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Use of Ultrasound for Central Venous Access

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Abstract

The use of ultrasound to guide central venous access has been suggested as one of the most important measures we can incorporate into our daily practice to improve patient safety. Though many physicians have embraced this recommendation, up to 41% do not agree that ultrasound guidance should be the standard of care for placement of central venous catheters in the internal jugular vein. This likely stems from a lack of knowledge of the relevant data as well as unfamiliarity with the technique. This chapter will review the evidence supporting ultrasound guidance for central venous access, review the technique, and suggest a program to allow for sufficient training.

Central venous catheterization is an essential component of the care of hospitalized patients. There are a number of indications for central line placement including hemodynamic monitoring, frequent blood draws, difficult peripheral access, urgent hemodialysis, parenteral nutrition, vasopressor support and long-term chemotherapy or antibiotic administration. More than 5 million central venous catheters (CVCs) are placed in the USA each year with an estimated complication rate of >15% [1, 2]. Mechanical complications such as pneumothorax or arterial puncture have been reported to be as high as 21%, and in some series more than 35% of attempts are unsuccessful [3, 4]. Factors that affect the complication and success rate include operator experience, urgency of placement and patient factors such as body habitus, prior difficult cannulation or coagulopathy [4–6].

Recent evidence suggests that placement of CVCs under ultrasound (US) guidance increases 1st-pass and overall success rate while decreasing complications. In the adult literature, there have been nine randomized trials (table 1) [7–15] as well as two meta-analyses [16, 17] that support the use of US guidance for the placement of internal jugular (IJ) CVCs. These data led both the Agency for Healthcare Research and Quality in the USA, and the National Institute of Clinical Excellence in the UK, to recommend the use of US guidance for CVC insertion [18, 19]. Many health care professionals consider US guidance for CVC insertion the standard of care, especially when used for the IJ vein position.

This chapter will review the technique of US central venous catheterization as it pertains to the IJ, subclavian (SC) and femoral vein sites. We will also provide recommendations for incorporating US training and use into daily clinical practice. The use of US for peripheral vein cannulation or for peripherally inserted central catheters is beyond the scope of this review.

Basic Physics of US Imaging

'Ultrasound' refers to sound with a frequency greater than 20 kHz (i.e. above the range of audible sound for humans). For the purposes of medical imaging the frequency used is generally between 3 and 20 MHz. There are several reviews describing the basic physics of US imaging. Briefly, an US pulse is generated by applying a voltage to piezoelectric crystals in the probe. The pulse is then directed into the tissue which reflects the sound back towards the probe. The reflected sound waves are then processed as an audio or visual signal. Doppler US transforms the sound waves from a moving object (i.e. red blood cells) into an amplified audio signal. The venous waveform is sufficiently distinct from the arterial waveform to allow localization of the central veins from arteries. For vascular access, Doppler US has been shown associated with a longer learning curve, takes

Table 1. Placement of CVCs under US guidance: nine randomized trials

Authors	n	Success, %		1st attempt, %		Time, s		Carotid puncture, %	
		US	landmark	US	landmark	US	landmark	US	landmark
Mallory et al., 1990 [7]	29	100	65	58	41				
Troianos et al., 1991 [8]	160	100	96	73	54	61	117	1	8
Denys et al., 1993 [9]	1,230	100	88	78	38	9.8	44.5	2	8
Slama et al., 1997 [10]	79	100	76	43	26	95	235	14	12
Teichgraber et al., 1997 [11]	100			96	52	15	51	0	12
Nadig et al., 1998 [12]	65	100	65		204	288	0	0	
Hayashi and Amano, 2002 [13]	188 (RVD)	97	96	86	84				
	52 (no RVD)	100	78	86	30			0	13
Leung et al., 2006 [15]	130	94	79	82	71				
Karakitsos et al., 2006 [14]	900	100	94			17	44	1.1	10.6

RVD = Respiratory venodilation.

longer to use for CVC insertion and is associated with a higher cost. As a result, Doppler guidance has been abandoned in favor of B-mode imaging. B-mode US (brightness mode) converts the reflected sound waves into a real-time grey scale image. Fluid (i.e. blood) is hypoechoic, and appears dark on the screen, while tissue is more isoechoic and appears grey. Unless otherwise stated the term US will refer to B-mode for the remainder of this chapter.

Technique

Even when using the direct method, the intended site for insertion should always be examined with US prior to creating a sterile field. This allows for the assessment of clot and the degree of overlap of the target vein on the associated artery. Preprocedure US visualization can also help identify possible vascular abnormalities that may impact on the success of the CVC insertion. In one study of hemodialysis patients, US abnormalities such as total occlusion, nonocclusive thrombus, stenosis and anatomic variation were found in 35% of patients prior to hemodialysis catheter insertion in the IJ vein. This led to a change in site selection in 75% of these patients [20].

There are two potential ways to use US to guide CVC insertion: the indirect method and the direct method. The indirect method involves visualizing the relationship between the artery and vein and planning the best angle of approach prior to creating a sterile field. US is not used during the actual CVC insertion. The direct method uses US to visualize the needle in real time as it enters the target vessel. One study comparing the direct to the both the indirect and landmark methods for CVC insertion showed that while use of either method improved outcomes when compared to the landmark technique, direct US visualization was the best method in terms of 1st-pass and overall success rate [21]. Furthermore, since even minor changes in position can greatly alter the relationship between the target vessel and its surrounding structures, we advocate the use of direct US guidance for CVC insertion.

In general, veins can usually be distinguished from arteries since they are compressible, nonpulsatile, and distend with the Trendelenburg position or Valsalva maneuver (online suppl. video 1). If the suspected vein is not compressible, it Video
may signify that there is an intraluminal thrombus which may or may not be seen directly by US. The IJ vein is typically anterior and lateral to the artery although significant anatomic variation exists, and it is crucial to note the effects of contralateral head rotation on the degree of overlap of the carotid by the IJ. The SC vein is usually inferior and anterior to the artery.

Once the appropriate vein is selected, the site is prepped and draped as per standard technique with full barrier precautions. The US probe is then placed in a sterile sheath. The probe is placed vertically on a stand, or the assistant holds the US probe vertically and conducting gel is applied to the probe. The operator then inserts a hand into the sterile sheath, takes hold of the probe and inverts the sheath over the probe to make both the probe and cable sterile. Additional sterile gel is then placed on the outside of the sheath to ensure adequate coupling. If an assistant is not available, and one does not have a stand with the US unit, the operator may hang the US probe from an IV pole, place sterile gel inside the sheath, and then grasp the probe from the pole, inverting the sheath as before to make the probe and cable sterile.

Once the US probe is inside the sterile sheath, it can be placed safely on the sterile field to allow the operator time to prepare the CVC insertion kit. Before beginning, it is important to make sure that the US screen is at a comfortable distance from the operator, and when possible, in the same line of vision as the desired insertion site. This will allow the operator to look back and forth from the US screen to the insertion site with minimal effort.

There are two possible methods for direct US-guided CVC insertion: the 'one-handed' method or the 'three-handed' method. In the one-handed method, the operator holds the US probe in the nondominant hand and the needle in the dominant hand. The 'three-handed' method requires an assistant in full sterile barrier precautions to hold the US probe while the operator directs the needle into the target vessel. While the 'three-handed' method may be easier for inexperienced operators learning how to place CVCs initially, the 'one-handed' method has been shown to improve 1st-pass success and overall procedural success when compared to the 'three-handed' method [21]. It also has the benefit of not requiring another operator in sterile precautions, and eliminates the need for communication between the primary operator and the assistant for proper positioning of the US probe. This is especially valid when using the transverse view as it is important to follow the needle tip into the vessel. With two operators, the operator controlling the US probe may see a hyperechoic dot that represents the middle of the needle as opposed to its tip. The 'one-handed' technique is the preferred method of US-guided CVC placement at our institution. As mentioned previously, using the US to mark the skin and proceed without real-time guidance is not recommended since many factors may alter the original position of the target vessel and its surrounding structures.

Once the desired method has been chosen, the target vein and associated artery are identified with US and centered on the screen. It is important at this time to pay careful attention to other objects on the US screen since in addition to minimizing arterial overlap, a path should be chosen that avoids any adjacent lymph nodes or muscle tissue. In order to help minimize this risk, the operator should use standard anatomic landmarks as the initial starting point of US probe placement and adjust the position accordingly to obtain the best view of the target vessel. It is thus important to remember the relationship of the US probe to the US screen. For this reason, all US probes have a groove or other mark that corresponds to a dot (or other mark) on the US screen. Prior to needle insertion (for the transverse approach) the operator should orient the probe such that the left of the probe is the left of the screen.

After an appropriate site has been identified, the lidocaine needle is inserted through the skin directly anterior to the vessel, and the wheal of subcutaneous lidocaine is visualized with the US as an enlarging hypoechoic area in the center of the screen. After allowing the topical anesthetic to take effect, the introducer needle is inserted into the same location. A 'finder' needle is not necessary as the target vein puncture will occur with real-time guidance. If using the 'one-handed' method, the operator may need to put the US probe down in order to pull the skin taut to allow the introducer needle to penetrate the skin. Once the introducer needle is through the skin, the probe is picked up with the nondominant hand and used to guide the needle into the vessel. The introducer needle will indent the anterior vein wall and may even penetrate the posterior wall, resulting in a flash of venous blood upon withdrawal of the needle. This 'double-wall' puncture occurs about 15–20% of the time and is directly related to the diameter of the target vessel [22]. This underscores the importance of choosing a site, head position, and angle of needle insertion that minimizes arterial-venous overlap.

Passage of the introducer needle into the IJ vein can be performed either with a transverse (short axis) view or a longitudinal (long axis) view (fig. 1). The transverse view has been associated with a shorter learning curve and can more easily identify smaller vessels. The longitudinal view provides better visualization of the advancing needle tip and may reduce the risk of posterior vessel wall perforation or injury. If using the transverse view, it is critical to follow the advancing needle tip with the US, making sure the plane of the US is not too proximal or distal (fig. 2). If using the longitudinal view, one needs to keep the US and needle in the same plane.

A needle guide is also available to assist with insertion of the introducer needle. This is a piece of plastic that attaches to the US probe over the sterile sheath. It is designed to angle the needle so that it will intersect with the center of the US beam at a given depth. There are different needle guides for different depths. Needle guides have been shown to improve 1st- and 2nd-pass success rates, but have not been shown to decrease the number of arterial sticks when compared to US guidance without the use of a guide. We generally find needle guides to be cumbersome, and an added step that is generally not required for more experienced operators.

Once the target vein is entered with the introducer needle, the US probe is placed on the field and the typical mod-

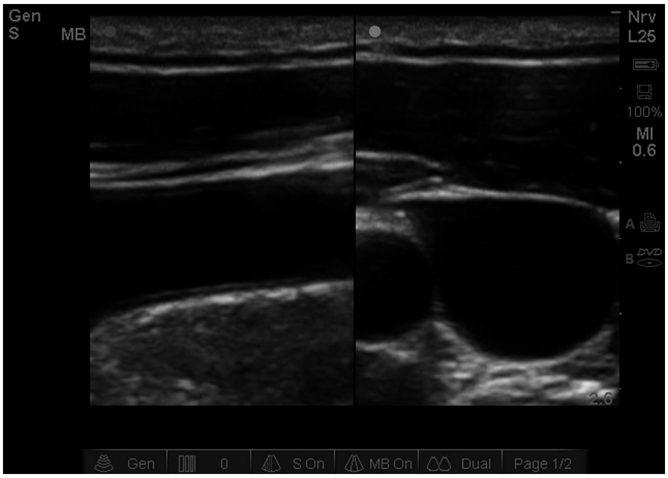

Fig. 1. Longitudinal and transverse view of right IJ and carotid (see online suppl video 2).

ified Seldinger technique is used to place the CVC. If there is any doubt as to whether or not the wire has been passed into the vein or artery, the US can be used to confirm wire placement in the target vessel prior to dilation.

Site-Specific Issues

IJ Vein

Most of the available evidence for the utility of US-guided CVC placement comes from studies that looked at the IJ vein site as the primary location [7–13, 16, 17, 23]. One possible reason for the beneficial effects of US in the IJ vein location is that the landmark technique does not allow for evaluation of arterial-venous overlap. In a prospective study of 1,136 patients, 54% of patients had more than 75% overlap of the carotid artery and IJ vein when the proposed path of the needle by landmark technique was examined by US [24]. It has been shown that contralateral head rotation increases the degree of overlap of the carotid by the IJ. As a result, if there is significant overlap of the IJ vein and carotid artery under US examination, the head should be returned to the neutral position and the relationship reexamined at varying degrees of head rotation before attempting US-guided cannulation.

US also allows for evaluation of IJ symmetry prior to choosing the ideal side of the body for attempted CVC insertion. There is considerable anatomic variation between patients, with more than 60% having a 2-fold difference in the size of the left and right IJ. Since vessel diameter is related to risk of posterior wall puncture [22] and likely overall success, US guidance allows the operator to choose both the optimal side and neck position prior to attempted IJ vein CVC insertion.

SC Vein

Some authors have suggested that given the more reliable anatomic position of the SC vein and the interference of the clavicle with obtaining a high quality image, the use of US guidance may actually hinder the placement of SC vein CVCs [1]. Unfortunately, there are limited data available to assess the efficacy of US for SC vein CVC insertion. One study in inexperienced operators showed that success rate improved from 44% with the landmark technique to 92% with US guidance while decreasing complication rate and number of needle sticks. Furthermore, failed landmark attempts could be converted to successful CVC placements with US 'salvage' 80% of the time [25]. Other studies that failed to show a benefit of US relied on Doppler and thus may not be applicable to the current B-mode US machines that most operators use. Some authors have advocated using US to enter the axillary vein more laterally in the infraclavicular position. However, since anatomic landmarks are not as reliable in this position, it is difficult to extrapolate these results to the more traditional landmark SC vein approach. At our institution we typically attempt SC vein cannulation using the landmark technique and use US guidance only as a 'salvage' strategy. Further work needs to be done to better evaluate the role of US in the insertion of SC vein CVCs.

Femoral Vein

As with the SC vein there is minimal evidence for the effect of US guidance on the placement of femoral vein catheters. In one randomized study of hemodialysis patients, US guidance was shown to improve 1st-pass success rate and overall procedural success, while reducing the number of femoral artery sticks, hematomas and the total length of the procedure [26]. Since femoral veins CVCs are known to have a higher incidence of both infectious and mechanical complications, most notably catheter-related bloodstream infections and deep venous thrombosis [2], the placement of femoral catheters is strongly discouraged at our institution, especially in critically ill patients. As a result, most femoral vein CVCs are placed in emergency situations where US guidance may or may not be readily available. These results suggest that if femoral vein CVC insertion needs to be undertaken for emergency reasons, it should be attempted with US guidance if the US device, and an operator trained to use it, are readily available. For an elective, but unavoidable, femoral vein CVC insertion we recommend the routine use of US guidance.

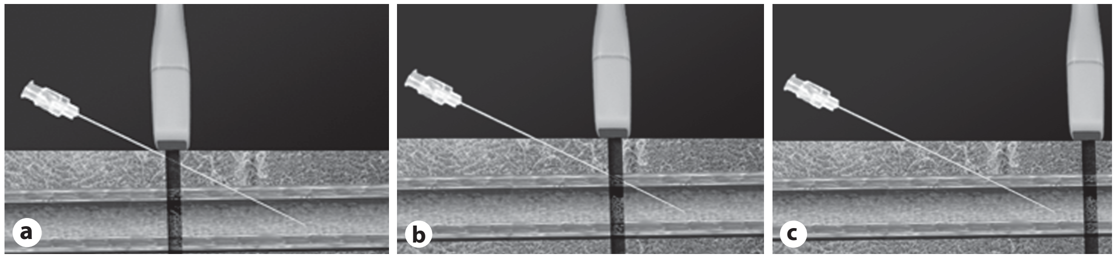

Fig. 2. Transverse US showing relationship of US plane to advancing needle tip (see online suppl video 3). Video

Confirming Line Placement

In addition to placement of CVCs, there is some evidence to suggest that US examination may be helpful in assessing for mechanical complications such as catheter tip malposition or pneumothorax. In one study of 85 CVC insertions, 10 misplacements and 1 pneumothorax were observed. The pneumothorax and all but one of the misplacements were detected by bedside US after the procedure. The time to obtain US confirmation was on the order of minutes, while radiographic confirmation routinely took longer than 1 h [27]. Another study looked at real-time US to assess for abnormal catheter or guidewire position in the ipsalateral IJ vein during SC vein CVC insertion. Using this approach, 42 of 49 (86%) malpositioned catheters were detected during the procedure and 81% were able to be repositioned at the time of detection [28]. The benefits of US confirmation are readily apparent – decreased time until the line can be used, decreased radiation exposure to the patient, and in some cases, real-time correction of aberrant placement that might decrease the time, risk and cost of the procedure. The use of US confirmation of CVC insertion may become more commonplace in the future as more physicians are trained in the use of bedside US. However, it has still not supplanted radiography as the standard of care in assessing for mechanical complications.

US Machine Requirements

US units have become smaller and more portable in recent years, making them well-suited for the ICU environment. For vascular access, a 7.5- to 10-MHz linear array transducer provides the best resolution and sufficient depth of visualization. There are a number of machines available, some designed specifically for vascular access, others with broader US applications. In addition to the US unit and transducer, sterile sheaths and sterile US gel are a necessary investment. A conservative estimate for the initial outlay required to perform US-guided CVC insertion is USD 25,000–40,000.

Cost Effectiveness

Given the initial expense and the fact that experienced operators are able to safely place CVCs with the landmark technique, it is reasonable to ask whether or not US-guided CVC insertion is cost-effective. A conservative analysis of US guidance in the National Health Service in the UK found that US use added only GBP £10/procedure, while potentially saving GBP £2,000 for every 1,000 procedures performed (assuming 90 prevented complications/1,000 procedures) [29]. It appears, at least in this analysis, that the use of US ultimately saved the health system money by avoiding potentially costly complications.

Implications for Training Programs

The use of US as both a diagnostic and procedural tool is not limited to radiologists. It is the responsibility of individual programs and hospitals to develop training and credentialing guidelines and to then incorporate them into our daily practice and fellowship training programs. A comprehensive approach to developing a formal training program for US-guided CVC insertion has been presented elsewhere [30].

Procedural skill requires integration of a knowledge base and psychomotor skill sets. In general, the learning curve for US vascular access is much steeper than other US procedures such as echocardiography and abdominal trauma exams. There are, however, no prospective data examining the appropriate amount of training and experience required to become proficient at US-guided CVC insertion. For the landmark technique, operators who have performed more than 50 insertions have half the complication rate of operators who have performed less than 50 [4]. For the operator who is already an expert at landmark CVC insertion we suggest 2–3 h of didactics, 2–4 h of lab training, and 5–10 proctored examinations as a minimum to ensure competency in US-guided CVC insertion, recognizing that certain operators may require more or less experience to become proficient. Lab training should include exposure to a variety of US units that the operator may encounter in clinical practice, examination of normal vascular anatomy on healthy volunteers as well as hands-on simulation with vascular access models. If possible, lab training should also include visualization of abnormal anatomy such as intraluminal thrombus, significant arterial-venous overlap or even anatomy in obese patients, since these factors all decrease the rate of success in landmark-based attempts. The proctored examinations should include US evaluation of normal anatomy followed by CVC insertion attempts on vascular models or simulators. Following this initial training, operators should undergo a knowledge assessment of the basics of US-guided CVC insertion to ensure that they have a firm grasp of the fundamental issues and techniques of US use. For the physician who is already experienced in CVC placement, we would recommend 2 proctored exams on real patients followed by a review of the next 5 US-guided CVCs.

Quality improvement measures need to be in place to ensure a comprehensive review of all complications. Skill maintenance is critical as well – at least 10 US-guided CVCs should be performed each year in order to maintain an acceptable level of proficiency.

Barriers to the Use of US for CVC Insertion

Despite the growing evidence that US guidance improves both success rate and safety of CVC insertion, especially in the IJ vein site, there has been some delay in adopting US into daily clinical practice. A survey of 250 anesthetists in the UK found that 41% disagreed with the recommendation that US imaging should be the preferred method for insertion of a CVC into the IJ vein [31]. In addition to the initial financial investment required to establish a program for US-guided CVC insertion, there are other barriers to its widespread use. One such barrier is the lack of knowledge among practitioners that US improves outcomes, a factor that has been directly related to the frequency of its use.

Limitations of US

It is important to recognize that while the current data suggest improved success rate and decreased risk of arterial puncture with US guidance, there are no prospective data linking US use to long-term outcomes such as mortality, length of stay, catheter-related bloodstream infections or catheter-related thrombosis. As mentioned previously, while the evidence is compelling for the IJ vein position, there is a relative paucity of information regarding US in other central venous access sites.

Conclusion

US has become an integral part of the examination and care of hospitalized patients. US-guided CVC insertion is relatively easy to learn and has been shown to decrease complications while improving both 1st-pass and overall success. For many physicians it has already become the standard of care. We strongly recommend the use of US guidance for CVC insertion in the IJ vein. We encourage US use for femoral vein CVC insertions where possible. We also advocate the use of US in SC vein insertion attempts, especially when anatomic landmarks are difficult to appreciate or the landmark approach has been previously unsuccessful.

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