In 1952, Sven-Ivar Seldinger developed an innovative technique for the percutaneous insertion of large-bore catheters into blood vessels that allowed for the application of angiocatheters for angiography. The Seldinger technique for central venous catheter (CVC) placement is ubiquitous in medical practice and the procedure is well known. Briefly, the procedure involves introducing a percutaneous needle into the vessel, passing a guidewire through the needle, and then placing the catheter over the guidewire and inserting it into the blood vessel. In addition to revolutionizing the fields of cardiology and interventional radiology, this technique has had a profound impact through its contribution to the development of central venous infusion catheters.1

CVC placement is common in the United States, with an estimated several million catheters placed annually.2 Data from the European Prevalence of Infection in Intensive Care study, which included 10,038 patient case reports, showed that 78% of critically ill patients had a CVC placed.3

Traditionally, the site of initial needle insertion during CVC placement is determined by using palpable or visible anatomic structures with known relationships to the desired vein as landmarks.1 However, ultrasound is increasingly being used to identify vessels and guide needle insertion for CVC placement. Real-time ultrasound-guided CVC placement is employed by a variety of medical specialties, and there is ample support for its use in the medical literature.4–10 This review discusses the practice and techniques of real-time ultrasound guidance for CVC insertion.

EVIDENCE FOR UTILITY OF ULTRASOUND GUIDANCE

The clinical utility of CVC placement is well established, but its associated complications are an important consideration given the prevalence of this technique. Evidence has shown that landmark-guided percutaneous CVC insertion is associated with significant complications, including arterial puncture, pneumothorax, hemothorax, brachial plexus injury, and catheter malposition.11–15 The frequency of these complications is dependent on such factors as selection of insertion site, operator experience, and patient anatomy.12,14

Studies have established the indications and benefits of employing ultrasound guidance for CVC placement in a range of clinical settings (eg, intensive care units, emergency departments).15–17 Most of these studies have explored and supported the utility of ultrasound-guided access for the internal jugular vein (IJV), particularly in the pediatric population.4,5 Several meta-analyses that reviewed landmark versus ultrasound-guided IJV

TAKE HOME POINTS

- Landmark-guided central venous catheter (CVC) placement is associated with significant complications, including arterial puncture.
- Ultrasound-guided CVC placement is associated with reductions in complications, mean insertion attempts, and placement failure rates.
- Specific groups of patients, such as those with poor anatomic landmarks or coagulopathies, particularly benefit from the use of ultrasound to guide CVC placement.
- Short-axis and long-axis sonographic views are most useful in targeting and cannulating a prospective vessel.
- Ultrasound guidance enables direct visualization of needle advancement and entrance into the target vessel to accomplish the Seldinger technique for central venous catheterization.
CVC placement demonstrated significant relative risk reductions in complications, mean insertion attempts, and failed catheter insertions when ultrasound was employed.\(^7,\)\(^18,\)\(^19\) Additional studies that demonstrated the benefits of ultrasound guidance for IJV CVC placement are reviewed in the following section (Indications for Ultrasound Guidance).

Relatively few studies have explored the utility of ultrasound-guided access to the femoral vein. In a small prospective, randomized study that examined ultrasound for identifying and accessing the femoral vein, this technique significantly reduced the number of venipuncture attempts (2.5 versus 5.0; \(P = 0.0057\)) and the rate of complications (0% versus 20%; \(P = 0.025\)).\(^20\)

There are few studies of ultrasound guidance for the supraclavicular and infraclavicular axillary approaches, and more studies examining the feasibility of these techniques are needed before they can be recommended.\(^7,\)\(^18,\)\(^19\) A randomized controlled study compared the landmark and ultrasound-guided techniques for infraclavicular subclavian vein catheter placement. The ultrasound group had a significantly higher success rate (92% versus 44%; \(P = 0.003\)), lower complication rate (4% versus 41%; \(P = 0.002\)), and fewer venipunctures before access was attained (1.4 versus 2.5; \(P = 0.0007\)).\(^21\) In addition, 80% of failed landmark-guided attempts were salvaged by use of ultrasound.

**INDICATIONS FOR ULTRASOUND GUIDANCE**

Real-time ultrasound guidance for CVC insertion is indicated to ameliorate the risks associated with the landmark-guided technique. A 1996 meta-analysis found that compared with the landmark technique, ultrasound guidance resulted in a significant reduction in CVC placement failures (relative risk, 0.32) and complications during placement (relative risk, 0.29).\(^9\)

In a prospective study comparing the ultrasound and landmark techniques, the rate of carotid artery puncture decreased by approximately 7% with ultrasound guidance.\(^22\) In a study that evaluated IJV cannulation in infants, the incidence of carotid artery punctures was 25% in the landmark group, while no punctures occurred in the ultrasound group (\(P < 0.0001\)).\(^5\)

Ultrasound guidance may also be indicated for clinical scenarios requiring expedient and efficient placement of a CVC. In a prospective study of the 2 techniques for IJV access,\(^23\) the ultrasound group had a significantly shorter average access time (9.8 s versus 44.5 s; \(P < 0.0001\)) and a higher proportion of successful cannulations on the first attempt (77.8% versus 38.4%; \(P < 0.001\)). Verghese et al\(^5\) also found that ultrasound-guided cannulation of the IJV was superior to the landmark technique in terms of overall success (100% versus 77%) and speed (10 min versus 3.3 min). Hrics et al\(^15\) performed a prospective study of ultrasound-guided IJV cannulation in patients requiring urgent intravenous vasopressors, fluids, and pacing in the emergency department. Compared with the landmark technique, ultrasound guidance led to significantly higher rates of successful first attempts (50% versus 12.5%) and completed cannulations (81.3% versus 62.5%).

There are specific groups of patients in which landmark-guided access could be considered relatively contraindicated if ultrasound guidance is available. Skolnick\(^24\) recommended that CVC placement should be performed under sonographic guidance if patients are obese or have a swollen neck or upper extremity that would obscure anatomic landmarks; this author also noted that ultrasound guidance has benefits in patients with coagulopathies and patients being treated with anticoagulants. Denys and Uretsky\(^25\) recommended considering ultrasound-guided access in patients with short necks, patients with Cushingoid appearance, and patients who have undergone surgical interventions or radiation therapy to the neck area that may alter landmarks and anatomy. Fry et al\(^25\) expanded these recommendations to include patients who are unable to assume the supine position, those who are hypovolemic, and those with severe respiratory compromise. The aforementioned classes of patients are reasonably considered to be within the “difficult access” category, and ultrasound has been shown to facilitate a higher success rate and lower complication rate in these patient groups.\(^8\)

**EQUIPMENT**

**B-Mode Ultrasound**

B-Mode ultrasound allows for detailed evaluation of vascular anatomy and structural characteristics and has been employed to outline the vascular system and locate blood vessels. This modality can provide information on vessel size, the presence of luminal obstructions, and morphologic abnormalities. As a real-time imaging modality, ultrasound can update image frames at a rate of at least 30 frames per second, which allows the operator to visualize vessel compliance and observe changes in vessel caliber when variable pressure is applied to the overlying tissue.\(^26\)

The tissues comprising vascular structures determine their sonographic appearance. With thicker tunica media and generous smooth muscle walls, arteries appear to have relatively thick *hypoechoic* (white) walls and *anechoic* (black) lumens. Veins, which consist of less smooth muscle and have more compliant walls, appear to have thin *hypoechoic* (grey) walls and an anechoic lumen.
The ability to compress and collapse the veins is a particularly useful characteristic that helps distinguish between arterial and venous images.27

Transducer

The ultrasound transducer is the component of the ultrasound system that contacts the patient and is held within the sonographer’s hand. The transducer emits ultrasound energy into biologic tissues and detects the reflected echoes, which are then processed into sonographic images. The essential components of the transducer are the housing, an electrode, backing material, piezoelectric crystals, and a matching layer. The piezoelectric crystal elements in an ultrasound transducer are made of a ceramic material and usually consist of lead zirconate titanate, a material that shows a marked piezoelectric effect. Arrayed within the transducer, the crystals mediate the conversion of electrical energy into mechanical vibration energy to produce the ultrasound waves. The crystals then convert the returning ultrasound echoes into small electrical signals.28 The backing material and matching layers, located on either side of the piezoelectric material, regulate the emission of ultrasound energy.29

Transducers differ in terms of the size and position of their contact surface (ie, footprint) and the orientation of the sonographic beam emitted. Linear transducers provide optimal visualization of vascular structures and greatly facilitate ultrasound-guided venous access. Linear transducers have a flat footprint and typically allow for a larger sonographic field of view in the near field of the ultrasound image compared with other types of transducers (ie, sector and curvilinear transducers). Moreover, due to their linear arrays of piezoelectric crystals, linear transducers allow the operator to focus the ultrasound beam at various depths, which increases their utility in tracking and cannulating prospective vessels.29

A 7.5-MHz linear transducer is most often used for ultrasound-guided CVC placement,18 although transducers in the range of 6 to 10 MHz are also suitable. These high-frequency transducers facilitate imaging of superficial structures and allow more accurate real-time monitoring of the advancing needle employed in CVC placements.26 To ensure appropriate imaging and ultrasound resolution, the highest frequency should be selected to maximize definition of the vessel image while maintaining adequate depth penetration of the ultrasound signal. Moreover, the ultrasound beam should be directed essentially perpendicular to the vessel.

Sterile Barriers

Maintenance of sterile technique is imperative in all CVC placement procedures due to the potential morbidity and mortality associated with catheter-related infections.2 Sterile barriers manufactured to facilitate the preservation of a sterile field during an ultrasound-guided procedure are usually designed to cover both the transducer and its cable. Many types of transducer covers are available, and they are usually made of rubber or plastic materials. An assistant is required to properly prepare and set up a sterile sheath, but once in place it often can be maintained by a single operator.23 When specifically designed sheath barriers are not available, alternative barriers can be used. The most commonly used alternative is a sterile glove, although boot covers intended for use with endovaginal ultrasound probes may also be used for linear transducers.30

Needles

There are no set requirements for needle types used in CVC placement, and preference is often operator or procedure dependent. The main caveat to keep in mind is that needles must be of a sufficient gauge to allow passage of the guide wire (ie, from 18 to 21 gauge to allow passage of 0.35 to 0.0018 in guidewires).31,32 The needle tip is highly echogenic, and is more echogenic than the shaft.33 It is hypothesized that these characteristics arise from the abrupt discontinuity in the homogeneously reflecting shaft and that the needle tip echoes likely arise from reflection produced at the tip of the needle and proximal edge of the beveled opening.33 In general, the needle tip and shaft have a hyperechoic sonographic image. Because ultrasound beams...
may be scattered and not pass through the needle, a shadow or loss of signal (appearing grey or black) may sometimes be seen posterior to the needle image. More often, a sonographic artifact termed reverberation, or ring-down, is seen posterior to the needle image; it appears as a linear formation of evenly spaced grey or white echoes (Figure 2).

Needle tip echogenicity and shaft visualization are influenced by needle gauge, the position of the needle bevel, and the angle of the needle in relation to the transducer. Needle gauge has been shown to correlate positively with a more prominent needle tip echo and ability to visualize the needle. Using A-mode and B-mode ultrasonography, Bondestam and Kreula demonstrated a linear and exponential increase in the intensity of standard needle tip echoes ($P < 0.001$) with increasing needle diameter. Studies have also shown that greater tip visualization can be achieved by positioning the bevel opening toward or away from the transducer, and more intense needle shaft reverberations can be achieved with an angle of needle approach between 30 and 60 degrees. Measuring varying angles of standard needle rotation and angles of needle approach, Hopkins and Bradley confirmed that positioning the bevel opening parallel to the ultrasound signal significantly improved visibility ($P = 0.01$) and that a needle-to-transducer angle of 20 degrees or less diminished needle echo intensity ($P = 0.0001$).

Procedure needles may be echogenically enhanced to improve ultrasonographic visualization of the needle shaft and tip. Commercially available needles that are coated, dimpled, or notched have been shown to have increased needle echogenicity compared with smooth standard needles. Moreover, enhanced needles have the advantage of maintaining adequate visibility when smaller gauge needles are used and in circumstances when a less than ideal needle-to-transducer angle must be used.

**Mechanical Guides**

Mechanical guides are manufactured to help the ultrasonographer position and advance the needle when attempting vascular access under ultrasound guidance. There are 2 types of mechanical guides: (1) a built-in needle slot located centrally or laterally on the ultrasound transducer itself, and (2) an attachment fitted to the transducer that contains a slot to assist with angling the needle. Guides are useful for the less experienced operator because they provide stability to the advancing needle, provide a fixed, predictable, uniform trajectory in relation to the transducer, and direct the needle in a plane in line with the focused ultrasound beam. Typically, they are built with a specific angulation such that the needle will intersect in the center of the ultrasound beam at a specific depth below the transducer surface.

Mechanical guides have some notable disadvantages. They represent an additional expense, they add bulk to the transducer, and they restrict the needle to a fixed presentation, thus preventing operator redirection. In addition, attachment mechanical guides are produced by companies that manufacture linear transducers, and most are manufactured to attach only to a specific transducer. When using a mechanical guide in association with the ultrasound machine, specific needle gauges or types may be required for proper use. Therefore, operators should review the preferences recommended by the specific mechanical guide manufacturer.

**ULTRASOUND-GUIDED TECHNIQUES**

**Vessel Visualization: Short-Axis Versus Long-Axis Views**

Short-axis and long-axis views are most useful in targeting and cannulating a prospective vessel. The short-axis view provides visualization of the vessel in the transverse plane and is produced by placing the long axis of the transducer perpendicular to the long axis of the vessel. When this view is obtained correctly, the vein with its corresponding artery should appear circular or oval in shape (Figure 3). When the transducer is centered over the target vein, the midpoint of the transducer becomes a reference point for introduction of the access needle. Transducers often have a marker that designates this reference point, facilitating localization of a puncture site and approach.

The long-axis view provides visualization of the prospective vessel in the longitudinal plane. This view is obtained by placing the transducer over the vessel so that
the long axis of the transducer is parallel to the long axis of the vessel, producing a sonographic image of the vessel along its length. The transducer is then oriented to view the vessel at its greatest anterior-posterior diameter (Figure 4). Unlike the short-axis view, the long-axis view allows only a single vessel to be maintained in the field of view and cannot be used to define the anatomic relationship between the vessels. Therefore, when using this view, confirmation of vessel type prior to cannulation is particularly essential because slight changes in the angle of the transducer may inappropriately target the accompanying artery.

General Approaches to Ultrasound-Guided Vascular Access

This section reviews the standard access techniques that are applicable to a real-time ultrasound-guided central venous access procedure irrespective of access site.

Short-axis approach. Preparation for sterile technique includes placing the transducer into a sterile sheath containing conducting medium at its tip and rolling the sterile sheath back over the transducer and cable. The transducer is then positioned to obtain short-axis views of the prospective vein and plan the approach. The skin entry site and angle of needle presentation should be chosen to maximize the chances that, as the needle tip touches the vessel wall, it will intersect the scan plane of the transducer. Abboud et al recommend that the operator pierce the skin with the needle placed at an angle of at least 45 degrees to the transducer. Nemcek agrees with this angulation and recommends piercing the skin surface at a distance from the transducer that is equal to the distance between the vessel and the transducer. For example, if the vessel is 1 cm deep, he recommends entering the skin surface at a 45 degree angle 1 cm away from the transducer (Figure 5).

Once adequate local anesthesia is injected overlying the access site, skin puncture utilizing a sterile needle may commence. Upon puncturing the skin, the operator should identify the hyperechoic needle image on the monitor. In this approach, the needle is perpendicular to the ultrasound signal. Because the ultrasound signal only interacts with a cross-section of the needle, the needle tip or shaft will appear as a hypoechoic (grey) or hyperechoic (white) point in the field of view (Figure 6). As noted earlier, the needle tip echo will often have greater intensity than the shaft.

The needle is advanced toward the target vessel and, ideally, the operator should directly visualize entrance of the needle into the vessel. Fine adjustments should be made continually in both the direction of advancement of the needle and in the transducer’s angle and field of view. When the needle comes into contact with the anterior wall of the vessel, the operator may see a “tenting” of the vessel wall (Figure 7). The vein collapses slightly just
before puncture and then reexpands after entry of the needle into the vessel. A concurrent flash of blood should be noted in the syringe upon aspiration. Visualization of the needle tip echo within the vessel lumen may provide final confirmation of needle entry (Figure 8). However, the needle tip may not always be clearly visualized, and vessel tenting, or distortion, may be the only indication of location. Once the vessel has been accessed, the transducer may be released and standard aseptic catheter introduction can proceed.\textsuperscript{15,23,30}

Long-axis approach. In this approach, the vein to be catheterized is identified and the access site and transducer are prepared for sterile technique as described earlier. The transducer is then positioned to obtain an appropriate long-axis view of the vessel. When utilizing the long-axis approach, Abboud et al\textsuperscript{41} recommend piercing the skin just outside one of the edges of the transducer and inserting the needle at a 30 degree angle (Figure 9) to the skin surface. As they are introduced, the needle tip and shaft will be visualized along their course due to the wider sonographic view provided by the long-axis view (Figure 10).\textsuperscript{24,42} The needle is advanced in a plane aligned with the long axis of the transducer, which as mentioned previously should center over the vessel in its longitudinal axis. Imaging the needle puncture and aspiration of venous blood confirm access to the vessel (Figure 11). As noted earlier, the vein will undergo mild deformation as the needle contacts the vessel wall just prior to needle penetration. Catheterization then proceeds and is completed.

The long-axis approach presents certain disadvantages. Body contour changes, such as at the neck or groin in protuberant patients, may make it challenging to place the transducer longitudinally and still enter the vessel with the advancing needle in a satisfactory position. Furthermore, in some cases the presenting needle may actually push the vessel away or slip off of the vessel. Some operators find that a short-axis approach allows easier real-time needle position and pressure adjustment to better address these concerns.\textsuperscript{42} Blaivas et al\textsuperscript{43} compared the 2 approaches in an inanimate model and found that novice emergency medicine resident operators could perform cannulation more quickly using the short-axis approach (short-axis mean time, 2.36 min; long-axis mean time, 5.02 min; \(P = 0.03\)). However, there were no statistical differences found in respect to mean difficulty, number of attempts, and mean number of needle redirections in this study.
Techniques for Accessing Specific Vessels

The following sections describe technical aspects specific to ultrasound-guided venous access of the IJV, subclavian vein, and femoral vein, including positioning of the patient and placement of the transducer. These specific techniques are rooted in the general techniques described above.

IJV. Typically, the IJV lies anterior and slightly lateral to the carotid artery (CA). However, anatomic variations that make blind insertion techniques more complicated have been reported to occur in up to 5.5% of patients. A sonographic study of the vessels of the neck found that the IJV overlays the CA in 54% of cases, an anatomic orientation that predisposes to CA puncture if the cannulating needle traverses the IJV.

Preparation for IJV catheterization entails positioning the patient in the Trendelenburg position with a 30-degree head rotation, thereby distending the prospective vein and reducing the risk of air embolism. The transducer should be placed just cephalad to the clavicle at the insertion of the 2 heads of the sternocleidomastoid muscle. The long axis of the transducer may be placed parallel and superior to the clavicle, thereby producing a short-axis view of the blood vessel. Skolnick noted that when ultrasound guidance is used the IJV can be punctured at a site farther cephalad on the neck than when the landmark technique is used.

Femoral vein. The approximate position of the femoral vein can be determined by dividing the distance between the anterior superior iliac spine and the pubic tubercle into thirds. In most patients, the femoral artery lies at the midpoint of the middle third, and the femoral vein lies just medial to the femoral artery. As with the IJV, there are variations in anatomic positioning and alignment, with a recent study reviewing computed tomography scans of the pelvis in 100 patients showing that a portion of the femoral vein and the femoral artery overlap in an anteroposterior plane 65% of the time.

In preparing for CVC placement, the patient should be placed in a supine position with the ipsilateral hip in a slight to fully externally rotated position. The transducer is placed a few centimeters distal to the inguinal ligament. Often, the long axis of the transducer is oriented parallel to the inguinal ligament to achieve a short-axis view of the femoral vessels. Once the arterial and venous structures are identified and differentiated, the transducer should be centered on the target vein for needle guidance.

Subclavian vein. The subclavian vein typically lies
adjacent to the subclavian artery in an inferior and anterior position. It originates from the axillary vein at the site of the first rib and extends to its junction with the internal jugular vein. Anatomically, it lies close to important structures, such as the lung, pleura, subclavian artery, and brachial plexus.47–49 Two approaches to ultrasound-guided subclavian vein access have been described: the supraclavicular approach and the infracavicular axillary approach. The supraclavicular approach requires holding the transducer just superior to the clavicle with sufficient pressure to provide adequate images. Patients often describe this procedure as uncomfortable due to the constant pressure over the clavicle. In addition, there is limited anatomic space for concurrent placement of the transducer and introduction of the needle.41

The ultrasound-guided infracavicular technique utilizes a more lateral approach. Cannulation may occur at the level of the axillary vein to provide access to the subclavian vein. The patient is placed in a supine position in 15 degrees Trendelenburg, with the ipsilateral arm abducted 45 degrees from the trunk.42 The literature describing this technique is fairly limited.41 A randomized controlled study compared the landmark technique and ultrasound-guided technique for infracavicular subclavian vein catheter placement.43 The site was imaged to view the axillary vessels just caudal to the lateral aspect of the clavicle. The artery tended to be more cephalad than the vein. Once the vein was identified in short axis, it was imaged along its course 2 cm more medially to ensure that normal anatomy was present up to the point of the prospective needle insertion site. A mechanical guide was used to guide the needle. Due to the more distal insertion site and longer trajectory to the central circulation, a catheter 20 to 25 cm long was used and is recommended.43

**CONCLUSION**

Central venous catheter placement under ultrasound guidance is widely supported in current medical practice. This technique has been shown to ensure safe and timely catheter placement and to reduce many of the potential complications associated with anatomic landmark methods. Through adherence to basic principles of ultrasonography, clinicians may readily incorporate the techniques presented in this review and enhance venous access performance.

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**REFERENCES**

17. Slama M, Novara A, Safavian A, et al. Improvement of