocity, better delineated with a lower Nyquist scale (±9 cm/sec) **(C)**.

Figure 7 Variable overlap between CA and IJ vein. *RIJV*, Right IJ vein. *Adapted from J Vasc Interv Radiol*.[24]

the vessel. Difficult catheterization may benefit from a second person with sterile gloves and gown assisting the primary operator by either holding the transducer or passing the guide wire.

6. VESSEL IDENTIFICATION

Morphologic and anatomic characteristics can be used to distinguish a vein from an artery with 2D ultrasound. For example, the IJ vein has an elliptical shape and is larger and more collapsible with modest external surface pressure than the carotid artery (CA), which has rounder shape, thicker wall, and smaller diameter (Figure 4). The IJ vein diameter varies depending on the position and fluid status of the patient. Patients should be placed in Trendelenburg position to increase the diameter of the jugular veins[14,15] and reduce the risk for air embolism when cannulating the SC vein, unless this maneuver is contraindicated. A Valsalva maneuver will further augment their diameter[15] and is particularly useful in hypovolemic patients. Adding Doppler, if available, can further distinguish whether the vessel is a vein or an artery. Color flow Doppler demonstrates pulsatile blood flow in an artery in either SAX or LAX orientation. A lower Nyquist scale is typically required to image lower velocity venous blood flows. At these reduced settings, venous blood flow is uniform in color and present during systole and diastole with laminar flow, whereas arterial blood flow will alias and be detected predominantly during systole (Figure 5) in patients with unidirectional arterial flow (absence of aortic regurgitation). A small pulsed-wave Doppler sample volume within the vessel lumen displays a characteristic systolic flow within an artery, while at the same velocity range displays biphasic systolic and diastolic flow and reduced velocity in a vein. A lower pulsed-wave Doppler velocity range makes this distinction more apparent (Figure 6).

Misidentification of the vessel with ultrasound is a common cause of unintentional arterial cannulation. Knowledge of the relative anatomic positions of the artery and vein in the particular location selected for cannulation is essential and is discussed below in the specific sections. Ultrasound images of veins and arteries have distinct characteristics. Veins are thin walled and compressible and may have respiratory-related changes in diameter. In contrast, arteries are thicker walled, not readily compressed by external pressure applied with the ultrasound probe, and pulsatile during normal cardiac physiologic conditions. Obviously, arterial pulsatility cannot be used to identify an artery during clinical conditions such as cardiopulmonary bypass, nonpulsatile ventricular circulatory assistance, and cardiac or circulatory arrest. Confirmation of correct catheter placement into the intended vascular structure is covered later in this document.

7. INTERNAL JUGULAR VEIN CANNULATION

7.1. Anatomic Considerations

The IJ is classically described as exiting the external jugular foramen at the base of the skull posterior to the internal carotid and coursing toward an anterolateral position (in relation to the carotid) as it travels caudally. Textbook anatomy does not exist in all adult and pediatric patients. Denys and Uretsky[16] showed that the IJ was located

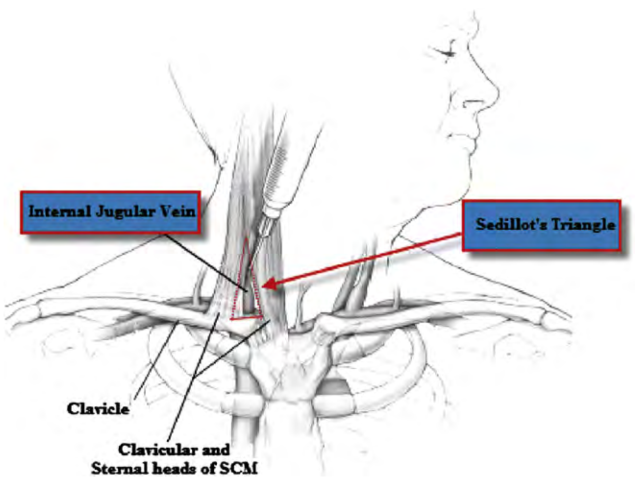

Figure 8 External landmarks for IJ cannulation. *SCM*, Sternocleidomastoid muscle. *Modified from N Engl J Med*.[4]

anterolateral to the CA in 92%, >1 cm lateral to the carotid in 1%, medial to the carotid in 2%, and outside of the path predicted by landmarks in 5.5% of patients. The anatomy of the IJ is sufficiently different among individual patients to complicate vascular access with a "blind" landmark method (Figure 7). Therefore at a minimum, a clear and intuitive advantage of using static ultrasound imaging for skin marking is the ability to identify patients in whom the landmark technique is not likely to be successful.

7.2. Cannulation Technique

The traditional approach to IJ vein cannulation uses external anatomic structures to locate the vein. A common approach identifies a triangle subtended by the two heads of the sternocleidomastoid muscle and the clavicle (Figure 8). A needle placed at the apex of this triangle and directed toward the ipsilateral nipple should encounter the IJ 1.0 to 1.5 cm beneath the skin surface. The use of external landmarks to gain access to the central venous system is considered a safe technique in experienced hands. A failure rate of 7.0% to 19.4%[17] is due partly to the inability of external landmarks to precisely correlate with the location of the vessel.[18] Furthermore, when initial landmark-guided attempts are unsuccessful, successful cannulation diminishes to <25% per subsequent attempt.[19] Additionally, there exists a strong direct correlation between the number of attempts and the incidence of complications, increasing patient anxiety and discomfort, and potentially delaying monitoring and infusion of fluids or medications necessary for definitive care. These are important quality of care issues that must be considered when choosing the best technique for central venous access.

Many studies have shown a clear advantage of ultrasound guidance over landmark guidance for IJ central venous cannulation.[8,12,13,19-22] Troianos *et al.*[19] demonstrated that the overall success rate of central venous cannulation could be improved from 96% to 100% with the use of ultrasound. This may not seem significant until one considers the improved first attempt success rate (from 54% to 73%), decreased needle advances (from 2.8 to 1.4 attempts), decreased time to cannulation (from 117 to 61 sec), and lower rate of arterial punctures (from 8.43% to 1.39%).

Several ultrasound studies have elucidated the anatomic relation between the IJ and CA, particularly in terms of vessel overlap.[23-27] Sulek *et al.*[25] prospectively examined the effect of head position on the relative position of the CA and the IJ. The percentage of overlap between the IJ and the CA increased as the head was rotated contralaterally from neutral (0°) to 40° to 80°. Troianos *et al.*[23] found >75% overlap among 54% of all patients whose heads were rotated to the contralateral side (image plane positioned in the direction of the cannulating needle; Figure 9). Additionally, two thirds of older patients (age ≥ 60 years) had >75% overlap of the IJ and CA. Age was the only demographic factor that was associated with vessel overlap. The concern is that vessel overlap increases the likelihood of unintentional CA puncture by a through-and-through puncture of the vein. The accidental penetration of the posterior vessel wall can occur despite the use of ultrasound when the SAX imaging view is used for guidance.[26] Typically, the anterior wall of the vein is compressed as the needle approaches the vein (Figure 10). The compressive effect terminates as the needle enters the vein (heralded by the aspiration of blood into the syringe) and the vessel assumes its normal shape. A low-pressure IJ may partially[14] or completely compress during needle advancement, causing puncture of the anterior and posterior walls without blood aspiration into the syringe.[26-28] IJ-CA overlap increases the possibility of unintentional arterial puncture as the "margin of safety" decreases. Some authors have describe the "margin of safety" as the distance between the *midpoint* of the IJ and the *lateral border* of the CA. This zone represents the area of nonoverlap between the IJ and CA. The margin of safety decreases, and the percentage overlap increases from 29% to 42% to 72% as the head is turned to the contralateral side from 0° (neutral) to 45° to 90°, respectively.[29] Vessel overlap increasing with head rotation is most apparent among patients with increased body surface areas (>1.87 m^2) and increased body mass indexes (>25 kg/m^2).[27] Ultrasound can be used to alter the approach angle to avoid this mechanism of CA puncture by directing the advancing needle away from the CA (Figure 11).[30] Vascular anomalies and anatomic variations of the IJ and surrounding tissues have been observed in up to 36% of patients.[31] Ultrasound identifies the vein size and location, anomalies, and vessel patency, thus avoiding futile attempts in patients with absent or thrombosed veins and congenital anomalies such as persistent left superior vena cava. Denys *et al.*[20] observed small fixed IJs in 3% of patients. An ultrasound vein diameter < 7 mm (cross-sectional area < 0.4 cm^2) is associated with decreased cannulation success,[32,33] prompting redirection to another access site, thus reducing cannulation time and patient discomfort.[24] Ultrasound also identifies disparity in patency and size between the right IJ and the left IJ (the right IJ usually larger than the left IJ).[33-36] Maneuvers that increase the size of the IJ and thus potentially improve the cannulation success include the Valsalva maneuver (Figure 12) and the Trendelenburg position.[14,15,34]

7.3. Complications

Several factors contribute to the success rate, risk, and complications associated with central venous cannulation, including patient characteristics, comorbidities, and access site. Although the landmark method is associated with an arterial puncture risk of 6.3% to 9.4% for the IJ, 3.1% to 4.9% for the SC, and 9.0% 15.0% for the FV,[4,19,34] Ruesch *et al.*[37] demonstrated a higher incidence of arterial puncture during attempted IJ versus SC central venous access. Obese patients with their attendant short thick necks and others with obscured external landmarks derive a particular benefit from

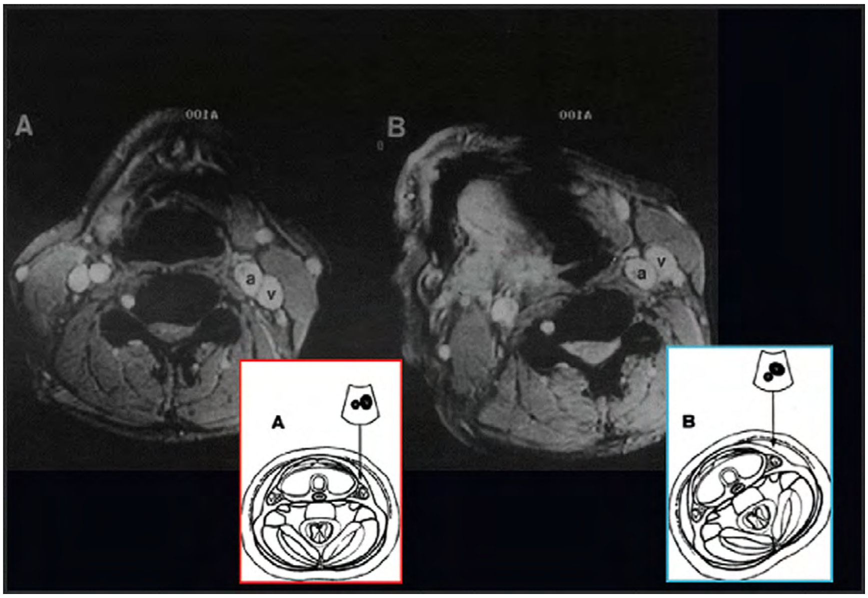

Figure 9 Magnetic resonance imaging of neck anatomy. Contralateral turn of the neck increases the overlap between IJ vein (v) and CA (a). From *Anesthesiology*.[23]

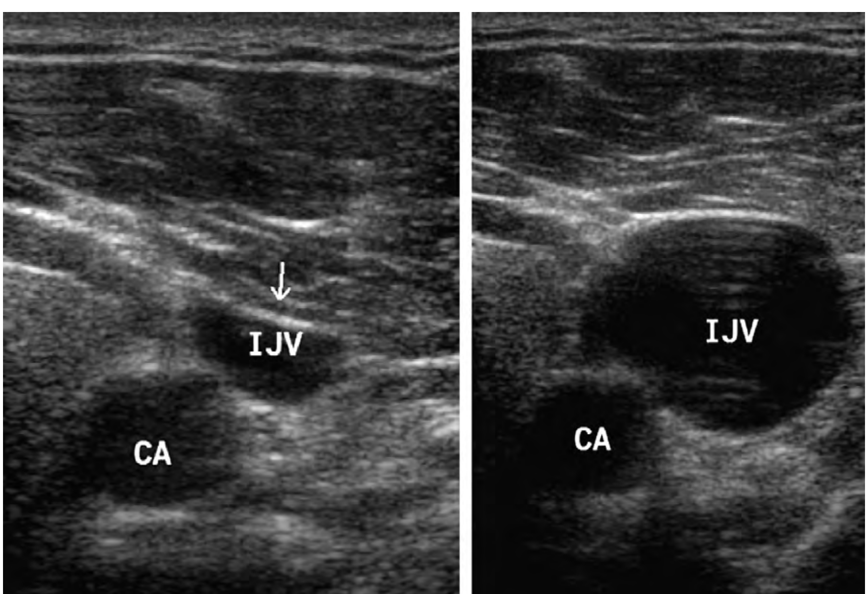

Figure 10 The anterior wall of the IJ vein (IJV) recesses as the needle approaches the vein (*left*). The vein assumes its normal shape after the needle penetrates its wall (*right*).

ultrasound guidance[38] by decreasing the incidence of arterial puncture, hematoma formation, and pneumothorax.[39] The recognition and avoidance of pleural tissue during real-time ultrasound imaging could potentially decrease the risk for pneumothorax for approaches that involve a needle entry site closer to the clavicle. High-risk conditions include hemostasis disorders,[40] uncooperative or unconscious patients, critically ill patients[21] who may be hypovolemic,[34] and patients who have had multiple previous catheter insertions. Oguzkurt *et al.*[41] prospectively reviewed 220 temporary IJ dialysis catheters placed sonographically by interventional radiologists in 171 high-risk patients (27.7% with bleeding tendency, 10% uncooperative, 2% obese, 37% with previous catheters, and 21.3% with bedside procedure because their medical conditions were not suitable for transport to the radiology suite). The success rate was 100%, with only seven complications among the 171 procedures. The carotid puncture rate was 1.8%, while oozing around the catheter, small hematoma formation, and pleural puncture without pneumothorax occurred at rates of 1.4%, 0.4%, and 0.4%, respectively.

In summary, ultrasound imaging of the IJ and surrounding anatomy during central venous cannulation both facilitates identification of the

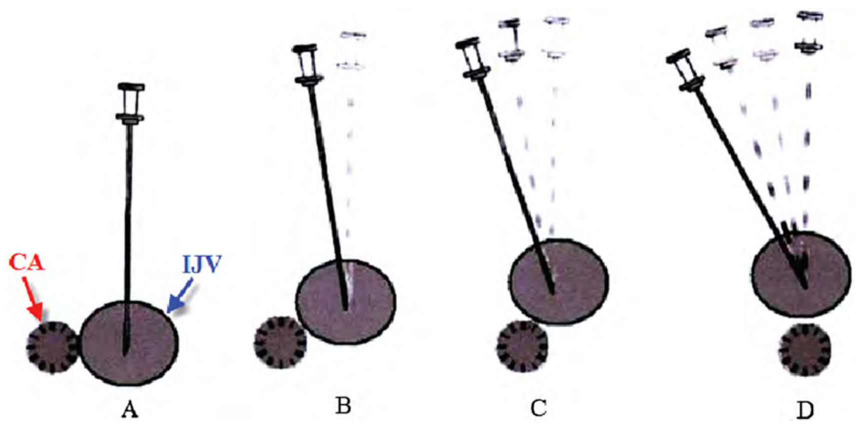

Figure 11 Under ultrasound guidance, the needle approach to the IJ vein (IJV) can be altered to avoid CA puncture. From *Cardiovasc Intervent Radiol*.[30]

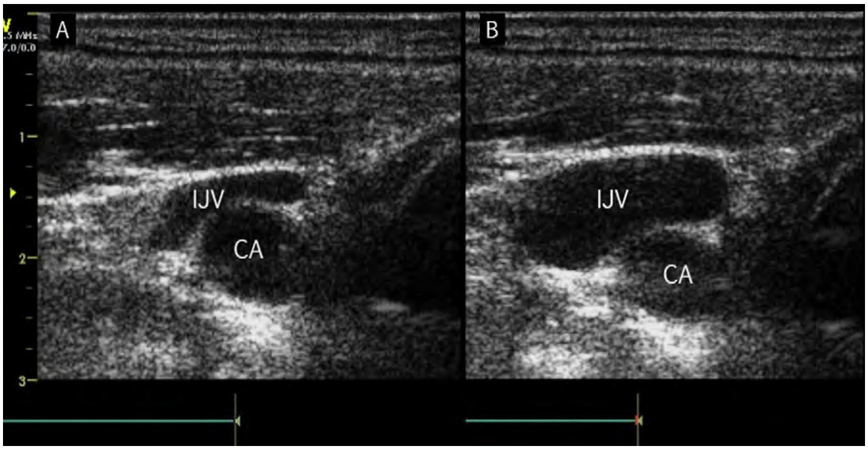

Figure 12 The size of the IJ vein (IJV) is increased with a Valsalva maneuver **(B)** compared with apnea **(A)**.

vein and improves first-pass cannulation but also decreases the incidence of injury to adjacent arterial vessels.

7.4. Recommendation for IJ Vein Cannulation

It is recommended that properly trained clinicians use real-time ultrasound during IJ cannulation whenever possible to improve cannulation success and reduce the incidence of complications associated with the insertion of large-bore catheters. This recommendation is based on category A, level 1 evidence.

The writing committee recognizes that static ultrasound (when not used in real time) is useful for the identification of vessel anatomy by skin-marking the optimal entry site for vascular access and for the identification of vessel thrombosis and is superior to a landmark-guided technique.

8. SUBCLAVIAN VEIN CANNULATION

8.1. Anatomic Considerations

Landmark-guided SC vein access uses the anatomic landmarks of the midpoint of the clavicle, the junction between the middle and medial border of the clavicle, and the lateral aspect of a tubercle palpable on the medial part of the clavicle. The most common 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. The degree of lateral displacement of the entrance point is based on the patient's history and anatomic considerations.

8.2. Cannulation Technique

The landmark-guided approach to the central venous circulation via the SC vein is generally considered by many clinicians to be the simplest method to access this vein. Several million SC vein catheters are placed each year in the United States. The risk factors for complications and failures are poorly understood, with the exception of physician experience. Advantages of using the SC vein for central venous access include consistent surface anatomic landmarks and vein location, patient comfort, and lower potential for infection.[42] In contrast to attempted IJ vein cannulation, in which unintentional injury to the adjacent CA can compromise circulation to the brain, unintentional injury to the adjacent SC artery during SC vein cannulation carries a less morbid sequela. The physician's experience and comfort level with the procedure are the main determinants for successful placement of a SC vein catheter, when there are no other patient-related factors that increase the incidence of complications. The SC

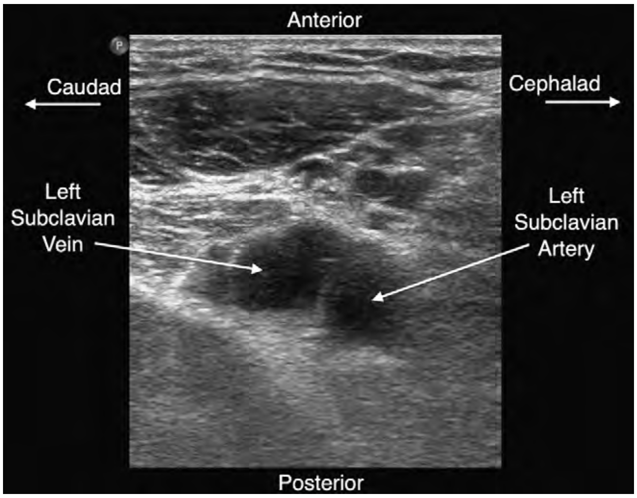

Figure 13 Two-dimensional ultrasound image of the left SC vein and left SC artery obtained from the left side of the patient during ultrasound-guided cannulation of the left SC vein.

vein may be cannulated from a supraclavicular or an infraclavicular approach. The infraclavicular approach is the most common approach and hence is the focus of this discussion. The supraclavicular approach (without ultrasound) has largely been abandoned because of a high incidence of pneumothorax. As experience with ultrasound-guided regional anesthesia for upper extremity blocks has increased imaging and identification of the supraclavicular vessels and nerves, clinicians are gaining more familiarity with imaging the supraclavicular approach to the SC vein using ultrasound for vessel cannulation. Whether this approach will continue to gain popularity remains to be demonstrated.

Tau *et al.*[43] analyzed anatomic sections of the clavicle and SC vein and determined that the supine position with neutral shoulder position and slight retraction of the shoulders was the most effective method to align the vein for a landmark-based technique. Although many clinicians place patients in the Trendelenburg (head-down) position to distend the central venous circulation, there is less vessel distention of the SC vein than the IJ vein because the SC vein is fixed within the surrounding tissue, so relative changes in size are not realized to the same degree as with the IJ vein. Thus, the primary reason for the Trendelenburg position is to reduce the risk for air embolism in spontaneously breathing patients.

Ultrasound-directed vascular cannulation may lead inexperienced operators to use needle angle approaches that lead to an increased risk for complications. It is important that traditional approaches and techniques are not abandoned with ultrasound guidance, particularly during cannulation of the SC vein, in which a steeper needle entry angle may lead to pleural puncture. The needle is directed toward the sternal notch in the coronal plane. The bevel of the needle should be directed anteriorly during insertion and gentle aspiration applied with a syringe, as the needle enters the skin at a very low (nearly parallel) angle to the chest wall. An increased or steeper angle increases the likelihood of creating a pneumothorax. The needle bevel may be turned caudally upon venopuncture to direct the guide wire toward the right atrium. The wire is advanced, leaving enough wire outside the skin for advancement of the entire catheter length over the wire (i.e., the wire should extend beyond the catheter outside the skin). The electrocardiogram should be closely monitored for ectopy that may occur when the wire is advanced into the right atrium or right ventricle. Chest radiography is mandatory not only to confirm proper line placement but also to rule out pneumothorax.

Similar preparation of the patient occurs with ultrasound-guided cannulation as with the landmark-guided approach with respect to positioning, skin preparation, and vascular access kits. The use of a smaller footprint transducer probe for SC vein access for real-time ultrasound imaging is recommended because larger probes make imaging of the vein more challenging. It is generally more difficult to position the larger footprint probe between the clavicle and rib to obtain an adequate SC vein image. Despite some loss of resolution in the far field that inherently occurs with phased-array transducers, smaller probes may allow better maneuverability underneath the clavicle. Similar to the landmark technique, the middle third of the clavicle is chosen as the site used for ultrasound imaging and subsequent needle insertion. The transducer is oriented to image the SC vein in the SAX view with a coronal imaging plane. The vein appears as an echo-lucent structure beneath the clavicle (Figure 13). It is important to distinguish between pulsatility on the vein due to respiratory variation and pulsatility of the artery. Confirmation of the venous circulation can be facilitated by the injection of agitated saline "echo contrast" into a vein of the ipsilateral arm (if available) with subsequent imaging of the microbubbles in the vein. Confirmation can also be achieved by addition of color flow Doppler to the ultrasound assessment. When positioning the transducer marker toward the left shoulder (during right SC vein cannulation), arterial flow will be the color that indicates flow away from the transducer, while venous flow will be the color that indicates flow toward the transducer. It is important to ensure correct transducer orientation before using color flow Doppler to determine the identification of artery or vein. Considerable skin pressure is required to obtain adequate imaging planes (windows) that may incur some patient discomfort.

A prospective randomized SC vein cannulation study favored the ultrasound-guided over the landmark-guided approach, with a higher success rate (92% vs 44%), fewer minor complications (1 vs 11), and fewer venopunctures (1.4 vs 2.5) and catheter kits (1.0 vs 1.4) per attempted cannulation.[44] A more recent study of 1,250 attempted central venous catheter placements included 354 SC vein attempts. The incidence and success rates with ultrasound guidance during central venous catheter placement supported the impression of many clinicians that the added benefit of ultrasound for cannulation of the SC vein is less than the benefit of ultrasound during attempted cannulation of the IJ vein. Although ultrasound use was uncommon for cannulation of the SC vein, either as the primary technique or as a rescue technique, success rates were high with ultrasound guidance even when surface techniques were unsuccessful.[45]

8.3. Complications

Complication rates for the landmark-guided approach to SC vein cannulation are 0.3% to 12% and include pneumothorax, hematoma, arterial puncture, hemothorax, air embolism, dysrhythmia, atrial wall puncture from the wire, lost guide wire, anaphylaxis in patients who are allergic to antibiotics upon the insertion of an antibiotic-impregnated catheter, catheter malposition, catheter in the wrong vessel, and thoracic duct laceration (left side only).[46]

Kilbourne *et al.*[47] reported the most common errors during failed SC vein catheter placement attempts by resident physicians were inadequate landmark identification, improper insertion position, advancing the needle through periosteum, a shallow or cephalad needle angle, and loss of intravenous needle position while attempting to place the guide wire. Factors associated with cannulation failure were previous major surgery, radiation therapy, prior catheterization, prior attempts at catheterization, high body mass index, more than two needle passes, only 1 year of postgraduate training, lack of classic anatomy, and previous first rib or clavicle fracture. If only one needle pass was attempted, the failure rate for subsequent catheter placement was 1.6%, compared with 10.2% for two passes and 43.2% for three or more passes. In the 8.7% of patients in whom initial attempts at catheterization failed, subsequent attempts by second physicians were successful in 92%, with a complication rate of 8%.[47] Similar success was demonstrated in a study of patients undergoing SC vein cannulation with and without ultrasound guidance.[48] The ultrasound group had fewer attempts, better patient compliance, and a zero incidence of pneumothorax, while the incidence of pneumothorax in the landmark group was 4.8%.

Identification of risk factors before catheter insertion may decrease complication rates by altering the approach to include ultrasound guidance. Additionally, in patients with body mass indexes > 30 kg/m^2 or < 20 kg/m^2, history of previous catheterization, prior surgery, or radiotherapy at the site of venous access, experienced physicians should attempt catheter placement rather than physicians who are learning the procedure.

Obese patients with their attendant short thick necks and others with obscured external landmarks derive a particular benefit from ultrasound guidance[38] by decreasing the incidence of arterial puncture, hematoma formation, and pneumothorax.[39] Mansfield *et al.*[46] noted that a body mass index > 30 kg/m^2 resulted in a cannulation failure rate of 20.1% for attempted SC vein cannulation. These investigators found no benefit of ultrasound guidance for SC vein catheterization, but in comparing ultrasound with landmark-guided techniques, Hind *et al.*'s[22] meta-analysis found that the landmark technique had a higher relative risk for failed catheter placements and mean time to successful cannulation. As operators gain more experience with the use of ultrasound for guiding catheterization and diagnostic procedures, it is likely that an incremental benefit with the use of ultrasound for SC vein cannulation will also be realized. Orihashi *et al.*[49] found a benefit to the use of ultrasound in SC venopuncture in a small cohort of 18 patients. Although Gualtieri *et al.*[44] demonstrated improved success and fewer minor complications with use of ultrasound for SC vein cannulation, there were no major complications in either group. The overwhelming evidence in the literature supports the routine use of ultrasound for IJ access, but the data on the SC approach warrant consideration of anatomic landmarks and interference of the clavicle as impediments to the use of real-time ultrasound for this approach.

8.4. Recommendation for SC Vein Cannulation

Current literature does not support the routine use of ultrasound for uncomplicated patients undergoing SC vein cannulation. Individual operators should not attempt cannulation more than twice, as the incidence of complication, particularly pneumothorax, rises significantly with additional attempts. *High-risk patients may benefit from ultrasound screening of the SC vein before attempted cannulation to identify vessel location and patency and to specifically identify thrombus before attempted cannulation.* The recommendation for ultrasound guidance during SC vein cannulation is based on category A (supportive), level 3 evidence.

9. FEMORAL VEIN CANNULATION

9.1. Anatomic Considerations

The femoral vessels are often used to provide access for left-sided and right-sided cardiac procedures. In addition, the common FV is often used for central venous access during emergency situations,[50] because of its relative safe and accessible location with predictable anatomic landmarks (i.e., lying within the femoral triangle in the inguinal-femoral region). A detailed understanding of the regional anatomy is important for performing FV cannulation using a landmark-guided technique.

The common femoral artery and FV lie within the femoral triangle in the inguinal-femoral region. The superior border of this triangle is formed by the inguinal ligament, the medial border by the adductor longus muscle, and the lateral border by the sartorius muscle. Another important landmark is the femoral artery pulse, because the common FV typically lies medial to the common femoral artery within the femoral sheath. The femoral artery lies at the midpoint of the inguinal ligament connecting the anterior superior iliac spine to the pubic tubercle, while the common FV is typically located medial to the common femoral artery. This side-by-side relationship of the common femoral artery and FV occurs in close proximity to the inguinal ligament, but significant vessel overlap may occur, particularly in children.[51,52] In addition, it is essential to understand that the relationship between the inguinal crease and the inguinal ligament is highly variable, so the inguinal crease is not always a useful surface landmark.[53]

The femoral site has numerous advantages both with elective vascular access and in critically ill patients. The femoral site remains the most commonly accepted site for vascular access for cardiac procedures because of relatively short access times and few complications. For critically ill patients, it is relatively free of other monitoring and airway access devices, allowing arm and neck movement without impeding the access line. Femoral access avoids the risks of hemothorax and pneumothorax, which is particularly important in patients with severe coagulopathy or profound respiratory failure. In addition, the femoral site permits cannulation attempts without interruption of cardiopulmonary resuscitation during cardiac arrest. However, the femoral approach is associated with complications, including bleeding and vascular injury, such as pseudoaneurysms, arteriovenous fistulas and retroperitoneal bleeding (see section 9.3, "Complications").

9.2. Cannulation Technique

Similar to other central venous cannulation sites, the modified Seldinger technique is most common method used to access the common FV.[3] The procedure requires patient positioning with the hip either in the neutral position or with slight hip abduction and external rotation. Abduction and external rotation increases the accessibility of the common FV from 70% to 83% in adults and increases the vessel diameter in children compared with a straight-leg approach.[54,55] The reverse Trendelenburg position increases common FV cross-sectional area by >50%.[56]

The surface landmarks are identified and the FV located by palpating the point of maximal femoral artery pulsation 1 to 2 cm below the midpoint of the inguinal ligament.[50,57] The FV is located by inserting a needle 1cm medial to the maximal pulsation, directed cephalad and medially at a 45° angle to the skin.

Many clinicians advocate the use of a small (25-gauge) exploratory or "finder" needle to initially identify the vein location. A larger

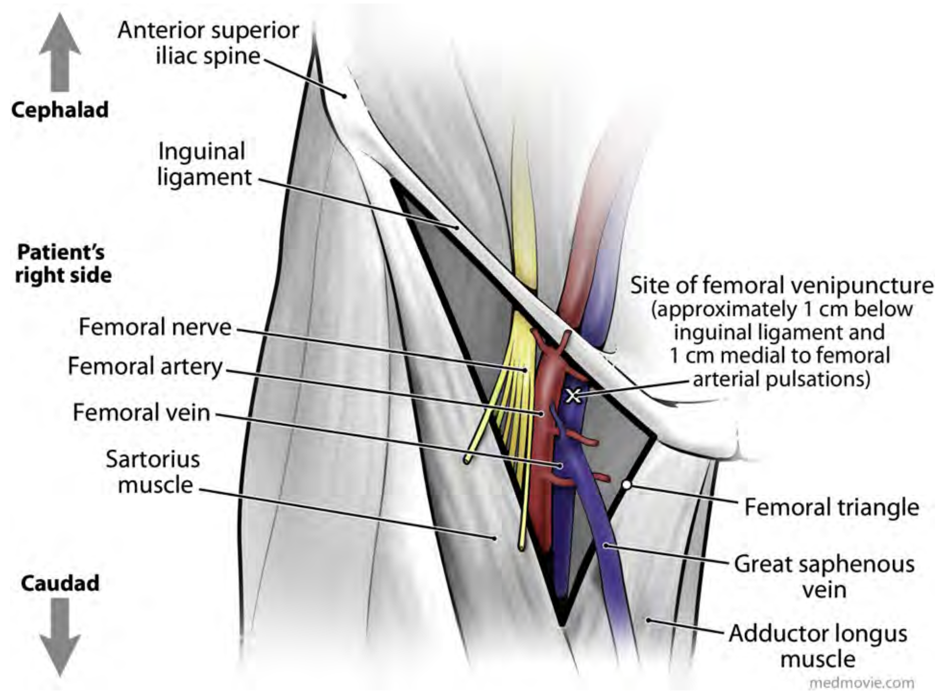

Figure 14 Femoral vascular anatomy illustrating that the femoral nerve is lateral, while the FV is medial to the femoral artery; top of the figure is cephalad.

20-gauge to 22-gauge needle is subsequently placed directly adjacent to the finder needle along a parallel path to the FV. The vein is normally 2 to 4 cm beneath the skin in most adults.

9.3. Complications

There are a number of complications associated with FV cannulation.[58,59] Infection remains one of the most common problems with femoral catheters because of their close proximity to the perineal region, which is the reason that this site is not typically recommended for long-term catheters. Some investigators, who have demonstrated that the incidence of catheter-related bloodstream infection with femoral catheters is not significantly different from the incidence with the supraclavicular access sites, dispute this risk.[60,61] The number of attempts to gain access may increase the risk for infection but seems to be primarily related to the duration of catheter use at the site. The complications of FV cannulation directly related to catheter insertion technique are most often due to unintentional femoral artery puncture. Because of the close proximity to the common femoral artery, arterial puncture may occur if the needle is directed too laterally. This may result in hematoma, retroperitoneal bleeding, pseudoaneurysm, and arteriovenous fistula formation. In addition, thrombus may develop within the FV or iliac vein because of the presence of the catheter or during compression upon removal. If the needle is directed too laterally, the patient may experience paresthesia with the potential for femoral nerve injury. Other rare but serious complications include bowel penetration and bladder puncture.

Complications occur despite the optimal use of surface landmark-guided techniques (Figure 14). Ultrasound imaging at the femoral site has demonstrated that surface anatomic landmarks are less useful in projecting the underlying anatomy, although surface anatomy is more reliable when the cannulation site is closer to the inguinal ligament.[21] Ultrasound-guided femoral artery and FV cannulation most likely reduces the incidence of complications because the anatomy is better defined.[62] Iwashima *et al.*[63] and Seto *et al.*[64] demonstrated reduction in vascular-related complications due to inadvertent femoral artery or FV puncture with the use of ultrasound guidance during femoral vessel cannulation.

9.4. Recommendation for FV Cannulation

The scientific evidence for real-time ultrasound-guided FV cannulation is category C, level 2: equivocal with insufficient scientific evidence to support a recommendation for routine use. In addition, complications during FV cannulation are less severe than those that occur with SC and IJ vein cannulation. *It is therefore the recommendation of this writing committee that real-time ultrasound be used only for examining the FV to identify vessel overlap and patency when feasible.*

10. PEDIATRIC ULTRASOUND GUIDANCE

The United Kingdom's National Institute for Health and Clinical Excellence guidelines recommend real-time use of ultrasound during central vein cannulation in all patients, children and adults.[5] Data to support this practice in pediatrics are limited. In a meta-analysis that included pediatric studies, Hind *et al.*[22] confirmed a higher success rate with 2D ultrasound compared with anatomic landmark techniques for the IJ vein cannulation among infants. Hosokawa *et al.*[13] demonstrated in a randomized trial of 60 neonates weighing <7.5 kg that real-time ultrasound reduced the cannulation time and needle passes necessary for cannulation of the right IJ vein compared with a surface-marking technique. Grebenik *et al.*[65] demonstrated that

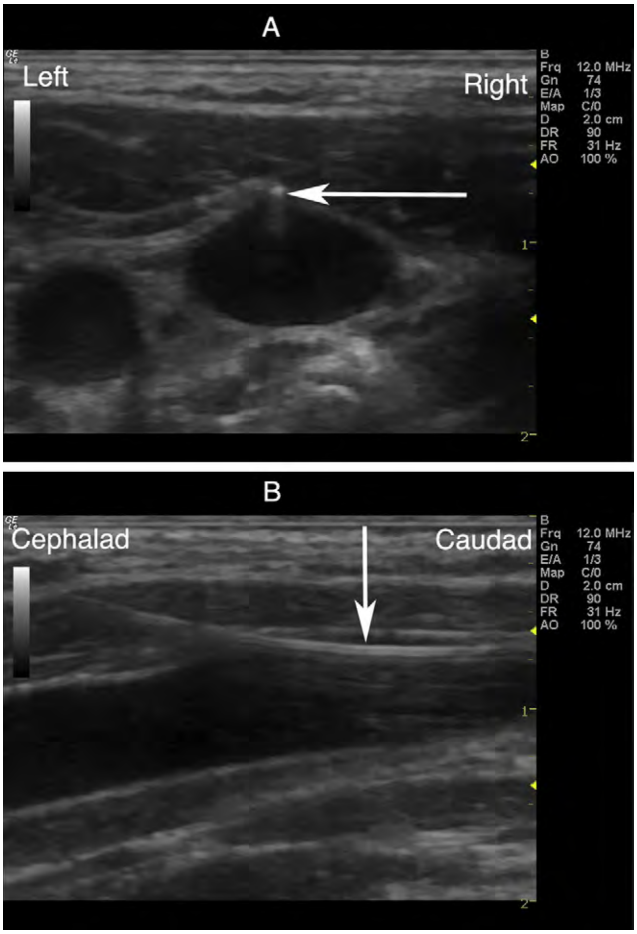

Figure 15 The guide wire (*arrow*) is demonstrated entering the right IJ vein, in SAX **(A)** and LAX **(B)** views.

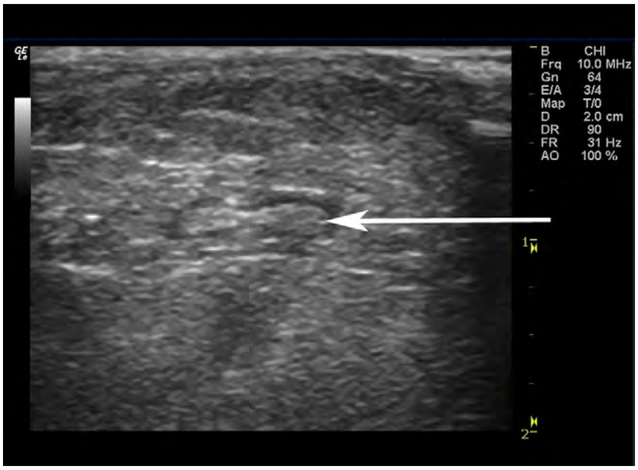

Figure 16 Left FV completely occluded by thrombus (*arrow*).

use of ultrasound during IJ vein cannulation in children improved success rate and lowered the incidence of carotid puncture. Some have suggested that use of ultrasound by experienced operators during central venous cannulation in children may be an initial hindrance.[13,65] Avoiding compression of small veins by the ultrasound probe in real time takes experience to overcome. As noted by Hosokawa *et al.*, most studies demonstrating a positive correlation with ultrasound use tend to involve operators in training (e.g., fellows), whereas negative correlation studies usually involves "*experienced*" anesthesiologists (i.e., the "can't teach a old dog new tricks" phenomenon).

Despite governmental recommendations and improvement in patient safety, the adoption of ultrasound for central venous placement by practitioners has been slow. Tovey and Stokes's[66] survey showed that ultrasound was used in only 25% of pediatric patients undergoing elective surgery. In addition, three quarters of the respondents were not specifically trained in the technique. This is consistent with the National Institute for Health and Clinical Excellence guideline 49 follow-up survey, which demonstrated that only 28% of the anesthesiologists surveyed were compliant with the guidelines.[67] Two years after the guidelines were instituted, almost half of those surveyed did not have access to the ultrasound technology, and two thirds lacked necessary training in the technique.

10.1. Cannulation Technique for Pediatric Patients

10.1.1. IJ Vein. The most frequently accessed central vein using ultrasound in pediatric patients is the right IJ vein. Ultrasound allows easy visualization of the vessel, demonstrating its position, its patency and the presence of thrombus.[68] Hanslik *et al.*[69] demonstrated a 28% incidence of deep venous thrombosis in a series of children with short-term central venous line placement. This is problematic in children requiring frequent central venous access, as in the pediatric cardiac surgical population.

Although one meta-analysis involving five ultrasound studies performed solely among infants and children did not demonstrate an effect on failure rate, nor the rate of carotid puncture, hematoma, hemothorax, or pneumothorax, the studies included in this meta-analysis used ultrasound for "prelocation" and/or guidance.[70] Ultrasound was not used in real time for all patients in this meta-analysis. The council recommends real-time use to derive the most benefit from ultrasound guidance.

Liver compression may be used to increase IJ size in pediatric patients.[34] Alternatively, the Trendelenburg position can be used. With the patient in this head-down position, the sterile probe is placed transverse to the neck, creating a cross-sectional view of the vessels. The right IJ vein should lie lateral to the right CA and be easily compressible by the ultrasound probe (Figure 4). The neck should be scanned with ultrasound to identify the access point that is most conducive to cannulation of the vein, while avoiding the artery. This may or may not be the same point identified with landmarks alone. The probe should also be positioned to allow the needle to enter at an angle away from the carotid. Shorter needles and a more superior entry point may reduce the risk for pleural or great vessel puncture, which is a particularly important concern for pediatric patients.

The cannulating needle or catheter should be observed entering the vessel. The technique of observing vessel entry in real time is critical to avoid the complications associated with the landmark-guided techniques. The guide wire is inserted using the Seldinger technique, and its presence within the vein lumen and its absence within the artery are confirmed in two image planes, as demonstrated in Figure 15, before dilation and placing the central venous catheter.

10.1.2. Femoral Vessels. Both the FV and the femoral artery are frequently used in neonates for access during cardiac procedures. Hopkins *et al.*[55] recently defined the anatomic relationship between

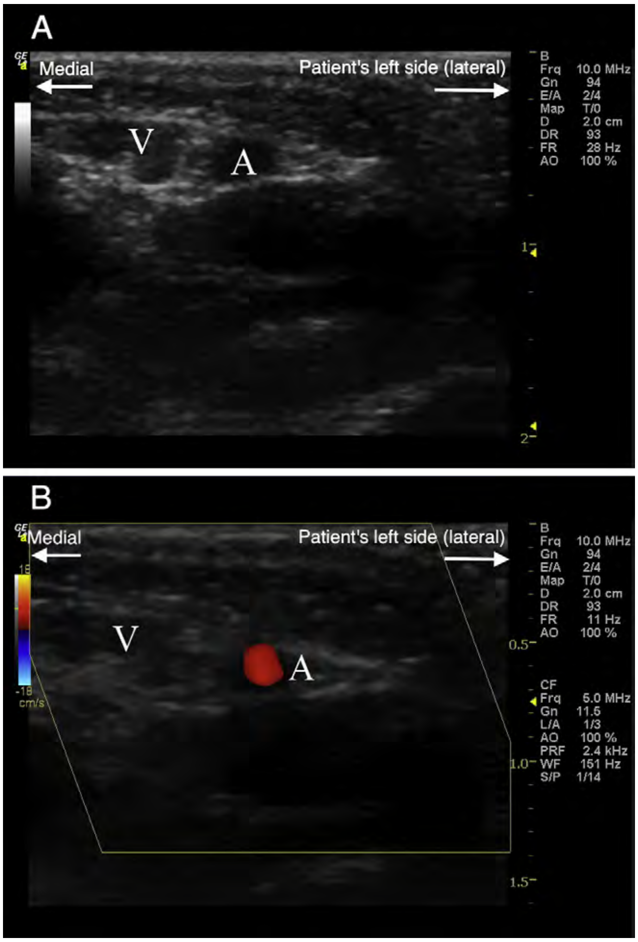

Figure 17 **(A)** Left femoral vessels in a 3-kg neonate demonstrating the small size of the FV (V) and femoral artery (A). **(B)** Color flow Doppler demonstrating a velocity signal in the femoral artery (A) and FV (V). The sonographer is positioned at the patient's lower extremities and facing cephalad. Note depth scale along side of image: 2.0 cm for 2D image and 1.5 cm for color Doppler image.

the common femoral artery and common FV when a child is placed in a frog-leg position versus a straight-leg position during attempted cannulation. They demonstrated that the FV was overlapped by the femoral artery in 36% of patients in the straight-leg position and in 45% of patients in the frog-leg position, at the level of the inguinal ligament. The frequency of overlap increased as the vessels were imaged more distally. At 3 cm from the inguinal ligament, the incidence of overlap was 93% and 86% in the straight-leg and frog-leg positions, respectively. This significant overlap provides credibility to the routine use of ultrasound guidance for cannulation, as vessel overlap may increase the risk for complications and is not predictable with surface landmarks alone. Hip rotation with 60° leg abduction decreases femoral artery overlap at the level of the inguinal crease in both infants and children. Thus, the optimal place for FV cannulation in pediatric patients seems to be at the level of the inguinal crease, with 60° leg abduction and external hip rotation.[71] Another frequent problem encountered in neonates is the high incidence of venous and arterial thrombosis (Figure 16) when multiple cardiac catheterization procedures have been performed.

Visualization of the FV in small neonates is improved with several useful maneuvers. First, a small towel or sheet is placed under the child's buttock; second, the child is placed in the reverse Trendelenburg position; and finally, abdominal compression to further expand the vein can be used if necessary. A high-resolution linear-array probe is most frequently used for optimal imaging. Figure 17 demonstrates the common anatomy and small vessels encountered among neonates. Because the vein is more superficial in children, it is important to direct the needle at an angle of <30° with the skin when attempting cannulation in pediatric patients.

Many studies have shown a clear advantage of ultrasound guidance over landmark guidance for FV cannulation. Aouad *et al.*[72] prospectively randomized 48 patients undergoing FV cannulation with a landmark-guided technique compared with real-time ultrasound and demonstrated a shorter time to complete cannulation with ultrasound (155 [46–690] vs 370 [45–1620] sec, $P = .02$). The ultrasound group required fewer needle passes (1 [1–8] vs 3 [1–21], $P = .001$) to successful cannulation and had a greater number of successful cannulations performed on the first needle pass (18 [75%] vs 6 [25%], $P = .001$) compared with the landmark group. The overall success rate was similar in both groups (95.8%), and the incidence of femoral artery puncture was comparable.[72]

In another prospective randomized study, Iwashima *et al.*[63] showed no difference in the overall rate of success of achieving FV access between a landmark-guided approach and an ultrasound approach for pediatric cardiac catheterization. The success rate, defined as achieving access within the first two attempts without femoral artery puncture, was similar in both groups (67.4% for ultrasound guidance vs 59.1% for landmark guidance). The procedure time was not significantly different between groups. There were two FV occlusions detected in the ultrasound group in patients with prior vascular entry. In addition, there was a significant reduction in the complication rate with the use of ultrasound guidance. Unintentional femoral artery puncture occurred in three of 43 patients (7%) in the ultrasound group compared with 14 of 44 patients (31.8%) in the landmark group, for a significantly higher complication rate in the landmark group ($P < .01$).[63]

10.2. Recommendations for Pediatric Patients

It is the recommendation of this writing committee that trained clinicians use real-time ultrasound during IJ cannulation whenever possible to improve cannulation success and reduce the incidence of complications associated with the insertion of large-bore catheters in pediatric patients. This recommendation is based on category A, level 1 supportive literature. *It is also the recommendation of this council that trained clinicians use real-time ultrasound during FV cannulation whenever possible to improve cannulation success and reduce the incidence of complications associated with insertion of large-bore catheters in pediatric patients.* This is a category C, level 2 recommendation.

11. ULTRASOUND-GUIDED ARTERIAL CANNULATION

Arterial access is an important aspect of vascular access and includes the radial, brachial, axillary, femoral, and dorsalis pedis arteries. The preferred site depends on the experience of the operator, availability of the site, and expected duration of access. The advantages of the radial artery are its accessibility, predictable location, and low complication rates associated with both its access and use. It is usually palpable

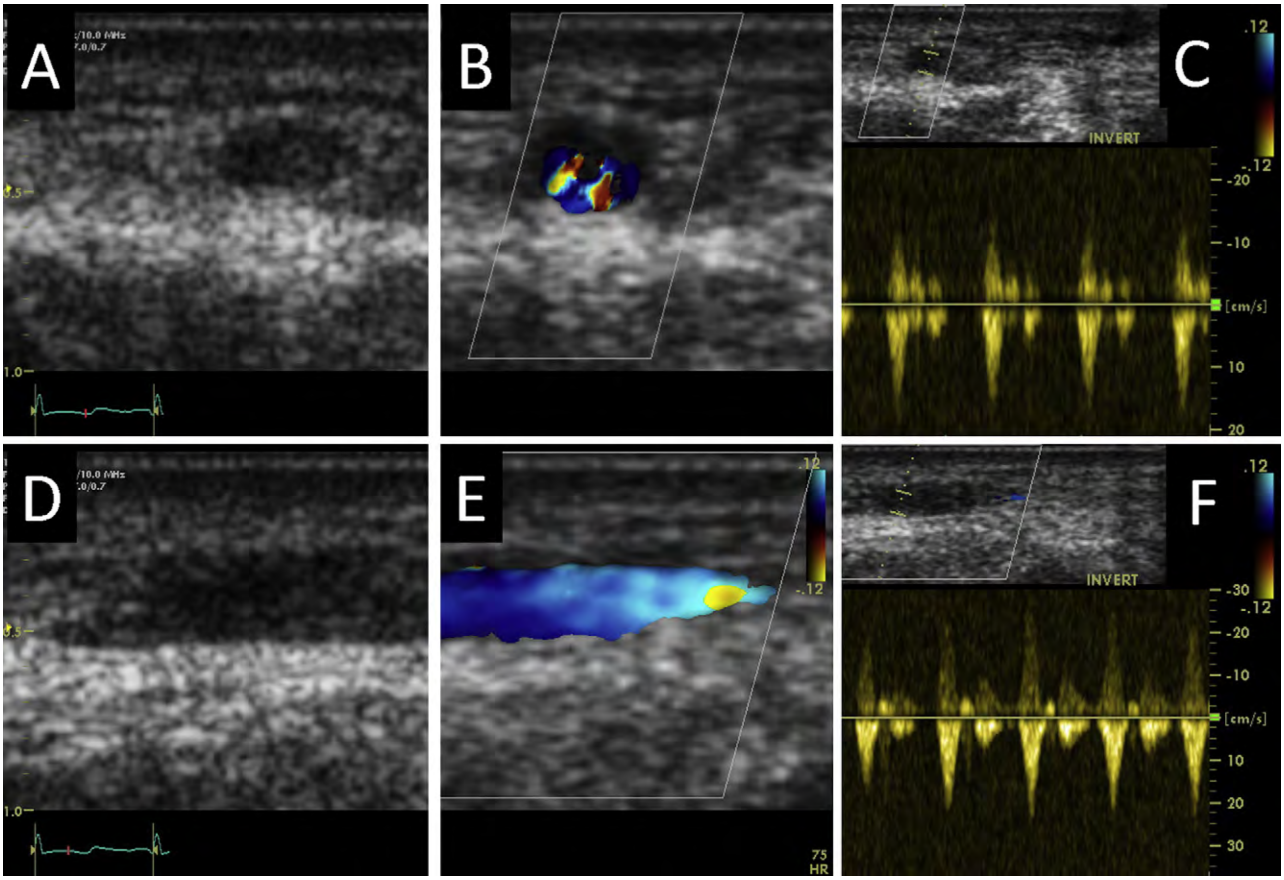

Figure 18 Surface ultrasound imaging of the radial artery with a small probe. Two-dimensional ultrasound in SAX **(A)** and LAX **(D)** orientations. Doppler ultrasound demonstrating systolic flow with color Doppler **(B,E)** and pulsed-wave Doppler in SAX **(C)** and LAX **(F)** orientations, respectively.

among most patients with a pulsatile circulation. Another advantage to using the radial artery as the cannulation site is that this artery is not the sole blood supply to the distal extremity,[73] unlike the axillary, brachial, and femoral arteries. Ultrasound guidance for arterial cannulation improved success and reduced time to cannulation compared with the palpation method in a prospective comparison of ultrasound-guided and blindly placed radial arterial catheters.[74]

Ultrasound can facilitate access to all these arteries but is particularly useful in patients with obesity, altered anatomy, low perfusion, nonpulsatile blood flow, and previously unsuccessful cannulation attempts using a landmark-guided approach.[75] Ultrasound-guided arterial access can be performed at the traditional locations used with landmark-guided approaches but has the added advantage of allowing the use of nontraditional sites of entry where landmarks are not useful. Ultrasound-guided placement for femoral artery catheters is more challenging than FV cannulation because the artery is smaller and not amendable to expansion with positioning or volume loading.

Hypotension, low cardiac output, absent or barely palpable arterial pulse, the presence of arterial spasm or hematoma, and excessive limb circumference are reasons for failure or repeated attempts at arterial cannulation of different sites (radial, brachial, axillary, femoral, dorsalis pedis) when using the palpation or external landmark–based approach.[76] It should be noted, however, that these cannulation conditions may be equally challenging despite ultrasound guidance, because the application of the probe may compress venous structures in the hypovolemic patient.

11.1. Cannulation Technique

As described in detail in the sections describing the technique of venous structure cannulation, arteries appear to be pulsatile on 2D echocardiography and are not fully compressible with external pressure from the transducer (Figures 18A and 18D). The addition of a color flow Doppler sector should demonstrate phasic blood flow in either the SAX (Figure 18B) or the LAX orientation (Figure 18E). The placement of a small sample volume (<0.5 cm) within the lumen of the artery will demonstrate a typical systolic-diastolic pattern of arterial blood flow (Figures 18C and 18F). Scanning both arteries before attempted cannulation should identify the artery with the largest diameter. The real-time guided insertion of the catheter (with or without a guide wire) is preferred over a skin-marking static imaging technique. The transducer is placed inside a sterile sheath, and the operator should observe sterile or aseptic technique. The nondominant hand of the operator holds the ultrasound transducer, while the dominant hand holds the arterial catheter. The catheter-needle system is inserted at an angle of 45° to the skin and is advanced under ultrasound guidance until it is observed entering the vessel, in either the

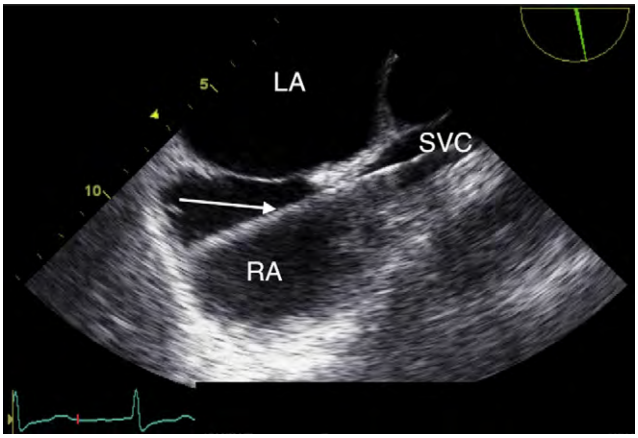

Figure 19 Successful cannulation of the IJ vein with a guidewire shown entering the right atrium (RA) via the superior vena cava (SVC) (midesophageal bicaval view). *LA*, Left atrium.

SAX or the LAX view. The catheter is inserted over the needle or over a guide wire.

11.2. Ultrasound-Guided Arterial Cannulation Versus Palpation

The first-attempt success rate during arterial cannulation is higher when using ultrasound-guided approach compared with palpation alone. In either the emergency room or the operating theater setting, the success rate for the ultrasound-guided approach is in the range of 62% to 87% in adults (compared with 34%–50% for palpation)[74,77,78] and 14% to 67% in the pediatric population (compared with 14%–20% for palpation).[79,80] A recent meta-analysis that included four controlled trials of radial artery cannulation with a total of 311 adult and pediatric patients demonstrated an overall 71% improvement in first-attempt success (relative risk, 1.71; 95% confidence interval [CI], 1.25–2.32).[81]

Seto *et al.*[64] randomized 1,004 patients undergoing retrograde femoral artery cannulation to either fluoroscopic or ultrasound guidance. There was no difference in the primary end point, with similar common femoral artery cannulation rates with either ultrasound or fluoroscopic guidance (86.4% vs 83.3%, $P = .17$). The exception was in the subgroup of patients with common femoral artery bifurcations occurring over the femoral head (82.6% vs 69.8%, $P < .01$). Ultrasound guidance resulted in an improved first-pass success rate (83% vs 46%, $P < .0001$), a reduced number of attempts (1.3 vs 3.0, $P < .0001$), reduced risk for venipuncture (2.4% vs 15.8%, $P < .0001$), and reduced median time to access (136 vs 148 sec, $P = .003$). Vascular complications occurred in seven of 503 patients in the ultrasound group and 17 of 501 in the fluoroscopy group (1.4% vs 3.4%, $P = .04$). Thus, ultrasound guidance improved common femoral artery cannulation rate only in the subset of patients with high common femoral artery bifurcations but reduced the vascular complications in femoral arterial access.

11.3. Recommendation for Arterial Vascular Access

Although ultrasound may identify the presence, location, and patency of arteries suitable for cannulation or vascular access, *the council does not recommend routine real-time ultrasound use for arterial cannulation in general.* However, for radial artery cannulation, there is category A, level 1 support for the use of ultrasound to improve first-pass success.[81]

Ultrasound is most effectively used as a rescue technique for arterial access and to identify the location and patency of suitable arteries for cannulation or procedural access. LAX imaging is particularly useful to identify vessel tortuosity, atheromatous plaques, and difficulties with catheter insertion.

12. ULTRASOUND-GUIDED PERIPHERAL VENOUS CANNULATION

Peripheral venous access is usually performed by cannulating superficial veins that are directly visualized within the dermis. Intravenous access can be difficult in obese patients, chronic intravenous drug abusers, edematous patients, and long-term hospitalized patients. Ultrasound facilitates access to anatomically deeper veins not directly or easily visible within the dermis. Reports in both the anesthesiology and emergency medicine literature describe the use of ultrasound to facilitate peripheral access in these difficult patient populations.[82,83] Keyes *et al.*[82] had success using a SAX view but encountered some arterial punctures and early catheter failures due to catheter dislodgement. Sandhu and Sidhu[83] advocated a LAX ultrasound approach and the placement of a catheter with ≥2.5 cm of catheter in the vein. Placement of a shorter catheter should be converted to a Seldinger technique to minimize inadvertent dislodgement.

A follow-up study of emergency medicine physicians placing peripheral intravenous catheters in difficult-access patients compared the use of real-time ultrasound guidance with traditional approaches of palpation and landmark guidance.[84] Cannulation was more successful for the ultrasound group (97%) than the control group (33%). The ultrasonographic group required less overall time (13 vs 30 min, for a difference of 17 min [95% CI, 0.8–25.6 min]), less time to successful cannulation from first percutaneous puncture (4 vs 15 min, for a difference of 11 min [95% CI, 8.2–19.4 min]), and fewer percutaneous punctures (1.7 vs 3.7, for a difference of 2.0 [95% CI, 1.27–2.82]) and had greater patient satisfaction (8.7 vs 5.7, for a difference of 3.0 [95% CI, 1.82–4.29]) than the traditional landmark approach. It is important to note that all sonographers in this series participated in 15 hours of didactic lectures related to ultrasound and 100 ultrasound exams during their training or practice.[84] Another prospective emergency medicine study did not demonstrate a decrease in the number of attempts or the time to successful cannulation with ultrasound or improved patient satisfaction compared with the nonultrasound group.[85] A comparison of skin marking with static imaging to real-time ultrasound for peripheral vein cannulation in an adult patient population did not demonstrate improve success rates but decreased the time to successful cannulation when ultrasound was used in real time.[86]

Percutaneous intravenous central catheterization (PICC) is a similar but distinct procedure and patient subset. PICC lines are placed for long-term intravenous access for antibiotic or chemotherapy administration or in long-term acute care patients in need of intravenous access. Venography was the standard access method before two reports describing the use of ultrasound. Sofocleous *et al.*[87] promoted the use of sonography over venography for central access with a series of 355 patients and a 99% success rate. Parkinson *et al.*[88] described the success of ultrasound versus blind cannulation at their facility, with 100% success for ultrasound-guided versus 82% for blind procedures.

Table 2 Recommended training objectives for ultrasound-guided vascular cannulation

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

Robinson *et al.*[89] showed that a dedicated PICC team, using ultrasound guidance, increased the success rate from 73% to 94%, reduced the wait time for a catheter and overall placement costs, and reduced the overall usage of catheters by disapproving inappropriate requests.

12.1. Recommendation for Peripheral Venous Access

Although ultrasound may identify the presence, location, and patency of peripheral veins, *the council does not recommend routine real-time ultrasound use for peripheral venous cannulation*, although there is category B, level 2 (suggestive observational studies) support for the use of ultrasound for PICC insertion. Ultrasound is most effectively used to identify the location and patency of suitable veins for peripherally inserted central venous catheters.

13. VESSEL SELECTION

The benefit of ultrasound guidance for improving cannulation success and reducing complications varies according to the site selected. The risk for thrombosis and infection also varies according to the access site chosen for cannulation and is an important consideration when choosing a particular site. Prior cannulation and radiation exposure are specific to the affected area. Femoral access has the highest incidence of infection and thrombosis at 19.8% and 21.5%, respectively.[4] It is often used for emergent access and secondary line access. The infection rate for the IJ vein ranges between 4% and 8.6%, and the thrombosis rate is 7.6%. SC access is favored for longer dwelling catheters, with the lowest infection rate (1.5%–4%) and thrombosis rate (1.2%–1.9%). The risk for infection and thrombosis for tunneled IJ vein catheters is similar to that of tunneled SC catheters.[60] Larger catheters with more lumens are associated a higher risk for infection.[90] Patient factors such as thrombocytopenia, obesity, chronic obstructive pulmonary disease, myocardial infarction, sepsis, and malnutrition increase the risk for infection at all access sites. Hypercoagulation disorders such as heparin-induced thrombocytopenia with thrombosis and factor V Leiden, catheter length, inability to anticoagulate, malignancy, and the duration of catheter indwelling increase the risk for thrombosis.[91]

14. VASCULAR ACCESS CONFIRMATION

The complications arising from the incorrect cannulation of an artery with a large bore catheter intended for an adjacent vein have significant morbidity and mortality. This is particularly true for unintentional CA cannulation during IJ vein cannulation attempts but also holds true for unintentional arterial puncture at other sites. Ultrasound reliably detects the guide wire in the target vessel before dilation and catheter insertion[92] but is not a substitute for roentgenography to verify catheter location and course or to identify complications such as pneumothorax or hemothorax. Other confirmation techniques of central venous cannulation and wire passage via the Seldinger technique include fluoroscopy, visualization of the wire with transesophageal echocardiography in the superior vena cava or inferior vena cava, manometry with a fluid column connected to a catheter, blood gas analysis, and direct pressure transduction.

14.1. Recommendations for Vascular Access Confirmation

The council recommends that real-time ultrasound be used for confirmation of successful vessel cannulation. It is vitally important for the guide wire to be visualized in the target vessel and that the adjacent structures be visualized to confirm the absence of the guide wire. Because there may be ambiguity of the guide wire tip with SAX ultrasound imaging alone, manometry with a fluid-filled catheter through a flexible catheter in the vessel is recommended when LAX imaging is not used for confirmation of venous catheter placement.[93] When available, transesophageal echocardiographic or fluoroscopic imaging of the guide wire in the superior vena cava or inferior vena cava provides definitive confirmation of placement into the central venous system (Figure 19).

15. TRAINING

Multiple training techniques have recently been described using ultrasound for central venous cannulation.[94-96] All forms of training must emphasize the importance of developing proficiency in both cognitive and psychomotor skill sets. Training must include image acquisition, interpretation, real-time use of ultrasound for vessel puncture and cannulation, and an experienced instructor who demonstrates to the trainee how to translate 2D imaging to perform a 3D task. The techniques used to enhance the safety of the procedure using landmark guidance should not be abandoned during ultrasound, but rather ultrasound imaging should enhance the safety of the techniques used during landmark-guided training. Comprehensive education should include a combination of didactic lectures, live or simulated demonstrations, and mentoring by a skilled sonographer. Formal training will reduce the failure rate of ultrasound-guided cannulation and ultimately improve patient safety.

There is a lack of scientific literature to specifically delineate the number of procedures necessary to develop competence in performing real-time ultrasound cannulation because clinicians acquire knowledge and develop dexterity for the technique at different rates. The opinion among expert users with >10 years of experience with this technique has suggested that training include a minimum of 10 procedures performed under the guidance of an experienced user. *It is the recommendation of this council that individuals gain the requisite knowledge, develop the required dexterity, and perform 10 ultrasound-guided vascular access procedures under supervision to demonstrate competence to independently practice this technique (Table 2)*. A portion of this training can also be accomplished in a simulated environment that allows a trainee to develop the dexterity needed for simultaneous probe manipulation and needle insertion. It is preferable that training occurs at one particular site, so that learning the ultrasound technique may be a priority over learning the approach to different sites. However, once the ultrasound technique is mastered, the principles can be used to access vessels at other sites without additional ultrasound specific supervision.

Proper training that imparts the cognitive knowledge and technical skills to perform ultrasound-guided cannulation is outlined Table 2. This training is necessary to realize the clinical outcomes supported by the literature. Most important, the operator must possess an appreciation of the ultrasound anatomy surrounding the target vessel, the ability to identify the optimal entry site and needle angulation, and an understanding of the limitations of the ultrasound-guided technique. The safety techniques used for landmark-guided approaches, such as a laterally directed needle angulation, should not be abandoned when ultrasound is used but rather enhanced with ultrasound imaging. For example, if ultrasound imaging reveals significant vessel overlap, an entry site with a more side-by-side vessel orientation should be selected as a direct response to the ultrasound information to enhance cannulation safety and reduce the likelihood of complications.

16. CONCLUSIONS

It is the recommendation of this council, on the basis of level 1 scientific evidence, that properly trained clinicians use real-time ultrasound during IJ cannulation whenever possible to improve cannulation success and reduce the incidence of complications associated with the insertion of large-bore catheters. Despite fewer scientific studies, the council also recommends the use of real-time ultrasound for the cannulation of the IJ and FV in pediatric patients. Complications during FV cannulation in adults are less severe than those that occur with SC and IJ vein cannulation, and therefore, ultrasound guidance is recommended only for identifying vessel overlap and patency when feasible for FV cannulation. Obese and coagulopathic patients should have ultrasound screening of the SC vein before attempted cannulation to identify vessel location and patency. If real-time ultrasound is not used as the initial technique for SC vein cannulation, it should be used as a rescue device. It is also an effective rescue device for arterial cannulation.

Proper training is necessary to realize the clinical outcomes supported by the literature, to gain an appreciation of the ultrasound anatomy, identify the optimal entry site and needle angle, and understand the limitations of the ultrasound-guided technique. Precannulation or static ultrasound with skin marking is useful for identifying vessel anatomy and thrombosis but may not improve cannulation success or reduce complications, as does real-time ultrasound needle guidance.

NOTICE AND DISCLAIMER

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APPENDIX A

Members of the Council on Intraoperative Echocardiography

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Appendix B Summary of Randomized Clinical Trials of USG Central Venous Cannulation

Study	Setting	Participants	Comparison (entry site)	Outcomes measured	Operator experience	Findings
Mallory *et al.* (1990)[14]	US tertiary care, teaching hospital	Critically ill adult patients in intensive care; high and low risk (disease not reported)	2D USG vs LMK method (IJV)	Number of failed catheter placements, failure on first attempt	Senior ICU staff and critical care fellows; number not reported; mean 6 y experience	Success 100% vs 65%
Troianos *et al.* (1991)[19]	US tertiary care, teaching hospital	Cardiothoracic surgical patients (age, disease, and risk factor not reported)	2D USG vs LMK method (IJV)	Number of failed catheter placements, number of complications, failure on first attempt, number of attempts to successful catheterization, time to successful catheterization	Not reported	Success 100 vs 96%
Alderson *et al.* (1993)	Canadian urban children's hospital	Infants (aged < 2 y) undergoing cardiac surgery; disease and risk not reported	2D USG vs LMK method (IJV)	Number of failed catheter placements, number of complications	Experienced cardiac anesthetist	Determined abnormal anatomy in 18%
Soyer *et al.* (1993)	French hospital	Adult patients with liver dysfunction requiring transjugular liver biopsy (risk assessment not reported)	2D USG vs LMK method (IJV)	Number of failed catheter placements, number of complications, number of attempts to successful catheterization, time to successful catheterization	2 radiologists with same experience (not quantified)	Success 100% vs 74%
Branger *et al.* (1994)	French teaching hospital	Patients needing central venous catheterization for hemodialysis, apheresis, or parenteral nutrition (disease not reported), low risk for complications (high-risk patients excluded)	Doppler USG vs LMK method (IJV and SCV)	Number of failed catheter placements, number of attempts to successful catheterization, time to successful catheterization	14 junior postgraduate students with <5 y clinical experience and 8 senior staff with >5 y experience, from nephrology, emergency, and intensive care; taught the Doppler technique over 2 wk, achieved ≥1 venous catheterization before entering study	Salvage of 4 of 12 failures of LMK attempts

(*Continued*)

Appendix B (*Continued*)

Study	Setting	Participants	Comparison (entry site)	Outcomes measured	Operator experience	Findings
Gratz *et al.* (1994)	US tertiary care, teaching hospital	Patients for cardiothoracic or vascular surgery (age and disease not reported)	Doppler USG vs LMK method (IJV)	Number of failed catheter placements, number of complications, failure on first attempt, number of attempts to successful catheterization, time to successful catheterization	Number not reported; "experienced anesthesiologists"	Success 84% vs 55%
Vucevic *et al.* (1994)	British hospital	Cardiac surgery and ICU patients (age, disease, and risk-assessment not reported)	Doppler USG vs LMK method (IJV)	Number of failed catheter placements, number of complications, time to successful catheterization	2 consultant anesthetists; 10 procedures	No difference; smart needle avoided carotid puncture in 2 cases
Gilbert *et al.* (1995)	US tertiary care, teaching hospital	Adult patients (disease not reported) at high risk from complications (obesity or coagulopathy)	Doppler USG vs LMK method (IJV)	Number of failed catheter placements, number of complications, failure on first attempt, time to successful catheterization	Number not reported; junior house staff "relatively inexperienced in using either technique"	Success 84.4% vs 61.4%; complications 2% vs 16.3%
Gualtieri *et al.* (1995)[44]	US urban teaching hospital	Critical care patients undergoing nonemergency procedures (age, disease, and risk not reported)	2D USG vs LMK method (SCV)	Number of failed catheter placements; number of complications	18 physicians with <30 procedures	Success 92% vs 44%; complications same
Hilty *et al.* (1997)	US urban teaching hospital	Patients undergoing cardiopulmonary resuscitation (age, disease, and risk not reported)	2D USG vs LMK method (FV)	Number of failed catheter placements, failure on first attempt, number of attempts to successful catheterization, time to successful catheterization	2 emergency medicine residents in PGYs 3 and 4; 15–20 procedures using LMK method; 6–10 procedures using ultrasonography	Success 90% vs 65%; complications 0% vs 20%
Slama *et al.* (1997)	French university hospital	Adults in intensive care requiring cannulation of IJV (disease and risk assessment not reported)	2D USG vs LMK method (IJV)	Number of failed catheter placements, number of complications, failure on first attempt; time to successful catheterization	Junior house staff (interns or residents) under the direct supervision of senior physician after ≥3 demonstrations by experienced operator and 3 attempts of right IJV using LMK method	Success 100% vs 76%

Teichgräber *et al.* (1997)	German university teaching hospital	Patients undergoing routine catheterization of IJV (age, disease, and risk assessment not reported)	2D USG vs LMK method (IJV)	Number of failed catheter placements, number of complications	Physicians; number and experience not reported	Success 96% vs 48%
Bold *et al.* (1998)	US tertiary care, outpatient oncology centre	Adult chemotherapy patients (cancer types not reported); high risk for failure or complications	Doppler USG vs LMK method (SCV)	Number of failed catheter placements	18 surgical oncology fellows (PGY 6–10); instruction in use of smart needle and "demonstrated competence" in use of Doppler probe	No difference
Lefrant *et al.* (1998)	French teaching hospital	Critically ill adults undergoing nonemergency procedures (disease and risk not reported)	Doppler USG vs LMK method (SCV)	Number of failed catheter placements, number of complications, failure on first attempt	1 staff anesthesiologist, untrained in Doppler guidance before study	Success: no difference; complications 5.6% vs 16.8%
Nadig *et al.* (1998)	German teaching hospital	Dialysis patients (age, disease, and risk level not reported)	2D USG vs 2D USG for vessel location followed by blind venipuncture (IJV)	Number of failed catheter placements, number of complications, failure on first attempt, time to successful catheterization	Physicians; clinical experience 1–7 y	Success 100% vs 70%
Verghese *et al.* (1999)	US university teaching hospital	Infants scheduled for cardiovascular surgery, aged < 12 mo, weight < 10 kg (disease and risk assessment not reported)	2D USG vs LMK method (IJV)	Number of failed catheter placements, number of complications, number of attempts to successful catheterization, time to successful catheterization	Number not reported; board-eligible anesthesia fellows who had completed residency training in anesthesia	Success 100% vs 77%; complications (carotid punctures) 0% vs 25%
Sulek *et al.* (2000)	US university-affiliated hospital; operating room	Adult patients scheduled for elective abdominal, vascular, or cardiothoracic procedures with general anesthesia and mechanical ventilation in whom central venous cannulation was clinically indicated (disease and risk assessment not reported)	2D USG vs LMK method (IJV)	Number of failed catheter placements, number of complications, number of attempts to successful catheterization, time to successful catheterization	Anesthetist; all operators experienced in cannulation of IJV (≥60 catheter placements) with known expertise in use of USG IJV technique	Success 95% vs 91%

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Appendix B (*Continued*)

Study	Setting	Participants	Comparison (entry site)	Outcomes measured	Operator experience	Findings
Verghese *et al.* (2000)	US university teaching hospital	45 infants scheduled to undergo IJ cannulation during cardiac surgery (disease and risk assessment not reported)	2D USG vs Doppler USG vs LMK method (IJV)	Number of failed catheter placements, number of complications, time to successful catheterization	Number not reported; fellows in pediatric anesthesia	Success (ultrasound, Doppler, LMK) 94%, 77%, 81.3%; complications (carotid puncture) 6%, 15%, 19%
Hayashi (2002)	University hospital	Intraoperative patients under general anesthesia	Doppler USG vs LMK method (IJV); presence of respiratory jugular pulsations used to stratify	Success rate, first time success, complications, presence of jugular pulsations	Anesthesiologist	If pulsations present, no difference: success rate 95.6% vs 96.9%, first attempt 85.7% vs 83.5%; if no pulsations (22%), access 86.2% vs 30.4%, success rate 100% vs 78.3%; arterial punctures 0% vs 13%
Bansal (2005)	University hospital	Nephrologist	2D USG vs LMK method: IJV for hemodialysis catheter	Success rate, first-attempt success rate, complications	Nephrologist	Success rate 100% vs 6.7%; first-time success 86.7% vs 56.7%; adverse outcomes 0% vs 16.7%
Karakitsos (2006)	University hospital	ICU patients	Doppler USG vs LMK method (IJV)	Overall success, time to insertion, number of attempts, complications	University faculty members experienced in both techniques	Success rates 100% vs 94% (ultrasound vs LMK); access times 17 vs 44 sec; complications 4% vs 23%; number of attempts 1.1 vs 2.6
Leung (2006)	Tertiary care ER	ER	Doppler USG vs LMK method (IJV)	Success rate, number of attempts, access times, complications	ER physicians	Success rate 93.9% vs 78.5% (ultrasound vs LMK); first attempts 82% vs 70.6%; access time not different; complications 4.6% and 16.9%
Schwemmer (2006)[79]	University hospital	Operating room	Traditional vs USG catheterization of radial artery in small children (<6 yrs)	Success rate, number of attempts, effects of positioning	Anesthesiologists in operating room	Success 100% vs 80%; attempts 1.33 vs 2.3 per; dorsiflexion reduced cross-sectional area

Koroglu (2006)	University hospital	Interventional radiology	Combined real-time ultrasound and fluoroscopy vs LMK for emergent hemodialysis catheters	Success rate, number of attempts, puncture of back wall of vessel	Interventional radiology	Success rate 100% vs 97.5%; complications 0% vs 14%; attempts not different
Hosokawa *et al.* (2008)	University hospital	Infants weighing < 7.5 kg	USG skin marking vs real-time cannulation	Times to puncture and catheterization, number of attempts, complications	University faculty members	Real-time cannulation improved speed to puncture and catheterization, number of attempts; 1 arterial puncture in marking group
Turker *et al.* (2009)	Turkish department of medicine	Spontaneously breathing patients	Doppler USG vs LMK method (IJV)	Overall success, number of attempts, time to cannulation, complications, access time	University faculty members	Success 97.4% vs 99.5%; access time 236 ± 110 vs 95 ± 136 seconds; complications 8.42% vs 1.57%; number of attempts 1.42 vs 1.08
Evans *et al.* (2010)	Tertiary teaching hospital	ER patients	Didactics plus competency-based simulation vs traditional teaching; blinded observer to outcome	Success at first attempt and overall cannulation were primary outcomes; secondary outcomes were errors and complications	115 residents	Simulation improved traditional: first attempt OR 1.7 (95% CI 1.1–2.8), overall OR 1.7 (95% CI 1.1–2.8)
Prabhu *et al.* (2010)[62]	Tertiary teaching hospital	Dialysis patients	2D USG vs LMK method: FV	Successful cannulation, number of attempts, complications		89.1% for LMK, 98.2% for USG; first-time success 54.5%, 85.5%; complications 18.2%, 5.5%; OR for success with USG 13.5 (95% CI 1.7–10.7)
Mitre *et al.* (2010)	Romanian operating room and ICU	Hospitalized patients	Doppler USG vs LMK method (EJ vein)	Overall success, number of attempts, time to cannulation, complications	Second-year residents	Success rates for puncture of EJ: 80% and 73% for USG vs LMK; no difference in time and number of attempts; successful cannulation 30% and 20%

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Appendix B (*Continued*)

Study	Setting	Participants	Comparison (entry site)	Outcomes measured	Operator experience	Findings
Seto (2010)[64]	Multicenter	Interventional radiology patients for retrograde femoral artery cannulation	2D ultrasound vs fluoroscopy	Success rates, time to sheath insertions, needle passes, complications	Interventional cardiologists	Ultrasound vs fluoroscopy, success rates: no difference except in population with femoral bifurcation over femoral head; first-pass success 82.7% vs 46.4%; time 185 vs 213 sec; complications (any) 1.4% vs 3.4%

EJ, External jugular; *ER*, emergency room; *ICU*, intensive care unit; *IJV*, IJ vein; *LMK*, landmark; *OR*, odds ratio; *PGY*, postgraduate year; *SCV*, SC vein; *USG*, ultrasound-guided.