Ultrasound Guidance for Placement of Central Venous Catheters

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Abstract

The author describes the use of ultrasound guidance for placement of central venous catheters.
Different anatomic approaches are discussed, as well as technique in difficult patients and the pediatric population. Procedure, one and two person technique, and pitfalls are reviewed.

MeSH Words: Catheterization, ultrasonography catheterization, central venous/methods, veins/ultrasonography, ultrasonography/procedures, ultrasonography/cost effectiveness, catheterization, central venous/complications.

Introduction

Central venous catheters (CVC's) are used in emergent situations to provide secure access to the central circulation in patients who require invasive hemodynamic monitoring, inotropic support, temporary transvenous cardiac pacing, or in whom adequate peripheral venous access is unobtainable. Successful CVC insertion requires minimizing placement complications such as multiple puncture attempts, arterial puncture, nerve puncture, pneumothorax, or hematoma as well as minimizing patient discomfort and overall procedure time. The traditional method of CVC placement is the 'blind' or anatomic technique, in which line placement is guided by surface anatomic landmarks such as the sternocleidomastoid muscle for the internal jugular (IJ) vein, the clavicle for the subclavian (SC) vein, and the inguinal ligament for the femoral vein (FV). The use of bedside ultrasound (US) to guide CVC placement allows direct visualization of target vessel, assessment for anatomic variations and vein thrombosis, as well as real-time visualization of target vessel puncture and cannulation. The use of US for placement of CVC's will be discussed here, including literature supporting the use of ultrasound, different methods of ultrasound assistance, and potential pitfalls.

Impact of Bedside Ultrasound use in CVC placement

The Agency for Healthcare Quality and Research (AHRQ), in its 2001 report on reducing medical errors [1], placed US guidance for CVC placement in the 'Top 10' list of ways to reduce medical error. According to that document, upwards of 'several million' CVC's are inserted annually in the United States with 20% of attempts as initially unsuccessful. The true incidence of complications of CVC placement is variable, and depends on patient (body habitus, comorbid conditions such as coagulopathy, etc.), physician experience, location of CVC (internal jugular, subclavian or femoral) and clinical scenario (medical code versus stable patient). In general, the incidence of major complication of CVC placement such as arterial puncture, large hematoma, nerve injury, pneumothorax or catheter malposition is reported between 1 and 10% [2,3,4,5].

The potential impact in utilizing US to guide CVC placement is to increase first-attempt success rate, decrease procedural complications, and decrease procedural time and patient discomfort. In a meta-analysis published in 1996 [6], use of ultrasound guidance versus traditional landmark approach for internal jugular (IJ) and subclavian (SC) vein cannulation resulted in significant decrease in complications without any difference in procedural time. In the above analysis, the number needed to treat (NNT) for reducing placement complication is 7, meaning that for every 7 CVC placements using ultrasound 1 complication is avoided. These results were irrespective of clinician experience in CVC placement. A more recent 2003 meta-analysis of 18 clinical trials comparing US and traditional landmark guidance for CVC placement reported a significantly lower overall failure rate (relative risk 0.14, 95% CI .06-.33) when real-time US guidance was utilized [7].

Use of Ultrasound for CVC Placement in the Difficult Patient

CVC placement in the Emergency Department (ED) frequently occurs in unstable or otherwise complicated patients (acutely dyspneic, coagulopathic, patients with multiple previous CVC placements with resultant scarring or thrombosis). A 2005 study by Oguzkurt et al. documented 220 IJ catheter placements under US guidance in patients defined as 'high-risk' due to coagulopathy or multiple previous IJ catheters with 100% success, and average of 1.24 puncture attempts, and an overall 4% complication rate [8]. A similar study in cancer patients involving 493 patients (of which 216 had at least one complicating factor), CVC placement under US guidance had a reported 94.5% overall success rate, 87% first-attempt success, and reported complications of arterial puncture (1.4%) and local hematoma formation (4.3%). [9]

Use of Ultrasound for CVC Placement in the Pediatric Patient

There is limited data on US guided CVC's in pediatric cases. Although ED studies are lacking, a pediatric ICU study involving 95 infants undergoing IJ catheterization for cardiac surgery demonstrated 100% overall success of CVC insertion with a 0% incidence of arterial puncture when US was used versus 77% overall success rate with 24% rate of carotid artery puncture. [10]

Cost effectiveness of Ultrasound Guided CVC Placement

Economic data are relatively scant regarding cost savings associated with ultrasound use. An economic model developed by Calvert et al. [11] from the United Kingdom in 2003 found that, based on the assumption of 15 ultrasound-guided central lines are placed per week, the average cost of ultrasound use is $15 per procedure, and overall cost savings of $4,000 for every 1000 procedures as result of decreased complications

Sonographic Probe Orientation

To allow for image uniformity, several points must be kept in mind when performing bedside ultrasound. The first of these is that each ultrasound probe has a 'marker' placed on one side which correlates to a mark on the image screen. This marker allows the sonographer to orient the probe and thus allow for uniformity of imaging.

Secondly, there are two standardized scanning planes: longitudinal (sagittal) and transverse. In the longitudinal (sagittal) plane, the probe is oriented with the marker towards the patients *head* (see image 1), providing a view of the vein along its long axis (see image 2). In the tranverse plane, which provides an image similar in appearance to a CT scan, the probe is placed with the marker facing towards to the patient's *right* (see image 3). In the transverse plane, the artery and vein appear round and not tubular, as if cut in cross-section (see image 4).

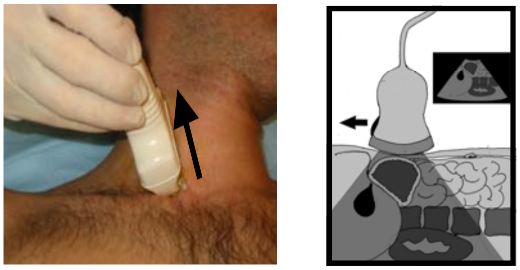

Image 1: Sagittal(longitudinal) plane with probe marker oriented towards patients head.

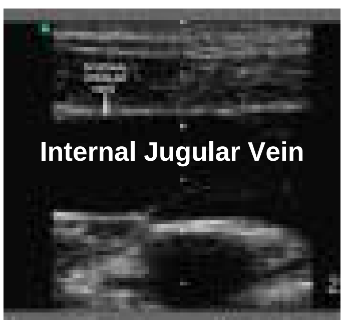

Image 2: Internal jugular vein (IJ) as seen in the longitudinal plane.

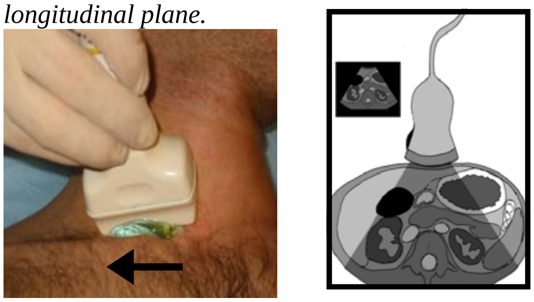

Image 3: Transverse plane with probe marker oriented towards patient's right.

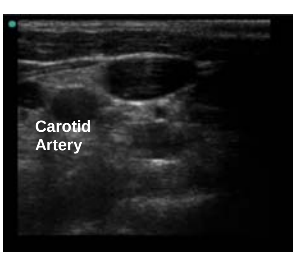

Image 4: Internal Jugular Vein and CarotidArtery as seen in the Transverse Plane.

Differentiating Artery from Vein Based on Sonographic Appearance

Both arteries and veins appear as round (transverse plane) or tubular (longitudinal plane) on ultrasound. However, several characteristics may be used to differentiate artery from vein:

1. Arteries appear smaller, thicker-walled, and more pulsatile
2. Veins are larger and thin-walled.
3. Veins collapse as downwards pressure is applied to the ultrasound probe. Note that veins become uncompressible when clot is present
4. Certain veins, such as the SC, will enlarge (engorge) with valsalva.

If pulse Doppler is available, arteries will have pulsatile waveforms while veins will have a more phasic appearance (see Image 5).

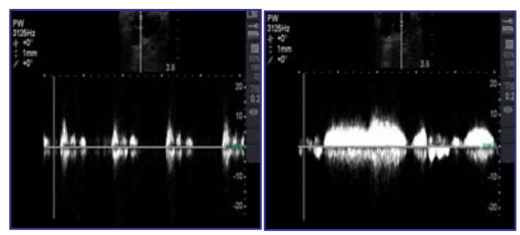

Image 5: With Pulse Doppler, arteries (image on the left) have a pulsatile waveform, while veins (image on right) have a more phasic appearance.

Prior to placing the CVC, it is recommended that a 'quick look' is done to ensure target vessel location and patency/compressibility and that no clots are present.

Approach to CVC

Central venous catheterization should be performed under sterile conditions utilizing the guidewire dilation (Seldinger) technique. This review will not detail the Seldinger technique, but rather focus on the utility of ultrasound and its role in CVC placement.

Common sites used for venous cannulation include the internal jugular (IJ), subclavian (SC), femoral (FV). The optimal approach in an

Table 1. Incidence of Acute and Infectious Complications in Relation to Site of CVC Insertion [5,12]

Site	Infection	Hemothorax or Pneumothrax	Vein Thrombosis
Femoral Vein (FV)	19.8%	--	21.5%
Internal Jugular (IJ)	8.6%	1.3%	0%
Subclavian Vein (SC)	4%	1.5%	1.2%

individual patient is determined by operator preference, experience, and the clinical setting and is reviewed elsewhere. However, Table 1 demonstrates the significantly higher rates of infection and vessel thrombosis in FV approach as compared to the IJ or SC. [5,12]

Internal jugular vein (IJ)

The IJ vein is the ideal location for US guided CVC placement. It is more easily visualized with ultrasound than SC, has a lower risk of pneumothorax as compared to the SC site, has ease of compressibility of the vessel in the event of bleeding or arterial puncture as compared to the SC site, decreased incidence of infection as compared to the FV site, and the straight path from the right IJ to the superior vena cava facilitates the passage of pulmonary artery catheters and temporary pacemakers into the heart (see Table 1.) However, IJ cannulation may be difficult in the patient who is unable to turn their head and in the acutely dyspneic patient who may not tolerate the recumbent position.

The Internal Jugular (IJ) is located in the triangle formed by the medial and lateral bellies of the sternocleinomastoid muscle and inferiorly by the clavicle. The vein courses lateral to the carotid artery and joins the subclavian vein to drain into the superior vena cava.

Longitudinal versus Transverse Approach to the IJ

The IJ can be located sonographically from both the longitudinal or transverse plane (see Images 1 and 3). Which approach is used depends on amount of space to place both ultrasound transducer and needle and physician comfort level. One small study of 17 emergency medicine residents without extensive ultrasound experience reported increased ease in learning the short-axis (transverse) approach versus the long-axis (longitudinal) approach. [1]

Subclavian Vein Approach

The subclavian vein approach has improved patient comfort, the lowest risk of infection, but an increased risk of pneumothorax due to proximity to the lung (see table 1). The subclavian vein courses posterior to the clavicle, making imaging with ultrasound difficult. The axillary vein, as it is called just distal to the first rib, is able to be imaged. The probe is placed in a longitudinal plane (probe marker towards patient's head) just inferior to the most lateral aspect of the clavicle. The axillary vein will be visualized deep to the clavicle and axillary artery.

Femoral Vein Approach

The femoral vein may be cannulated with no risk of pneumothorax, no interference with airway management or cardiopulmonary resuscitation, and relative patient comfort. Unfortunately, femoral vein catheterization has a 20% incidence of infectious and thrombotic complications, much higher when compared to the IJ or SC site (see table 1).

Locating the femoral vein songraphically is relatively straightforward, with the probe placed in a transverse plane (marker to the patient's right) just inferior to the inguinal ligament.

Dynamic versus Static Ultrasound Technique

Ultrasound may be used to assist in the placement of CVC's in two ways. The first is the dynamic, or 'real time' method, in which the probe is draped in a sterile sheath and used to guide the needle until vessel puncture. The other method, known as static, is one in which the ultrasound probe is used to assess for vessel location and patency prior to skin puncture, and then the procedure is performed without the use of further sonographic assistance.

In a randomized trial evaluate static ultrasound versus the traditional landmark method in 240 patients undergoing anesthesia, pre-puncture ultrasound visualization of the IJ vein allowed greater success of catheterization, especially in patients in whom surface landmarks were not apparent (success rate 78% without pre-puncture ultrasound versus 100% when ultrasound was utilized). [14] In a 2005 ED study designed to prospectively compare blind landmark, static and dynamic ultrasound for CVC placement, 201 CVC's were placed with an overall success rate of 98% for the dynamic method, 82% for the static method, and 64% for the traditional blind landmark method.[1] Once again, the 2001 AHRQ guidelines strongly recommend the real-time, dynamic method of ultrasound guidance for CVC placement.[1]

Preparing the transducer in a sterile sheath

Once CVC location has been chosen and a 'quick look' taken to ascertain target vessel location and patency, the ultrasound probe must be draped in a sterile sheath. A commercially available kit, which includes a plastic sheath, sterile ultrasound gel and rubber bands to secure the sheath to the probe (image 6) is recommended. If a kit is unavailable, a sterile glove with gel on the inside (sterile or non-sterile gel) and gel on the outside of the glove (sterile) may be used. It is important to have enough gel both inside the sheath covering the head of the transducer as well as outside the sheath. Lack of gel or air pockets will impede ultrasound transmission and result in poor image quality.

Image 6: Sterile probe sheath kit, including sterile gel, rubber bands and the plastic sheath. Image on the right is the probe draped in a sterile fashion, note that gel is both on the inside and outside of plastic sheath.

The transducer must be placed in the sheath in a sterile manner. This may be done using two people, one person with a specialized probe-holder, or else the sheath may be draped by one user by placing the hand in the sheath when grasping the probe (image 7). Once sheathed, rubber bands may be placed to secure it to the probe (image 6).

Image 7: Grasping probe in a sterile fashion

Procedure

Once CVC location has been chosen, a pre-procedure 'quick look' has been performed to assure vessel location and patency, and the probe has been draped in a sterile sheath, the patient and clinician performing the procedure should be prepped in the usual sterile manner. Note that if the static method is chosen, puncture location may be marked prior to sterile preparation and CVC placement can proceed according to standard procedure.

In using ultrasound to guide vessel puncture, a few important points must be kept in mind:

1. The image on the ultrasound monitor is a two-dimensional representation of three-dimensional structures.
2. The middle of the ultrasound image on the monitor corresponds to the middle of the ultrasound probe.
3. Some probes project a line, or needle track, onto the image to enhance the ability to guide the needle correctly.
4. Using basic geometry, skin puncture should occur at a 45-degree angle a distance from the probe that is equal to the depth of the vessel (see image 8). In other words, if the vessel is 2 cm below the skin surface, then ideal skin puncture should occur 2cm from the ultrasound probe at a 45-degree angle.

5. The majority of needles are sono-lucent, and thus vessel puncture may only be evident by vessel tenting from needle pressure and a small amount of flash artifact from the needle tip (see image 9). However, careful attention for the flash of blood in the syringe will indicate vessel puncture.
6. There are commercially available needles coated in a sonographically opaque material that allow greater visibility of the needle.
7. The needle may be guided in either the transverse or longitudinal orientation, depending on anatomic space and physician comfort level.Once flash of blood into the syringe occurs, the ultrasound probe may be placed aside and the remainder of the procedure continues as in the traditional landmark method.

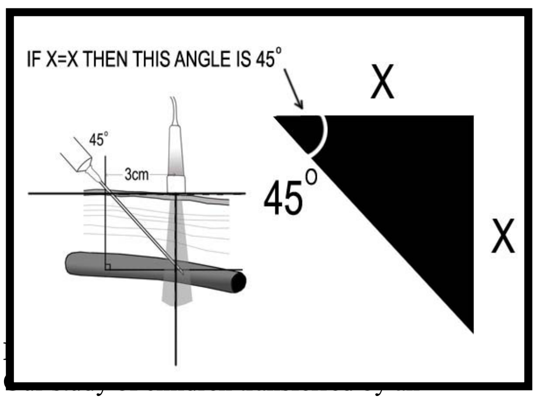

Image 8: If the needle punctures the skin at a 45-degree angle, then the distance from the probe (X) should be approximately equal to the depth of the target vessel (X).

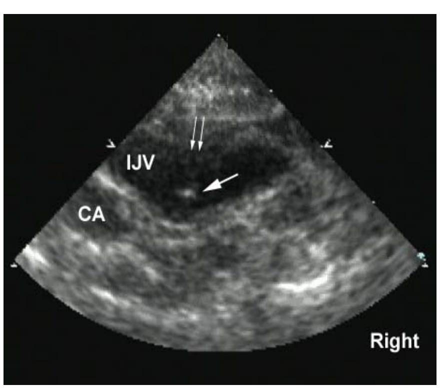

Image 9: Although the needle may not be visible on ultrasound, tenting of the vessel (double arrow) and flash artifact from the needle tip (single arrow) may be present to indicate target vessel puncture.

One-Person versus Two-Person Technique

Placement of CVC using ultrasound guidance may be performed as a one-person or a two-person technique. In the one-person technique, the ultrasound probe is held in the non-dominant hand and the needle in the dominant hand. Once vessel puncture occurs, the ultrasound probe is set aside and the procedure continues in standard fashion. In the two-person approach, the person performing the procedure is assisted by another person who holds the ultrasound probe.

Pitfalls in Ultrasound Guided CVC's

There are several pitfalls and difficulties specific to using ultrasound to guide the placement of CVC's. By far the greatest difficulty lies in acclimating to the additional coordination involved in using the ultrasound probe. Increasing the chance of success involves:

1. Stabilizing the hand holding the probe to minimize drift and thus move away from the target vessel.

2. Performing skin puncture the correct distance from the probe. Again, in referring to the triangle formed by vessel, probe and skin puncture, there should be a roughly equal distance from probe to vessel and from skin puncture to probe.

3. Not forgetting the patient! Oftentimes, the image on the ultrasound monitor becomes engrossing and attention must be continuously shifted from the screen to the patient. While the screen must be watched for needle movement and location, attention must also be on the patient and the syringe for blood flash. This is less of an issue in the two-person approach, in which the assistant holds the probe and observes the screen while the person performing the puncture maintains full attention on the patient.

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