Ultrasound guidance for vascular access

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The ability to establish central venous access efficiently is a fundamental skill for emergency physicians. Central venous access is essential for hemodynamic monitoring, volume resuscitation, and the delivery of vasoactive drugs\cite{1}. It is important in the management of shock and other conditions such as renal failure and complete heart block because it contributes to temporizing and life-saving therapies.

Traditionally, central venous access has been guided only by palpable anatomic landmarks such as bony prominences, muscle surfaces, and arterial pulsations. This “blind” approach to the central veins assumes anatomic homogeneity, does not account for the possibility of thrombosis, and depends on correct discernment of the relationship among multiple anatomic landmarks\cite{2}.

Research in emergency department (ED) and intensive care settings has supported the efficacy of traditional landmark approaches to the internal jugular vein (IJV), subclavian vein (SV), and femoral vein (FV) in adult\textsuperscript{[3–12]} and pediatric patients\textsuperscript{[13–16]}. Failure rates, however, have been reported as high as 30\% in some series\textsuperscript{[17]}. The failure rate has been demonstrated to be greater for emergent cases and highest for patients in cardiopulmonary arrest\textsuperscript{[18]}. Nonrandomized studies of central venous cannulation specifically for critical trauma\textsuperscript{[4,6,11]} or cardiopulmonary resuscitation\textsuperscript{[8,10,11]} have reported success rates ranging from 62\% to 99\%. One study of failed cardiopulmonary resuscitation cases demonstrated that 31\% of attempted FV catheters were not in the FV\textsuperscript{[19]}.

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Complication rates related to central line placement are reported to range from 0.3% to 18.8%, depending on the site of insertion, patient population, and definition of complications [17,20–22]. Acute complications associated with the landmark approach commonly include pneumothorax, arterial puncture, hemothorax, hematoma (subcutaneous or mediastinal), misplaced catheter tip, nerve injury, and dysrhythmia [16,17,23–25]. Cases of transient Horner syndrome and dysphonia after IJV catheterization have been reported in some series [21,26]. Death due to complications from a central venous line also has been reported [27]. The complication rate depends on the time needed for catheter insertion [22], the number of needle passes [28], the extremes of body habitus, previous central venous cannulation, prior surgery or radiation therapy in the area of the vein, and operator inexperience [20]. Characteristics associated with difficult or complicated central access include limited sites for access attempts (other catheters already in place, pacemaker, local surgery, or infection), known vascular abnormality, coagulopathy, mechanical ventilation or severely diminished pulmonary function (leading to worse morbidity from a possible pneumothorax), severe peripheral vascular disease, soft tissue edema, chronic intravenous drug use, and patient intolerance of supine position (orthopnea, increased intracranial pressure) [29–34]. Under these circumstances in which the margin for error is small, central venous access must be undertaken carefully.

Emergency medicine has developed an expanding familiarity with portable two-dimensional (2-D) real-time ultrasound (US) over the past decade [35]. In that time, a body of research has developed that supports US for guidance of central venous cannulation. Descriptions of US guidance for central venous access first were published in the anesthesiology literature and, subsequently, in the surgery, radiology, nephrology, critical care, and emergency medicine literature.

In 1978, Ullman and Stoelting [36] first described the use of a “pencil-shaped Doppler probe” to identify the “windstorm” sounds of the IJV to mark the overlying skin site for cannulation. Legler and Nugent [37] published the first experience with Doppler localization of the IJV before catheterization. In 1986, Yonei et al [38] first reported the use of 2-D real-time US guidance for cannulation of the IJV.

The first case series of 2-D US for central venous access in the ED was published in 1997 [39]. The reported technique involved two operators: one for line placement and one to hold the US probe. Since then, emergency physicians have published four studies on the use of US for vascular access in the ED [33,40–42]. These studies, which are reviewed below, reported favorable experiences and improved success rates for venous access with US guidance.

In 1997, the American College of Emergency Physicians (ACEP) published a policy statement on the use of US imaging by emergency physicians. In 2001, a revised policy statement and accompanying ACEP
guidelines specifically included US guidance for central venous access in a list of “primary applications for emergency ultrasound” [43].

Evidence for ultrasound-guided central venous access

In 2001, the Agency for Healthcare Research and Quality published an evidence-based report on patient safety practices. This report, which has been highly publicized in professional and lay media, includes a chapter on US guidance for central venous access. US guidance for central venous access was listed among 11 practices with the most highly rated “strength of evidence for supporting more widespread implementation” [44]. This report based its findings on much of the same literature that previously had been reviewed in a meta-analysis by Randolph et al [1]. The meta-analysis, published in 1996, reviewed eight randomized controlled trials of 2-D or Doppler US guidance versus the landmark method for central venous access. No studies of FV access were included. A significant decrease in the failure rate, complication rate, and number of attempts for successful access of the SV and the IJV were reported. A subsequent meta-analysis commissioned by the British National Institute for Clinical Excellence (NICE) was published in 2003 [45]. It included 18 randomized controlled trials published through October 2001. These trials compared 2-D real-time or Doppler US with the landmark method for central venous access. The meta-analysis considered risk of failed placement, complications, failure on the first attempt, number of attempts to successful access, and time to successful access as outcome measures. These outcome measures were analyzed by type of vein studied (IJV, SV, and FV), by US method (2-D and Doppler), and by age category (adult and infant). This meta-analysis concluded that 2-D US guidance was more effective than the landmark method for all outcomes for IJV access in adults. The relative risks of failed attempts, complications, and failed first attempts were reduced by 86%, 57%, and 41%, respectively. Significantly fewer attempts were required for success, and the IJV was successfully accessed more quickly when using US. Limited evidence suggested that 2-D US guidance reduced the relative risk of failed access in the SV and FV.

The three studies of IJV access in infants included in the meta-analysis were limited by small sample size [46–48]; however, the analysis suggested that 2-D US was more effective in these studies. Using US, the relative risk of failed placements and complications in infants was reduced by 85% and 73%, respectively. No studies of SV or FV access among infants were included in the meta-analysis. The investigators [45] also undertook a cost-effectiveness analysis of 2-D US guidance based on the evidence from their systematic review of the literature. The analysis of a simple decision analytic model suggested that US guidance avoided 90 arterial punctures for every 1000 patients and reduced costs by a negligible amount (approximately $5).
per patient. Given the evidence for its superior efficacy, the recent Agency for Healthcare Research and Quality mandate for improving patient safety, and the 2001 ACEP emergency US guidelines, US guidance for central venous access has been transformed from an interesting novelty to an important skill for emergency physicians to acquire.

General technical issues

There are several commonly accepted variations of US guidance: indirect, direct or real-time, free-hand, mechanical guide, and Doppler. Choosing among these approaches mostly depends on the location of the vessel to be cannulated and the specific characteristics of the operator, patient, and the equipment at hand. In addition, vessel visualization can be obtained in two different ways: in the long axis or the short axis. A solid understanding of these technical issues is necessary to successfully cannulate a vessel, regardless of the approach used or the location of the vessel.

Indirect method

The indirect method employs the least amount of actual guidance. With this approach, US is used only to identify the vessel and then center it on the US screen (Fig. 1). Next, a temporary mark is placed on the skin that corresponds to the vessel’s subcutaneous position. This mark is used for the puncture site after US identifies the target vessel’s location, dimensions, and depth below the skin. The easiest way to accurately make this mark is to identify the point where the center of the transducer overlies the skin surface just above the center of the vessel (Figs. 2 and 3).

Fig. 1. IJV and carotid artery viewed in their short axes.
There is no direct visualization of the needle as it enters the vessel, however. This technique has been used for localization and cannulation of larger structures but has been criticized for not taking full advantage of the potential of US for greater precision [49]. Mansfield et al [20] compared the indirect method of US guidance with the standard landmark approach for SV cannulation. This study was closed after an interim analysis of 824 patients showed that US guidance by the indirect method had no effect on the rate of complications or failures.

**Real-time visualization**

The alternative to the indirect method is to perform needle placement under direct, or real-time, US guidance so that the entire procedure is visualized continuously. With this technique, a sterile sheath whose tip is filled with transmission gel is unrolled over the transducer (Fig. 4). The

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**Fig. 2.** Subcutaneous location of IJV is identified on the skin surface.

**Fig. 3.** Subcutaneous location of IJV is marked on the skin surface.
A transducer is then placed on the skin and the target vessel is identified and centered on the viewing screen. With the other hand, local anesthetic is injected at a point corresponding to the middle of the US transducer. After anesthetization is achieved, the cannulation needle is advanced through the skin.

After the skin has been punctured, the operator can switch visual focus to the US monitor where the needle will appear sonographically as an echogenic line with a ring-down artifact (Fig. 5). Advancement of the needle is then guided by viewing its progression on the US monitor. When the operator visualizes the needle piercing the anterior wall of the vessel (Fig. 6) and after the subsequent flash of blood into the syringe, the transducer is placed aside and the remaining aspects of the procedure can be completed normally.

Few studies have compared indirect and real-time US guidance methods for insertion of venous catheters. Nadig et al [50] randomized 73 patients to an external landmark or a real-time US guidance of IJV cannulation. There were 87 unsuccessful attempts among 37 patients in whom cannulation was performed using the indirect method. In comparison, there were only 10
unsuccessful attempts among the 36 patients who underwent real-time US guidance.

**Mechanical guides**

A mechanical guide is an attachment to the US transducer that controls the depth, angle, and trajectory of the needle during cannulation (Fig. 7). In addition to venous cannulation, mechanical guides are used for many other US-guided invasive procedures, including amniocentesis, follicle retrieval, cordocentesis, biopsies, and fluid aspiration [51–54]. The approach uses an attachment to the transducer that provides a fixed trajectory for the needle. Advancement of the needle through the designated path ensures a predictable, uniform trajectory of the needle relative to the transducer. This stability may be particularly advantageous for inexperienced operators.
because it incorporates control of the transducer’s placement with the needle’s angle of entry [55].

The use of mechanical guides has some notable disadvantages. It requires investing in an additional piece of equipment that makes large, linear transducers even bulkier. Mechanical guides restrict the angle of the needle and the skin entry point. This restriction prevents the operator from continuously redirecting the needle as may be needed in certain cases [56]. Lastly, the fixed angle of entry may make some superficial structures difficult to access [57].

The largest study to evaluate needle-guided US was published by Denys et al [58]. This nonrandomized study reported a 100% success rate for US guidance among 928 patients. In comparison, the success rate for the landmark approach was 88% among 302 patients. With needle-guided US, there also was a significant improvement in venous access time (9.8 versus 44.5 seconds), carotid puncture rate (1.7% versus 8.3%), brachial plexus irritation (0.4% versus 1.7%), hematoma development (0.2% versus 3.3%), and average number of attempts to success (1.3 versus 2.5).

Free-hand method

The alternative to using a needle-guide system is to perform the procedure using the free-hand technique. In this situation, the transducer and the advancing needle are positioned and stabilized with the operator’s or an assistant’s hands (Fig. 8). Continuous fine adjustments can be made in the needle’s direction and in the transducer’s view. Although it generally is considered to be a more technically demanding procedure, this approach offers more flexibility for the operator. In addition, if an assistant is available, he or she can hold the transducer on a site distant from the needle entry point, thereby removing it from the sterile field [57] and potentially increasing the speed with which the target vein can be cannulated.
Another variable to consider is the axis of visualization for the target vessel. For the short-axis approach, the vessel is identified in the transverse plane and centered under the transducer (see Fig. 1). The midpoint of the transducer then becomes a reference point for insertion of the needle. The needle is inserted at a 45° angle to the transducer (Fig. 9). As the needle is advanced, the tip is visualized as it approaches the anterior wall of the vessel. After contacting the anterior wall of the vessel, further insertion of the needle will cause posterior displacement of the vessel wall (Fig. 10). A flash of blood in the syringe signifies that the needle has entered the vessel. At this point, the transducer can be set aside and the rest of the procedure performed normally.
In contrast, the long-axis approach identifies the vessel in its long axis and involves lining up the transducer over the greatest anterior–posterior diameter of the vessel (Fig. 11). The needle is then inserted through the skin just off one end of the transducer in a plane that is in line with the long axis of the transducer and at an approximate 30° angle to the skin surface (Fig. 12). As the needle is advanced, its progress through the subcutaneous tissue is monitored in real-time on the US screen (Fig. 13). After the needle has punctured the anterior wall of the vessel and a flash of blood is apparent in the syringe, the transducer can be set aside and the rest of the procedure completed normally.

In the authors’ experience, the advantages of the short-axis over the long-axis approach are that it is easier to perform in anatomic areas where space
is limited (eg, neck), inexperienced users can acquire proficiency more quickly, and smaller vessels (eg, deep brachial vein) are more consistently visualized. On the other hand, performing the procedure along the vessel’s long axis allows much better visualization of the advancing needle tip and, therefore, may avoid inadvertent punctures of the posterior vessel wall (Fig. 14). A study that compared the short- and long-axis approaches with vascular access found that novice users could perform cannulation more quickly using the short-axis approach. There was, however, no statistically

Fig. 13. Real-time visualization of needle through subcutaneous tissue.

Fig. 14. Needle visualized perforating posterior (post.) vessel wall.
significant difference in terms of mean difficulty, number of skin breaks, and mean number of needle redirections [59].

Doppler method

Historically, Doppler US for venous access has not been used in many American EDs, most likely because these EDs purchased real-time 2-D US machines. These multipurpose machines have been favored over purchasing additional equipment that is needed to implement the Doppler method. In the interim, research has shown 2-D real-time US to be superior to Doppler for central venous access [45]. The authors expect most future research on US-guided techniques to focus on 2-D real-time US.

Internal jugular vein approach

Anatomic considerations

The IJV is the most studied vein for US-guided catheterization. It usually lies anterior and slightly lateral to the carotid artery. It normally is larger in diameter than the carotid artery and expands in diameter with a Valsalva maneuver [60]. Many studies have documented its anatomic variations with regard to potential complications. Yonei et al [38] first reported the use of real-time US guidance for IJV cannulation in 1986. In this series, central lines were placed successfully in 160 intensive care patients without complication. In 1991, Denys and Uretsky [61] reported a series of 200 patients who underwent IJV cannulation in the cardiac catheterization laboratory, coronary care unit, and intensive care unit. The investigators found anatomic anomalies of the IJV (small diameter, unresponsiveness to Valsalva maneuver, and unexpected lateral or medial displacement) in 8% of patients.

Troianos et al [62] reported the largest case series for determining the anatomic relationship between the IJV and carotid artery. Among 1009 patients admitted for surgery, 54% had an IJV overlying the carotid artery, rather than coursing it laterally, as expected. This anomalous anatomy might predispose the patients to arterial punctures if the needle traversed the IJV.

In a prospective series of 31 patients with known difficult central venous access, Hatfield and Bodenham [29] reported a success rate of 100% using real-time US guidance for 22 patients. Among the remaining 9 patients, for whom indirect US guidance was used, 66% were cannulated successfully within three attempts. Of 23 patients who had been referred specifically because of prior difficulties with or complications from cannulation, 16 had an anatomic reason for difficulty that was determined by US.

Docktor et al [63] reported a 100% success rate with real-time US guidance in a prospective series of 150 patients referred for nonemergent central venous access. Using US, the investigators were able to document the phenomenon of double wall puncture among 30 patients. Double wall
puncture occurs in cases of an IJV with low pressure. The anterior wall is pushed against the posterior wall before the needle punctures it. If the carotid artery is located underneath the vein along the needle tract, then a double wall puncture can extend into the carotid artery. In this study, the IJV was visualized directly over the carotid artery in 25% of cases. The investigators surmised that this high rate was partially due to variable transducer positioning and different degrees of head rotation. The only complications were two cases of carotid artery puncture. These occurred among patients whose IJV was visualized to lie directly over the carotid artery. Based on their findings, the investigators recommended using real-time US to visualize the anatomic relationship between the IJV and carotid artery and then determining the optimal needle track that would miss the carotid artery in the event of a double wall puncture.

Denys et al [58] compared real-time US guidance that used a transducer needle guide with the landmark approach in 1230 patients who had IJV cannulation. Among patients in the US-guidance group, 3.4% had a right IJV that was not visualized or was deemed too small to cannulate. In all of these cases, the left IJV was successfully cannulated. The investigators also recognized the double wall phenomenon, commenting, “the IJV is actually compressed completely by the needle before the vessel is penetrated. The needle must be advanced a little deeper and then retracted slightly to be positioned in the center of the lumen.” This finding underscores the need to identify an underlying carotid artery.

Evidence-based analysis

Eleven of the 18 articles included in the 2003 NICE-sponsored meta-analysis investigated the IJV approach in adults [45]. Of these 11 studies, 7 used real-time US guidance and 4 used Doppler US guidance. Notable improvements over the landmark approach were demonstrated with real-time US guidance. The relative risk of failed first attempts was 0.59 (95% confidence interval: 0.39–0.88, \( P = 0.009 \)) and the relative risk of failed catheter placement was 0.14 (95% confidence interval: 0.06–0.33, \( P < 0.0001 \)). The relative risk of complications decreased by 57%, the mean number of attempts to successful cannulation decreased by 1.5, and the mean time to successful cannulation decreased by almost 70 seconds (all \( P < 0.02 \)).

Subsequent to the meta-analysis, another randomized trial that compared real-time US with the landmark approach among intubated patients undergoing elective surgery was published [64]. This study investigated the use of indirect US guidance with two different frequency transducers: 7.5 MHz and 3.75 MHz. In measuring the number of successful first attempts, mean number of attempts to success, and rate of complications, the investigators discovered no significant differences between the two frequencies. They noted that the 7.5-MHz transducer visualized structures with higher resolution but that “the image quality of 3.75 MHz was acceptable
for the purpose of locating the IJV and CA.” When the results of two US groups were pooled for comparison to the landmark group, the rate of successful first attempts showed improvement (73% versus 86%, $P<0.05$); however, no statistically significant differences were found regarding the overall success or complication rates. The investigators noted that in a subset of 52 patients who lacked the anatomic landmark of respiratory jugular venodilation (visible bulging of the vein beneath the skin synchronized with inspiration of positive-pressure ventilation) on which they traditionally depended, US guidance was superior to the landmark approach for all outcomes. The number of successful first attempts was almost tripled (86% versus 30%, $P<0.001$) and the number of successful cannulations was greatly improved (100% versus 78%, $P<0.05$). There were no complications among the US-guided attempts, whereas the landmark approach was associated with three carotid artery punctures. These results, although not surprising, further support the use of US guidance, especially for patients with poor percutaneous landmarks.

Emergency medicine literature

Hudson and Rose [39] first reported the use of US guidance for IJV cannulation specifically in the ED in 1997. In this article, they described their successful experience in 2 patients with challenging percutaneous landmarks due to severe skin graft scarring or morbid obesity. Since then, two prospective studies of ED patients have been published. Hrics et al [41] reported a small case series in which patients who needed central venous access within 1 hour of arrival to the ED underwent cannulation either with real-time or indirect US guidance. The success rates were 87.5% among the 8 patients in the real-time US group and 71% among the 24 patients in the indirect US group. Miller et al [33] have published the only trial as yet of real-time US versus a landmark approach in the ED setting. This trial was pseudorandomized. It used odd- and even-day assignment of 122 patients to real-time US guidance or to the landmark approach to the IJV, SV, FV, or peripheral vein. It did not analyze results by the type of vein cannulated; however, the largest subgroup (55%) of the US-guided cases were for IJV cannulation. The investigators noted an overall decrease in the mean time to successful cannulation and number of attempts when using US. These improvements occurred across the range of operator experience.

Subclavian vein approach

Anatomic considerations

As with the IJV, the SV offers ideal size for central access. Its proximity to structures such as the lung, subclavian artery, and brachial plexus, however, can lead to significant morbidity. Other challenges for accessing the SV with US guidance are its deeper location and the presence of the
clavicle bone. Because bone does not transmit US waves, placing the transducer over it provides no information to guide the operator.

US guidance can be used to cannulate the SV in its midportion as is most commonly taught with the landmark approach. In this case, the apex of the lung can be less than 1 cm away from the SV [65]. Attempting US visualization of the SV in short axis also can be challenging in this location because it involves holding the transducer on top of the clavicle. Maintaining appropriate pressure for the transducer over the clavicle can be uncomfortable for the patient and may add to the technical difficulty of this approach.

**Supraclavicular approach**

Due to its inherent anatomy, the supraclavicular approach to the SV is troublesome to achieve with US guidance. In most patients, little space is available for the transducer to be placed concurrently with needle insertion, which makes real-time US guidance difficult at best. Two alternatives for successful US-guided supraclavicular approach exist. The first is to use the indirect method (previously described). Another alternative is to use the low-IJV approach. This approach has been found to be a safe and direct route to the superior vena cava and right atrium for US-guided central venous access. Silberzweig and Mitty [66] investigated 116 low-IJV punctures among 109 patients in the interventional radiology suite. They reported no complications and an average of 1.2 attempts (range, 1–3) needed for success.

**Axillary approach**

Yet another approach is to access the SV more laterally on the shoulder so that the needle cannulates the axillary vein. This more distal approach eliminates the problem of holding the transducer over the uneven surface of the clavicle and removes the potential for the placed catheter to be pinched between the subclavius muscle and the costoclavicular ligament complex associated with the standard approach [67]. It also decreases the risk of pneumothorax because the lung generally is farther away from the vascular structures in the lateral shoulder. A misplaced needle passing through the axillary vein will travel posteriorly through the axillary fat and layers of muscle and, finally, to the scapula, thereby missing the pleural space [68]. The landmark approach to the axillary has been demonstrated to be safe in adults [69] and critically ill infants and children [70].

Potential advantages for using the axillary approach specifically in the ED include easier access for patients in cervical collars or with neck trauma. Using this more lateral approach in critical trauma patients may also allow for more efficient simultaneous management of the airway and acquisition of central access. In addition, the landmark approach to the axillary vein has been reported to be efficacious among severe burn victims who often present with burns of the face, neck, and proximal shoulders [71].
Drawbacks of the axillary approach include the decreased diameter and deeper location of the axillary vein compared with the SV. Smaller caliber and deeper location may lead to difficulty visualizing it with a high-frequency transducer, especially in larger patients, and may increase the need for a longer catheter to reach the vena cava in larger patients. No studies specifically comparing the axillary and SV approaches have been published.

**Evidence-based analysis**

Four studies of SV access were included in the 2003 NICE-sponsored meta-analysis [45]. Of these, three used Doppler US guidance and one used real-time US guidance. The real-time US study evaluated 53 cannulation attempts among 32 critically ill patients in a combined trauma and medical intensive care unit [55]. The investigators used the axillary vein approach for US guidance and reported an improved success rate compared with the landmark method (92% versus 44%, \( P = 0.003 \)). With US guidance, there was also a decrease in the complication rate (4% versus 41%, \( P = 0.002 \)), the mean number of attempts (1.4 versus 2.5, \( P = 0.0007 \)), and the mean number of insertion kits used (1.0 versus 1.4, \( P = 0.0003 \)). Malpositioned catheters in the landmark group also led to the need for additional chest radiographs.

Fry et al [30] reported 100% success with the US-guided placement of 43 SV catheters in patients who had relative contraindications to the landmark approach. The investigators subjectively noted that awake patients who have US-guided access “seem less apprehensive.” The investigators further suggested that “the ability to watch what is going on via the ultrasound video screen, a decrease in the number of attempts, and better local anesthesia along the intended needle path” contribute to improved patient satisfaction with US guidance.

**Femoral vein approach**

**Anatomic considerations**

Modern study of the FV has discovered variations from generally accepted anatomy. Reviewing CT scans of the pelvis in 100 patients, Baum et al [72] discovered that a portion of the FV and the femoral artery overlaps in the anteroposterior plane 65% of the time. A subsequent study that used US in 50 intensive care unit patients confirmed this finding: “in most patients there was overlap of the artery over the vein far closer to the inguinal ligament than conventional anatomical textbooks would indicate” [73]. Furthermore, landmarks were not predictive of the underlying anatomy that was documented on US.

**Evidence-based analysis**

Only one randomized trial of US guidance for FV access has been published. This trial was undertaken among 20 patients undergoing cardio-
pulmonary resuscitation in the ED [40]. Compared with the landmark approach, real-time US had a higher success rate (90% versus 65%, \( P = 0.058 \)), a lower mean number of needle passes (2.3 \( \pm \) 3 versus 5.0 \( \pm \) 5, \( P = 0.006 \)), and a lower rate of arterial catheterization (0% versus 20%, \( P = 0.025 \)). The investigators suggested that the better performance of US was due to the ability to localize a nonpalpable FV by visualizing it instead. They also noted that chest compressions were associated with changes in FV diameter visualized on US. This finding is contrary to the expectation of arterial pulsations with chest compressions. It implies that palpat ing for a pulse during cardiopulmonary resuscitation as part of the landmark approach may be misleading. Furthermore, the color and pulsatility of returning blood may be unreliable for predicting arterial or venous source, especially in patients whose oxygen saturation is low [74]. This study demonstrated the ability of US to accurately identify the FV without dependence on these traditional signs. In a prospective series, Kwon et al [75] reported a 100% success rate among 28 patients who needed acute hemodialysis access. Compared with 38 patients with the landmark approach, these patients experienced a higher rate of successful first attempts (92.9% versus 55.3%, \( P < 0.05 \)) and improved mean total procedure time (45.1 \( \pm \) 18.8 versus 79.4 \( \pm \) 61.7 seconds, \( P < 0.05 \)). Femoral artery puncture occurred in 7.1% of US cases compared with 15.8% of landmark cases.

**Peripheral veins**

The subset of ED patients with poor peripheral access is well known to many emergency nurses and physicians. US offers a potential alternative to central venous access, surgical cutdowns, and blind, deep brachial vein catheterization for patients who need simple intravenous access but have no palpable or visible peripheral veins. Studies of peripherally inserted central venous catheter lines have shown that real-time US guidance is safe and successful in adult [76,77] and pediatric populations [78].

A case series of US-guided brachial and basilic vein cannulation among 100 ED patients with difficult intravenous access demonstrated a 91% overall success rate and a 73% rate of success on first attempt [42]. Two cases of brachial artery puncture were reported. The mean time to successful cannulation was 77 \( \pm \) 129 seconds (range, 4–600 seconds). No trials that have compared US guidance with the landmark approach have been published.

**Issues in pediatric patients**

**Procedural challenges**

Central venous access in infants and children is challenging under any circumstances. There are various possible reasons for the greater morbidity associated with central venous cannulation in pediatric patients: superficial
anatomic landmarks may be less distinct, vessel diameters are generally smaller, the proximity of important anatomic structures may be greater, there may be less patient cooperation than among adults, anatomic anomalies may be present, and nonpediatric specialists may not be as experienced with pediatric vascular access [46,79]. For these reasons, US guidance should be integrated into methods of central venous access for pediatric patients in the ED.

Evidence for ultrasound guidance in pediatric patients

Studies of real-time US guidance for central vein cannulation in pediatric patients currently are found mainly in the anesthesia literature. Three randomized trials of US guidance versus landmark method for IJV cannulation among infants and children have been published [46–48]. These trials and at least four case series [34,79–81] constitute the current body of evidence that supports the application of US guidance in pediatric patients. The 2003 NICE-sponsored meta-analysis used the three trials to determine overall relative risk reductions of 85% for failed placement and 73% for complications of IJV cannulation in pediatric patients [45].

Anatomic factors contribute to complications of the landmark approach to IJV cannulation in children. Alderson et al [46] determined that 18% of patients aged 3 days to 5.5 years had anatomic variations of the IJV. The investigators reported a superior success rate (100% versus 80%), shorter mean time to successful cannulation (27.4 versus 48.9 seconds), and lower mean number of attempts (1.37 versus 2.0) with US guidance. Two patients in the landmark group and one in the US group suffered a carotid artery puncture.

In comparing real-time US to the landmark approach for IJV cannulation among 95 infants aged 12 months or less who underwent elective cardiovascular surgery, Verghese et al [47] found that the US approach significantly improved success and complication rates. US guidance was successful and had no associated carotid artery punctures. In contrast, the landmark method had a 77% success rate and a 25% rate of carotid artery puncture. Almost half of the patients with carotid artery puncture sustained additional complications, including hemothorax, pneumothorax, jugular venous hematoma, catheter kinking, and threading difficulty. Among the subset of patients with unsuccessful landmark attempts, 25% were subsequently successfully catheterized under US guidance.

In a subsequent study, Verghese et al [48] found statistically significant improvements in the success rate and median number of attempts with real-time US guidance over the landmark approach. The small sample size of 16 patients in each group, however, limited the statistical evaluation of trends toward improved time to successful cannulation and complication rates. Three carotid artery punctures occurred using the landmark approach compared with one using real-time US guidance.
Limitations of pediatric emergency department ultrasound-guided venous cannulation

The three existing trials have been criticized for their relatively small sample sizes of less than 100 patients each. Because these trials reported results only with IJV access, definitive conclusions regarding other venous sites presently are impossible. No studies have been reported on SV cannulation and only one small study reported the successful use of real-time US to facilitate FV catheterization [34]. Although the pediatric studies consistently have reported positive findings for IJV cannulation, the importation of their success in the well-controlled, elective setting of scheduled surgery to the acute circumstances in the ED has yet to be demonstrated. To date, no studies of US-guided venous cannulation conducted in the pediatric ED setting have been published.

Limitations of emergency department ultrasound-guided venous access

Transducer type

Most US-guided vascular access is performed using a linear, high-frequency (6–10 MHz) transducer. The linear transducer provides a larger field of view compared with a sector transducer. This larger field of view allows visualization of the advancing needle through its entire course. In addition, because most of the target vessels are superficial, a high-frequency transducer can be used that yields superior resolution of the subcutaneous tissues, the advancing needle, and the vessels to be cannulated or avoided.

As a separate purchase, the cost of a linear, high-frequency transducer can be prohibitive. Some EDs may not have budgeted for additional transducers when they originally acquired US equipment. Consequently, many emergency physicians do not have access to this transducer.

Another approach is to use the large curvilinear transducer commonly used for abdominal imaging; however, this transducer has some drawbacks for real-time US guidance. Typically, the large curvilinear probe is bulkier than a linear transducer, and its lower-frequency images can make the procedure more technically challenging. The curvilinear transducer’s greatest obstacle is its curved visual field. Although the center of the visual field is relatively linear, the lateral aspects of the screen are curved to the extent that advancement of the needle under real-time US guidance is distorted. One possibility is to use the curvilinear transducer for indirect guidance, but this approach has not been formally studied.

Another approach is to use an endovaginal transducer for US-guided vascular access. This transducer is a common component of many ED US systems and its use for venous access has been promoted in the gynecologic and emergency medicine literature [82,83]. It has been described only for the short-axis approach to the IJV, and efficacy was not studied. For physicians
with access to only the curvilinear or endovaginal transducer, the endovaginal transducer may be the superior choice.

**Sterile barrier**

Another equipment issue unique to US-guided vascular access is that a sterile barrier typically is needed. Such barriers usually are designed to cover both the transducer and its cable (see Fig. 4) and allow sterile performance by a single operator.

Although there are many relatively inexpensive varieties of sterile transducer covers, occasionally, one may not be available. In this case, other alternatives can be employed. The easiest method is to use a sterile glove. A conducting agent is placed inside the glove wherever the largest uninterrupted flat surface is located. An assistant can then place the transducer inside the glove. The operator then folds back the fingers of the glove and holds the transducer so that the flat surface of the glove forms the scanning surface for the transducer. It is important to eliminate any air bubbles that may be interposed between the glove and the transducer’s scanning surface because they would compromise image quality severely.

**Mechanical guides**

Mechanical guides typically come in two forms. The first is a built-in needle slot within the central or side portion of the transducer that directs the needle at a predetermined angle within the plane of view of the US beam. Another form is a separate guide that can be fitted to a transducer (see Fig. 7). Presently, these guides are not interchangeable among different transducers. Most companies manufacture them for each linear transducer that they produce. Mechanical guides may not be necessary, especially for experienced operators [55].

**Education and training aids**

A significant issue pertaining to US-guided vascular access is the time and cost of training new operators. It is unfortunate that practical education for US-guided venous access currently is not available, and standard methods for teaching other US examinations, such as normal or dialysis models, cadavers, swine, or simulators, have significant limitations.

Because the procedure is invasive, practicing on normal or dialysis models is problematic. Although the anatomy of cadavers may demonstrate vascular structures well [84], the entry site would be revealed after the initial puncture, thereby limiting the educational benefits for subsequent students. Swine or other animal models not only have unique vascular anatomy but ethical and cost issues also limit their use. Lastly, although simulation would seem to be an attractive alternative, only one vascular model currently exists. This model is limited to teaching peripheral vein cannulation using
landmarks, not US guidance [85]. A newer development in the area of US-guided vascular access education is the use of phantoms. Phantoms are generally easy and inexpensive to produce. They simulate vessels well and, hence, the mechanics of US-guided cannulation.

**Time to cannulation and operator experience**

The time required to set up and complete the procedure commonly is considered a drawback to US-guided vascular access. As with any novel procedure, there is a learning curve; however, this curve has been shown to be short and steep [58]. Improved results have been demonstrated across the spectrum of operator experience [86]. Furthermore, due to fewer failed attempts, the average time to vessel cannulation is the same as or is decreased with US guidance versus the landmark technique.

Hilty et al [40] compared US-guided FV cannulation with the landmark approach in 20 patients presenting in cardiac arrest. The average time to flash of blood under US guidance was 30.8 ± 32 seconds versus 33.8 ± 35 seconds for the landmark technique. Time to cannulation also was decreased with US guidance (121.0 ± 60 versus 124.2 ± 69 seconds). In another study that compared the short- and long-axis approaches on a US phantom, the mean time to cannulation was 2.36 minutes versus 5.02 minutes, which was statistically significant [59]. Although it did not compare landmark and US-guided approaches, this study suggests that shorter intervals to vessel cannulation can be obtained, especially for inexperienced operators, when the vessel is approached in the short axis.

**Summary**

The evidence that supports the general application of US guidance for venous access in the ED has reached a critical mass. The increasing familiarity of emergency physicians with US and the recent focus on patient safety and clinical outcomes has intensified attention on the capacity for US to improve patient care in the ED. US guidance can increase the safety and efficiency of venous access procedures and offers improved outcomes. The potential for these improvements is compelling, especially among certain types of ED patients such as those with difficult or complicated access. Varying levels of evidence support the use of US guidance over the traditional landmark approach for venous access in adult and pediatric populations and for central and peripheral veins. Many different techniques may be applied, depending on the clinical situation and equipment available.

**References**


