Ultrasound First, Second, and Last for Vascular Access

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Invited paper

The Sound Judgment Series consists of invited articles highlighting the clinical value of using ultrasound first in specific clinical diagnoses where ultrasound has shown comparative or superior value. The series is meant to serve as an educational tool for medical and sonography students and clinical practitioners and may help integrate ultrasound into clinical practice.

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Abbreviations
IV, intravenous

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Vascular access is the most commonly performed invasive procedure in medicine. For more than 20 years, ultrasound has been shown to improve the success and decrease complications of central venous access; however, it is still not universally used for this procedure. Ultrasound may also be used to facilitate difficult peripheral vascular access, potentially avoiding other more invasive procedures such as central or intraosseus vascular access. This article reviews some of the indications and evidence for ultrasound-guided vascular access, provides tips for successful ultrasound guidance, and discusses barriers to adoption.

Key Words—emergency ultrasound; patient safety; procedures; ultrasound; vascular access

Venipuncture and vascular access are the most commonly performed invasive procedures in medicine. It is estimated that there are nearly 300 million vascular catheters placed annually in the United States, with 3 to 5 million of these being central venous catheters.[1,2] Vascular access is a routine part of modern medicine; however, even peripheral access can sometimes be difficult, and mechanical complications have historically occurred in 5% to 19% of central venous catheter procedures.[3]

Ultrasound guidance has been shown to increase the success and decrease complications associated with vascular access. Although evidence is strongest for the use of ultrasound guidance in central venous catheterization at the internal jugular site, evidence of the benefit ultrasound guidance for other central sites, arterial puncture, and peripheral venous access continues to accrue.[4–6]

Despite numerous recommendations from professional societies and other organizations, ultrasound guidance is not being used as widely as it should be. In 2002, the National Institute for Health and Care Excellence in Great Britain recommended ultrasound guidance for central venous catheter placement.[7] Following that recommendation, a 2004 survey found that although British anesthesiologists were aware of the recommendation, more than 60% were neutral or disagreed with the statement that "2-dimensional imaging ultrasound is the preferred method for insertion of central venous catheter into

the internal jugular vein," and nearly three-fourths of respondents did not think the recommendations could be implemented.[7,8] As of 2008 only 27% of senior anesthetists in Great Britain reported using ultrasound guidance as their first-choice technique for internal jugular vein cannulation.[9] A 2012 survey of more than 500 anesthesiologists in the United States found that more than half were "equivocal" or disagreed with the statement that "when available, real-time ultrasound guidance should be used for guidance during venous access when the internal jugular vein is selected for cannulation."[10]

There are several reasons why the actual adoption of ultrasound guidance for vascular access, as with many advances in health care, has been slower than expected.[11] In addition to simple resistance to change, the adoption of ultrasound guidance for vascular access suffers from a need for specialized equipment as well as the training required to effectively implement user-dependent technology. These challenges are acknowledged; however, equipment is increasingly available, and training for vascular access has become more accessible, particularly in the simulated setting. The care of our patients can be improved if practitioners who perform vascular access know when and how to use ultrasound guidance.

Ultrasound First: Central Venous Access

In 1996, now nearly 20 years ago, a meta-analysis of ultrasound guidance for central venous catheter placement concluded that "compared with the landmark technique for placement of internal jugular and subclavian central venous catheters, ultrasound guidance significantly increases the probability of successful catheter placement, significantly reduces the number of complications encountered during catheter placement, and significantly decreases the need for multiple catheter placement attempts."[12] Ultrasound guidance for central venous catheter placement has been endorsed as a key safety measure by both the Agency for Healthcare Quality and Research[13] in the United States and the National Institute for Health and Care Excellence[7] in Great Britain for more than a decade. Guidelines from 14 professional societies in addition to the American Institute of Ultrasound in Medicine have definitively recommended that ultrasound be used for central venous catheter placement, particularly when an internal jugular approach is used.[5,6,13–15] The strength and breadth of these recommendations and the length of time that they have been in place suggest that ultrasound guidance for internal jugular and femoral central venous catheter placement should now be standard practice. Anyone routinely placing central venous catheters in the United States (and throughout the developed world) should have access to ultrasound equipment, should have appropriate training in the use of ultrasound guidance for central venous catheter placement, and should use ultrasound guidance for all elective central venous catheter placements in these sites.

Both the internal jugular and femoral approaches are very amenable to ultrasound guidance. The internal jugular site, in particular, is often challenging to approach with a landmark method because of anatomic variations and other structures in the neck. Although the femoral vein is consistently located medial to the femoral artery when accessed high enough, ultrasound imaging helps avoid arterial puncture and shows the optimal location of the femoral vein for access.

Many clinicians continue to prefer a subclavian approach for central venous catheters because of the relative reliability of the anatomy, experience with the procedure, and slightly lower infection rates.[1] However, complications from a blind subclavian approach include pneumothorax in 1.5% to 3.1% of attempts and hemothorax in 0.4% to 0.6%, both serious or even life-threatening complications that are nearly nonexistent with the internal jugular or femoral approach.[3] An early large trial of ultrasound localization did not show a benefit, although dynamic guidance was not used.[16] A more recent trial, however, did show markedly improved success and decreased complications with dynamic ultrasound guidance at the subclavian site.[17] Ultrasound guidance for the subclavian approach is hindered by shadowing from the clavicle, and in many cases, what actually may be visualized more easily with ultrasound guidance and cannulated is the axillary vein, which then joins the subclavian vein.[18]

Whether ultrasound-guided central venous catheter placement is legally a "standard of care" will need to be decided by the judicial system. Although a "customary standard of practice" (ie, what most physicians do) may be argued, increasingly, states are shifting away from this idea when the evidence is strong and consistently endorsed by leading societies.[19] A 2009 opinion piece in the *Journal of Cardiothoracic and Vascular Anesthesia* argued that ultrasound guidance for central venous access meets the "Bolam principle" (established in a landmark legal case regarding the standard of care in 1957) that "the standard of care must be in accordance with a responsible body of medical opinion and evidence, even if there are doctors who differ in opinion."[20] It is likely that, as an "evolving technology," teaching centers will be expected to adopt ultrasound guidance as the standard of care, followed by community practice.[19]

Ultrasound First: Arterial Access

Arterial access is typically obtained for monitoring diagnostic and therapeutic catheterization procedures. Vascular complications are estimated to occur in 1.5% to 4% of diagnostic and interventional cardiac catheterization procedures.[21,22] A recent trial of more than 1000 patients undergoing femoral artery cannulation showed that ultrasound guidance improved the first-pass success rate (from 46% to 83%), reduced the number of attempts (from 3.0 to 1.3), reduced the risk of venipuncture (from 15.8% to 2.4%), and reduced the median time to access (from 148 to 136 seconds).[23] Use of ultrasound guidance in this trial also yielded lower vascular complications than fluoroscopy (1.4% versus 3.4%) in addition to not exposing the patient or clinician to ionizing radiation.[23] The radial artery may also be used for cardiac catheterization procedures and is the site typically accessed for arterial monitoring. The radial artery is small and may be difficult to access via palpation. A meta-analysis of ultrasound guidance for radial artery catheterization showed that ultrasound guidance markedly improved the first-pass success rate (from 27% to 43%).[24] Another trial showed that ultrasound guidance improved the first-pass success rate and time for radial artery cannulation when used by non–ultrasound-trained interventional cardiologists.[25]

Ultrasound Second: Difficult or Failed Peripheral Access

Ultrasound guidance may not be necessary as a first-line adjunct for peripheral venous access. However, when the landmark technique fails ultrasound guidance used by emergency physicians for peripheral intravenous (IV) access has been shown to improve the success rate, decrease the time required to obtain access, and increase patient satisfaction with the procedure.[26] Access via an external jugular approach is often considered if an IV line is not obtainable in the extremities; however, ultrasound guidance in the extremities has been shown to achieve better success, even when the external jugular vein is well visualized.[27] Peripheral IV lines are most often inserted by nurses, and ultrasound use by nurses has also been shown to yield a high success rate in patients with difficult access.[28] The Emergency Nurses Association lists ultrasound guidance as the first option when IV access is difficult.[29] For peripherally inserted central catheters, ultrasound guidance has been shown to increase success rates and decrease thrombosis.[30]

Pediatric patients may present special challenges even for routine IV placement given the smaller size of their veins. Ultrasound guidance for peripheral access in children with difficult access has been shown to improve success rates, decrease the time to cannulation, and decrease the number of attempts required for peripheral IV lines.[31,32] Infants may be particularly challenging, and ultrasound guidance has been shown to achieve success rates of greater than 95% for accessing the saphenous vein, even in children younger than 6 months.[33]

Ultrasound Last: Before Attempting Central Venous or Intraosseus Access

Central venous access may be the route of choice for longer-term intensive care, dialysis, and vasoactive medication administration. A central venous catheter may be considered when peripheral access is not obtainable, even when central access might otherwise not be desired. If ultrasound guidance can improve the success of peripheral vascular access, unnecessary central catheters (and their accompanying infectious and mechanical complications) may be avoided. Two recent studies in the emergency department setting have shown that using ultrasound guidance for difficult peripheral access can decrease the rate of central access, with one study showing an 80% decrease in central venous catheter use when ultrasound-guided peripheral access was consistently used.[34,35] Use of ultrasound guidance for peripheral access in the intensive care unit has been shown to decrease reliance on central venous catheters in this setting as well.[36] Another option is to use ultrasound to help access the internal jugular vein when using a peripheral catheter.[37]

Another option for failed peripheral access is intraosseous access, an option that is often described as a second line for vascular access in children.[38] Although intraosseous access can be accomplished relatively quickly and effectively and may be warranted in a truly emergent situation (such as cardiac arrest or shock), the technique is not without complications. These complications are typically cited as less common than complications associated with central venous access but include extravasation, iatrogenic fracture, growth plate injury, infection, fat emboli, compartment syndrome, and osteomyelitis.[39] A clinical practice guideline from the Emergency Nurses Association lists ultrasound-guided vascular access as the first-line choice before intraosseous access.[29] A recent study found that "real-world" use of intraosseous devices may result in lower success and higher complications than previously reported.[40] Perceived pain may also be substantially higher for intraosseous access compared to peripheral IV access.[41] However, head-to-head trials of ultrasound-guided versus intraosseous vascular access in terms of the time required, effectiveness, and patient satisfaction are lacking.

The Real World

Although there are many published studies demonstrating the benefit of ultrasound guidance for vascular access, simply placing an ultrasound probe on the patient does not ensure success. Some published reports highlight issues such as posterior wall penetration resulting from failure to track the needle tip appropriately when using the ultrasound image.[42,43] A recent randomized study of emergency physicians who had ultrasound training but limited experience in ultrasound-guided peripheral venous access failed to show a benefit for ultrasound guidance.[44] Published trials on the learning curve of ultrasound guidance for peripheral and central vascular access are lacking, and there is likely a range of how quickly and effectively practitioners are able to adopt it. However, learning to effectively use ultrasound guidance for difficult peripheral access is among the more challenging procedures performed in the emergency department, typically requiring 20 to 30 procedures to obtain true competence. Paradoxically, ultrasound guidance for central venous access is often easier because of the size of the vessels, but complications of central venous catheter placement are more severe if they occur. Using a stepwise approach in which clinicians learn to place peripheral catheters under ultrasound guidance would help ensure safety and success when ultrasound is then used to place catheters centrally.

Obtaining vascular access when necessary can be considered a core competency for physicians. A recent editorial comment in the *Annals of Emergency Medicine* about ultrasound guidance for difficult peripheral access stated: "Rather than commit the time and resources to ultrasound guidance, practitioners without extensive experience with this technique should pursue further attempts at standard cannulation or consider central line placement to obtain venous catheterization for patients with difficult peripheral access."[44] Practitioners who use this tool routinely and effectively objected to this statement.[45] Efforts to increase and improve training for providers who perform vascular access, particularly in medical school and residency, should be emphasized.[46]

Techniques and Tips

Success using ultrasound guidance for vascular access requires 3 things: (1) appropriate equipment and preparation; (2) optimal vessel selection; and (3) effectively using ultrasound to understand and guide the needle tip position. This discussion will focus on ultrasound-guided peripheral access. However, the needle guidance techniques are generalizable to other vascular access procedures and ultrasound-guided procedures in general. A more comprehensive description of different types and sites of access is beyond the scope of this article and has been published elsewhere.[5,6]

Although other probes have been described, a high-frequency linear probe with depth set to about 2 cm is recommended. Use of a high-frequency probe improves resolution and needle visualization, and the linear face of the probe allows the needle to be placed and visualized on the screen directly where it is located under the probe. Ultrasound-guided peripheral venous access usually targets vessels that are deeper than those that can be visualized or palpated by using a landmark technique. Intravenous catheters typically used during a landmark approach are 1.25 in long and will not be able to reach or remain in deeper vessels. It is recommended that longer catheters be used. Depending on the vessel size and depth, we typically use 1.88-in, 20-gauge needles or 2.5-in, 18-gauge needles, with longer catheters tending to stay in place more consistently. Even longer catheters (up to 15 cm) and placement techniques that incorporate the Seldinger method have been described for ultrasound-guided peripheral access.[47,48] Echogenic needle tips may enhance visualization, although a recent study did not show an advantage in using them for vascular access.[49] Needle guides are also available for vascular access, but most experienced users do not use them, as they involve another step in the process and can limit the flexibility of the approach.

When choosing a vessel in the upper extremity, occasionally a deep antecubital vessel may be visualized, but often the basilic vein in the medial upper arm (not paired with an artery) or a brachial vein (adjacent to the artery) is used.[50] Choosing a vein of maximal diameter and optimal depth will help ensure success. Veins that are very shallow can usually be visualized or palpated and are often compressed by an ultrasound probe, hindering cannulation. Success is more likely in veins that are 4 mm or greater in diameter and between 3 and 15 mm deep.[51]

Ultrasound can be used to assist vascular access in a "static" technique (visualize the vessel and then place the ultrasound device aside) or can be used to guide a "dynamic" technique (real-time visualization of needle positioning using ultrasound). Within the dynamic technique, a two-operator (one operator visualizing the vessel using ultrasound and the other performing the procedure) or a one-operator (ultrasound probe in one hand and needle in the other) approach may be used. Multiple studies have shown that dynamic guidance is superior to static guidance, and real-time dynamic guidance is recommended.[6]

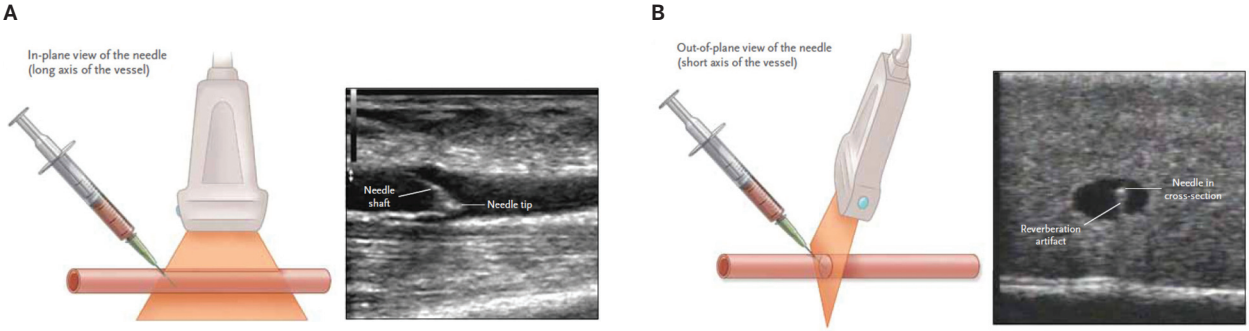
Studies comparing a one-person to a two-person dynamic technique have not found a significant difference in success rates[26,52,53]; however, it is the opinion of this author and the recent consensus of experts that the one-person dynamic technique is preferred.[5] Not only does this technique reduce the number of experienced personnel required to perform the procedure, but it also allows for fine adjustments and tracking of the needle tip position, which are difficult when the person holding the probe is different from the one holding the needle.[5]

The plane of visualization when using ultrasound may be described relative to the structure (in this case a vessel) or relative to the needle. Although the terms "short axis" and "long axis" in the literature are often used interchangeably when describing vascular access, the terms "in plane" and "out of plane" are more accurate to describe the ultrasound plane relative to the needle. This factor becomes important in other procedures, such as nerve blocks, when a short-axis view of the nerve is obtained but the needle is visualized in the ultrasound plane (thus, in plane).[54,55]

Vessels will always be accessed in the long axis (needle parallel to the vessel); however, there is some controversy over whether an in-plane or an out-of-plane orientation for the ultrasound probe is preferable.[56–58] A schematic and accompanying ultrasound image for each approach are shown in Figure 1. When properly aligned, the in-plane approach (long axis of the vessel) provides the advantage of visualizing the entire shaft and tip of the needle. However, particularly in smaller vessels that may not be completely straight, it can be challenging to keep the ultrasound plane centered over the middle of the vessel with the needle in view. The out-of-plane orientation (short axis of the vessel) has the disadvantage that the ultrasound plane may cut across the shaft of the needle proximal to the tip, underestimating the tip depth. However, an out-of-plane orientation has the advantage of ensuring that the needle is directed over the center of the vessel and allows the vessel to be visualized more easily.

A recent study found that a short-axis, out-of-plane orientation resulted in higher success rates for ultrasound-guided peripheral access.[57] To use and teach this technique correctly, it is essential to understand and locate the needle tip relative to the vessel dynamically as it is advanced. As the needle is advanced, the ultrasound probe should "fanned" or rocked distally and proximally to locate the needle tip, usually seen as a bright or hyperechoic dot on the screen. Visualizing the location of the needle tip in tissue may be enhanced by jiggling the needle slightly. Each time the needle is advanced, the tip should be located again by fanning the probe, advancing the needle tip slowly toward the middle of the vessel. The heel of the hand can be stabilized on the patient as the needle is advanced. With proper direction, the needle will indent and then puncture the vessel wall. When positioned properly, the needle tip should then form a bull's eye or target sign with the tip exactly in the center of the vessel (Figure 2A). Most importantly, as the ultrasound probe is fanned distally, the needle tip should disappear from the ultrasound view, ensuring that the tip is centered in the vessel both side to side and top to bottom and that the shaft and tip are not continuing more deeply through the far wall of the vessel. We call this view the "vanishing target sign" (Figure 2B).[59] When this sign is present, the catheter or wire can then be advanced with intraluminal placement ensured.

Figure 1. In-plane and out-of-plane needle visualization. Panel **A** shows the vessel being accessed in the long axis, with the needle visualized in the ultrasound plane. This approach has the advantage of being able to visualize the entire needle tip; however, it can be difficult to keep the needle centered and the plane aligned. Panel **B** shows the vessel being accessed in the short axis, with the needle perpendicular to the ultrasound plane. This approach allows centering of the needle within the vessel but can make it more difficult to locate the tip, as the ultrasound plane may cut across the needle proximally. Used with permission from Moore and Copel.[54]



Training, Education, and Simulation

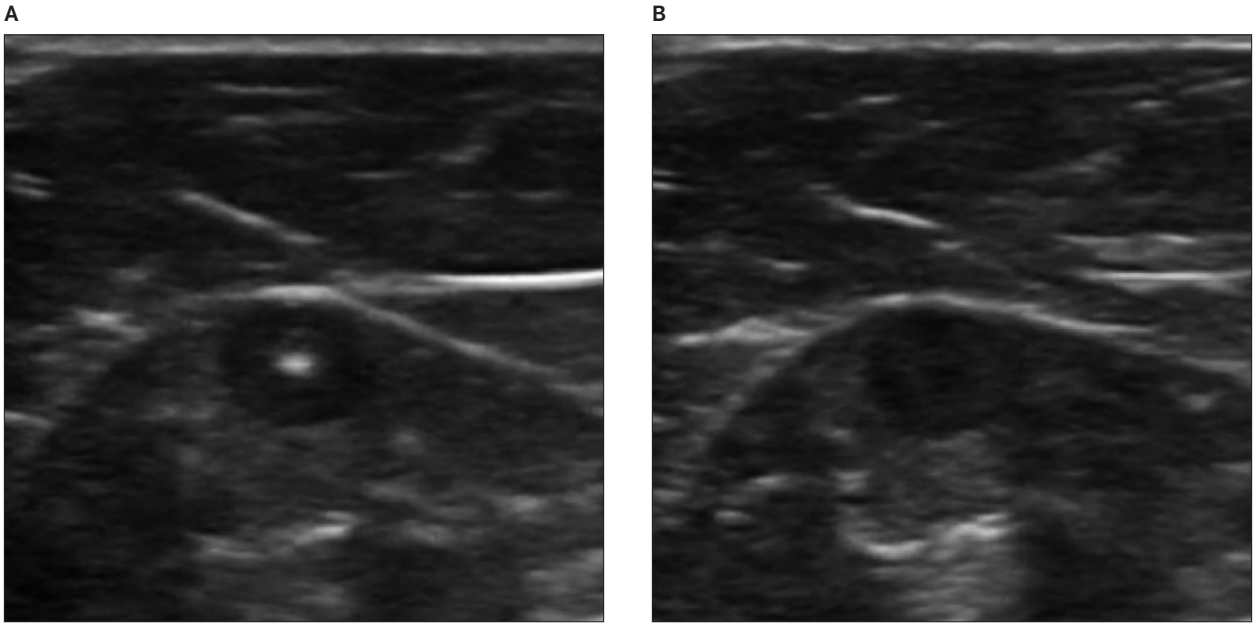
As with diagnostic ultrasound imaging, ultrasound guidance for vascular access is a user-dependent technology. Published research regarding what is required to ensure and maintain competency is scant; however, training and practice will undoubtedly improve use and success. For central venous access, some experts have recommended a minimum of 10 supervised ultrasound-guided access procedures, in addition to any training for the procedure itself.[6] Another recent consensus statement did not delineate a specific number but noted that training should include "principles and practice of ultrasound, instruction in the techniques of ultrasound guidance for vascular access, and assessment of competency in a simulated or actual patient care setting."[5]

Medical simulation is increasingly being used to train users and to assess performance and skill decay. Simulated ultrasound-guided vascular access offers an excellent method for learning and assessing this technique, and there are currently many high-quality, anatomically accurate vascular phantoms available. It is also possible to construct phantoms for lower cost using easily obtained ingredients.[60] Simulation training in central venous catheter placement has been shown to improve performance in clinical practice as well as to increase the use of ultrasound for central venous catheter guidance.[46,61] Further research into the amount and type of training required to reach and maintain competency in ultrasound-guided vascular access is needed.

Conclusions

Ultrasound is a proven tool that can increase success and decrease complications in a wide variety of vascular access procedures. Ultrasound guidance by trained practitioners should be the first-line standard for central vascular access and arterial access procedures. Ultrasound guidance as a second-line approach can achieve success in difficult peripheral vascular access, potentially avoiding other more invasive procedures such as intraosseus and central venous catheter placement. In the 21st century, institutions and individuals who perform vascular access should invest in resources and training to use ultrasound guidance as appropriate for vascular access.

Figure 2. The vanishing target sign.[59] In panel **A**, the needle tip is visualized in a peripheral vein by using an out-of-plane orientation, with the vessel seen in the short axis and the needle tip exactly in the center of the vessel (bull's eye or target sign). In panel **B**, as the ultrasound plane is fanned distally, the target sign disappears, creating the vanishing target sign. This view ensures that the tip is located exactly in the middle of the lumen, and that the ultrasound plane is not cutting across the needle shaft proximally.



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