

Ultrasound imaging in vascular access

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Physicians spend a considerable amount of time and effort inserting catheters and needles into patients. Central venous catheters are the mainstay of measuring hemodynamic variables that cannot be assessed by noninvasive procedures. These catheters also allow hemodialysis, parenteral nutritional support, delivery of medications, and catecholamine administration. Arterial pressure catheters are frequently used for hemodynamic monitoring and for obtaining arterial blood gases in critically ill patients. Such use of arterial and central venous catheters, however, is potentially associated with severe complications that can be injurious to patients and expensive to treat. Techniques involving the use of ana-

tomic landmarks have been the traditional mainstay of accessing the central venous system for decades. With the development and refinement of portable and affordable high-resolution ultrasound devices, imaging vascular access has changed the role of the traditional landmark techniques. In this article, we explain the use of ultrasound for vascular access to reduce complications associated with cannulation of veins and arteries. We will also provide a brief overview of the current literature regarding ultrasound-guided vascular access. (Crit Care Med 2007; 35[Suppl.]:S178-S185)

KEY WORDS: medical subject headings; ultrasound; catheterization; complications; arterial vessel access

In experienced hands, the landmark-based techniques have usually provided inexpensive and efficient central venous access (1-5). Historically, performing blind puncture procedures depended greatly on a correct knowledge of vascular anatomy and clinical experience. Until recently, however, there has been limited detailed information about the clinical nature of vascular puncture processing. Basic anatomic findings effectively underlie situations such as anomalies in anatomy of vascular structures, dependency on the patient's movements, and an increased variability of vessel position related to adhesive structures of the perivascular area. The landmark method fails, irrespective of anatomy, if the vein has thrombosed and may lead the operator to pass the needle in an inappropriate direction. All can result in a difficult puncture with or without complications. Thus, as early as in 1984, authors have recommended utilizing ultrasound guidance to optimize the success rate of cannulations and to minimize complications (6).

Vascular Access and Puncture Procedure

The following veins are frequently used for a central venous catheter: the internal jugular, femoral or subclavian vein, and to a lesser extent, the axillary vein. Using ultrasound for peripheral vein puncture has been described for paramedics and staff in the emergency department (7). The basilic or cephalic vein can also be used for peripherally placed central venous catheters. The femoral, axillary, or radial arteries are common access sites for the arterial system.

There are a number of different puncture techniques for vascular access. Currently, most physicians use only anatomic landmarks to guide vascular access. With this method, optimized positioning of the patient and accurate marking of standard anatomic landmarks are required to guide the puncture procedure. Compared with the landmark technique, the use of an acoustic Doppler provides for more accurate guidance of the puncture procedure. Detected signals with an acoustic Doppler reflect arterial or venous signals by a single A-scan line. Within this line, there is usually either a high-frequency signal of an artery or a low-frequency signal for a vein when the vessel is directly under the A-scanning probe.

The ultrasound procedure of choice is the two-dimensional ultrasound scan, or so-called B-scan; a B-scan is a depiction

of several A-lines transformed into a signal that is almost identical to an anatomic depiction of the subcutaneous structures. Currently, there is an increasing trend toward minimal invasive endovascular procedures (e.g., vascular surgery, coronary angioplasty). Parallel to this trend, however, is an increasing rate of iatrogenic pseudoaneurysms, fistulas, or hematomas, which may greatly alter subsequent vascular access options. B-scan imaging can be performed to detect these lesions (8). With color-Doppler imaging, irregular blood flow or differences in flow velocity can be measured. This can be helpful in determining the access site and in optimizing the exact localization of catheter placement.

The needle can be guided through the tissue directly or indirectly. In indirect ultrasound guidance, ultrasound scans are performed before puncture and needle insertion is without ultrasound. We think that this technique is not the best choice for vessel cannulation when very precise needle placement is required but that this may be suitable in other situations, such as in the drainage of pleural effusions.

Direct ultrasound guidance visualizes the needle in real time, throughout the puncture process. A technical option is to use accessory needle guidance devices that fit exactly on the probe to control the needle trajectory. However, we prefer the direct free-hand puncture technique for more flexibility. With this technique, one

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The authors have not disclosed any potential conflicts of interest.

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DOI: 10.1097/01.CCM.0000260629.86351.A5

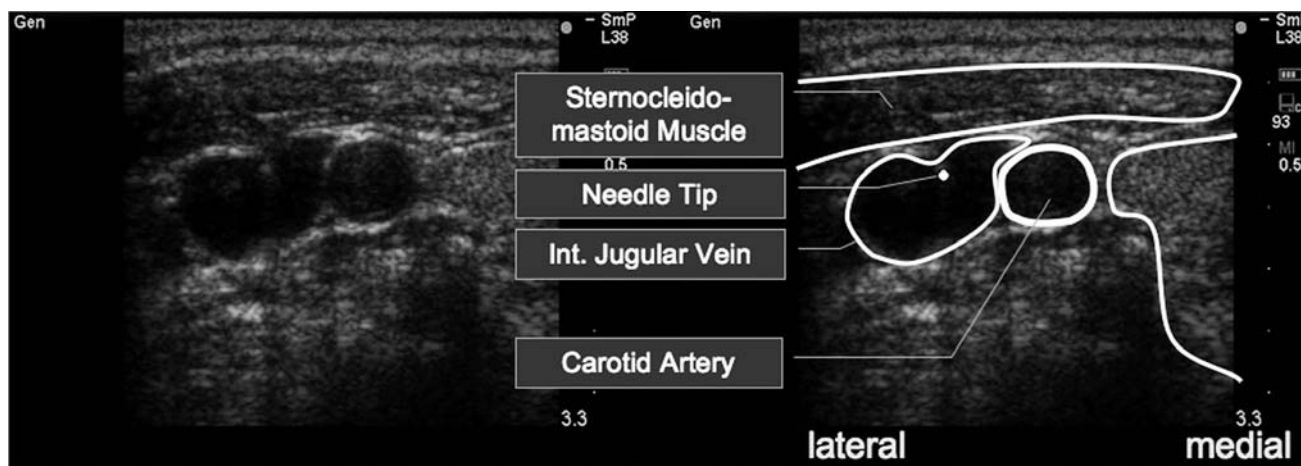


Figure 1. B-scan depiction of a puncture of an adult left internal (*Int.*) jugular vein for central venous access. The tip of the needle can be seen to be intravascular after penetrating the wall of the internal jugular vein, which is slightly compressed.

hand holds the ultrasound probe and the other the needle. Unfortunately, this technique requires high operator skills and experience.

The authors perform vascular access using a single-operator technique. Although the ultrasound probe has to be disengaged to introduce the guidewire, no problems were experienced without continuous visualization of the process of inserting the wire. In our opinion, a two-operator technique could be useful when problems occur while introducing the guidewire. However, the authors were already experienced in central venous access when starting to use ultrasound for vascular access. We do confirm the intravascular position of the wire after insertion. A study focusing on the specific question of whether single- vs. two-operator technique was advantageous revealed no significant differences. Unfortunately, only 44 patients were studied (9).

Ultrasound gel is required for acoustic coupling between ultrasound probe, protective sheath, and the skin surface. The gel must be sterile for interventional usage, both inside and outside the long, sterile plastic sheath. Local anesthetic and sterile saline solutions might also serve as coupling substances, especially in a patient who is awake.

Scans of the vessels can be longitudinal or cross-sectional. Similarly, needle insertion can be performed in either longitudinal or transverse relation to the ultrasound probe. The choice of axis depends on the location of the vessel, operator experience, and anatomic relationships. For the very common cannulation of the internal jugular vein (IJV),

we typically use a cross-sectional scan for a better view of the surrounding structures. However, puncturing a vessel in cross-sectional imaging with transverse needle placement can be difficult; a hyperechogenic signal (white spot) is seen when the needle is in axis to the ultrasound beam (Fig. 1). Ideally, this white spot is the tip of the needle and not the shaft. In this situation, the operator does not always know where the end of the needle actually is placed. Despite these difficulties, Blaivas et al. (10) reported that the technique utilizing a transverse, short-axis view of the needle in vascular access was easier for novices to learn than a technique using longitudinal scan.

Mechanical Complications of Central Venous Catheterization in Adults

Safe cannulation of the IJV was described by Hermosura et al. (5) in adults in 1966 using the landmark technique. Nevertheless, there are reports of up to a 40% complication rate (Table 1). Common complications for central venous access include accidental arterial puncture, hematoma, pneumothorax (11, 12), and even death (13). Serious bleeding-related consequences of accidental arterial puncture include hematoma of the neck and hematoma of the mediastinum or hemothorax. There are also possibilities of potential damage to the cervicothoracic ganglion (stellate ganglion), phrenic nerves, and other important nerves described (14–16). McGee and Gould (17) described complications of central venous catheters to be dependent on the

route of cannulation. They found a rate of accidental arterial puncture during access of the IJV of 6.3–9.4%. Hematoma occurred in 0.1–2.2%. The relatively rare complication of a pneumothorax while accessing the IJV happened in 0.1–0.2% of cases. In contrast to IJV catheterization, cannulation of the subclavian vein was associated with a higher rate of pneumothorax or hemothorax (1.5–3.1% and 0.4–0.6%, respectively). Accidental puncture of the subclavian artery occurred in 3.1–4.9% of cases. Compared with cannulation of the internal jugular and subclavian veins, the highest rate of arterial puncture and hematoma occurred while accessing the femoral vein (9.0–15% and 3.8–4.4%, respectively). A recently published study by Eisen et al. (18) reported mechanical complications in 14% (excluding failed attempts) for central venous cannulation in 385 critically ill patients. Only 67% (256 of 385 patients) had an uneventful catheter insertion. This publication confirms the frequency of accidental arterial puncture by catheter insertion site reported by McGee and Gould (17): highest rate for femoral approach (7.1%), followed by jugular approach (5.0%), and lowest for subclavian approach (3.2%). Other complications (pneumothorax, hematoma, incorrect position) were also comparable with previous publications (12, 19–21). Eisen et al. (18) defined “failure to place” as multiple attempts without success and calling for help, which was the most common complication (22%). More than two failed punctures were significantly associated with an increased complication rate.

Table 1. Rates of mechanical complications for central venous catheterization

Access Complications	Internal Jugular Vein, %		Subclavian Vein, %		Femoral Vein, %		Overall Range, %
	Adult	Pediatric	Adult	Pediatric	Adult	Pediatric	
Arterial puncture	5	0–26.7	3.2–4.9	5.1–6.6	7.1–15	6.3–12.8	0–26.7
Pneumothorax	0	0	1.5–2.8	1.3–2.5	NA	NA	0–2.8
Hemothorax	0	0	0.5	1.2	NA	NA	0–1.2
Failed puncture	25	20–39.1 ^a	12	9.9	15–37	No data	9.9–39.1
Catheter malposition	No data	20	No data	2.2–16.1	No data	4.7	0–20
Other severe	No data	No data	No data	No data	1.4	No data	0–1.4
Other minor	No data	No data	6.9	No data	1.4–4.4	No data	1.4–6.9
Overall range	0–32.5	0–39.1	0.5–12	1.2–16.1	1.4–37	4.7–12.8	0–39.1

NA, not applicable.

^aAccounts for children <1 yr of age and/or <10 kg of body weight. Data collection from references 18–21, 24, 25, 27, 32–35.

Mechanical Complications of Central Venous Catheterization in Pediatric Patients

In children, Stenzel et al. (22) demonstrated a 3.7% complication rate for catheterization of the femoral vein compared with a rate of 7.3% for nonfemoral access. Previous cardiac catheterization complicated femoral vein puncture and increased the complication rate when the same site was punctured (23). A low complication rate was reported by Johnson et al (24). In this retrospective survey, the overall complication rate was 3.1% (1,435 central venous catheter insertions). Reports of complication rates of subclavian vein catheterization in pediatric populations range from 3% to 34% (22, 25, 26). Citak et al. (27) concluded that the subclavian approach for central venous access in children is a safe procedure. Of 156 central venous catheters, the subclavian vein was chosen for venous access 148 times, with an overall arterial puncture rate of 12.8%. As in adults, the IJV provides a relatively reliable and useful access site. Hematoma and arterial punctures were the most frequent complications of IJV catheterization (28), followed, to a lesser extent, by pneumothorax. Anatomic variations of the common carotid artery (CCA) and the IJV and the smaller diameter and lesser depth of the IJV may account for failed punctures in children (28–30). Especially for IJV access, there are some publications that demonstrated fewer complications in children when two-dimensional ultrasound (B-scan) was used (31).

Position of the Internal Jugular Vein

Many different techniques for IJV cannulation do exist, but palpation of the

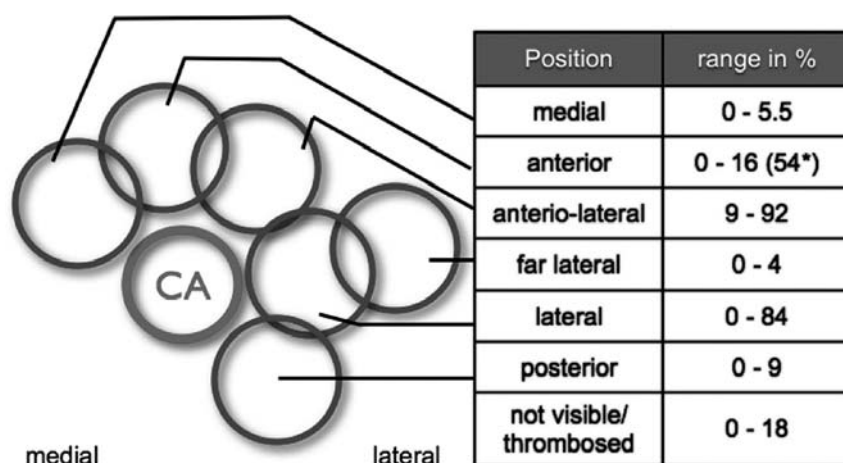


Figure 2. Prevalence of occurrence of variation in the position of the internal jugular vein in relation to the common carotid artery (CA). Circles describe reported positions of the internal jugular vein. Data extracted from references 36–40. *jugular vein overlaps $\geq 75\%$ of the CA. Table 2 provides details and the number of patients in the referenced studies.

CCA is a common procedure. The CCA usually lies directly under the medial part of the sternocleidomastoid muscle. Needle insertion, slightly lateral to the carotid pulse and above the angle of the sternocleidomastoid muscle with advancement toward the ipsilateral nipple, reduces the risk of accidental arterial puncture. Unfortunately, this procedure is not foolproof. Figure 2 shows examples of anatomic variation in the position of the IJV based on ultrasound examinations (36–40); Table 2 provides details. Figure 3 demonstrates an atypical vein medial to the CCA.

The ultrasound findings of Forauer and Glockner (41) revealed an 18% total occlusion rate of the IJV in patients scheduled for dialysis catheter placement. IJV occlusion (thrombosis) increases complication rates because of both failed “dry” punctures and subsequent deviation of the presumed optimal puncture site and direction (Fig. 4). In the authors’ opinion, these marked differ-

ences in reported position of the IJV in regard to the CCA indicate that a reliable and constant anatomic position of the IJV does not exist. Even an anterolateral approach carries the risk of accidental arterial puncture. Two-dimensional, ultrasound-guided, real-time puncture of veins demonstrates how the needle tip compresses the vein’s wall without really penetrating it (Fig. 1 shows a successful puncture). A consequent deeper advancement (no aspiration of blood) can result in penetrating the artery through the vein.

Location and successful cannulation of the IJV depend on a number of factors, including the size of the IJV, intravascular volume status, and the degree of pressure exerted by the ultrasound probe on the patient. Head rotation and patient positioning are further factors influencing the procedure of cannulation and ultrasound detection (42, 43).

In patients undergoing surgery under general anesthesia with a laryngeal mask

Table 2. Frequencies given as percentage of position of the internal jugular vein relative to the common carotid artery

Reference	Position of the Internal Jugular Vein Relative to the Common Carotid Artery (%)						Not Visible or Occluded
	Medial	Anterior	Antero-Lateral	Lateral	Far Lateral	Posterior	
Denys, n = 200 (40)	2	92			1	2.5	3
Turba, n = 188 (37)	R 0.5 L 0.5 5.5	R 4 L 6	R 16 L 9	R 80 L 84			
Gordon, n = 659 (36)							
Caridi, n = 80 (38)		16	71		4	9	
Forauer, n = 100 (41)							18
Brederlau, n = 64 (46)			39 ^a				
Troianos, n = 1009 (39)		54.3 ^b	39.3	6.4			

R, right site; L, left site.
^aInternal jugular vein overlaps >50% the common carotid artery; ^binternal jugular vein overlaps common carotid artery >75%.

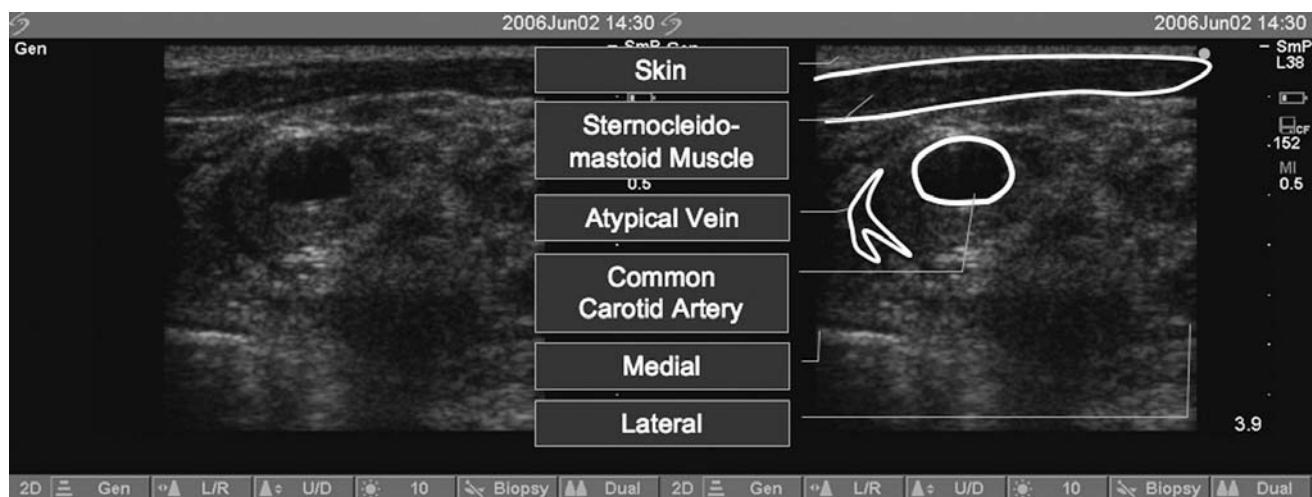


Figure 3. Depiction of the common carotid artery of a healthy adult patient. A small atypical vein is located medial to the common carotid artery.

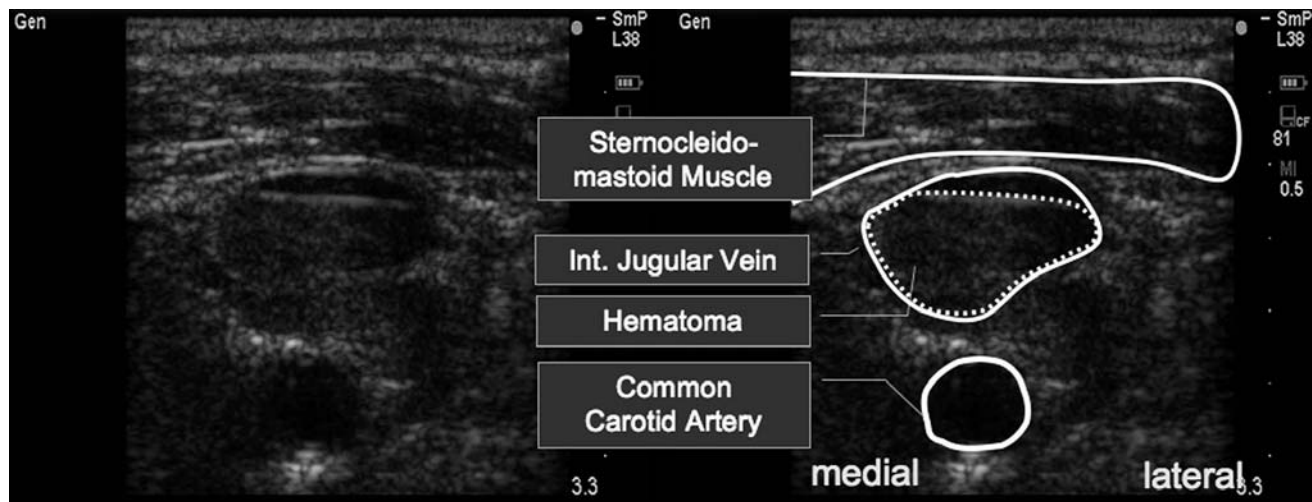


Figure 4. B-scan of the right jugular angle in an adult patient. Ultrasound was used for placing a central catheter after three failed punctures. The image shows an intravenous thrombosis of the jugular vein that almost completely fills the intravascular lumen. *Int.*, internal.

inserted, puncture of the IJV can be difficult because of difficulty in palpating the CCA and displacement of the sternocleidomastoid muscle (44). A study of Takeyama et al. (45) demonstrated that ventilation with a laryngeal mask increased the overlapping of the IJV and CCA when the head was in 30 degrees of rotation to the opposite site of puncture. This was reported at the high of the mid-point of the mastoid process and the intersection of the clavicular and sternal head of the sternocleidomastoid muscle but not in the supraclavicular vicinity. Overlapping of the IJV and CCA is asso-

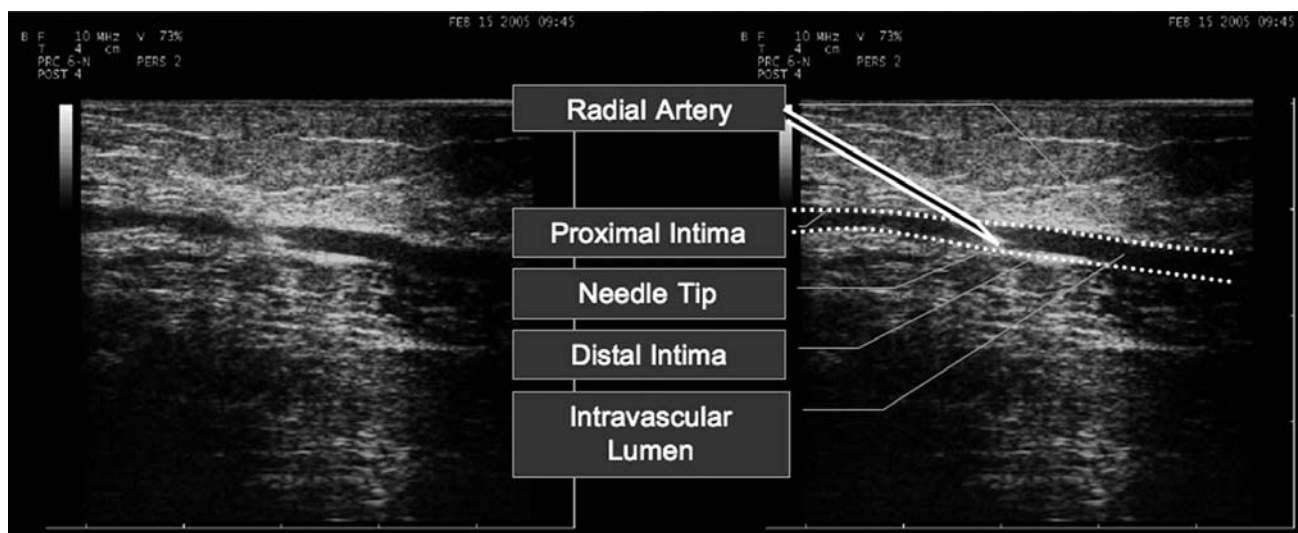


Figure 5. Cannulation of the radial artery in an adult patient. Longitudinal scan. Depiction of the proximal and distal intima.

ciated with an increased risk of arterial puncture. Takeyama et al. (45) concluded that ultrasound guidance should be used for IJV cannulation.

Ultrasound for Atypical Central Venous Access

In infants and obese or edematous patients, intravenous access of peripheral veins can be a challenge. The axillary, basilic, and cephalic veins are alternative access sites for peripheral or central venous catheterization (47–49). Veins in the cubital fossa are frequently thrombosed in intravenous drug abusers, patients with multiple operations and hospitalizations, and in those with frequent venous cannulations or peripherally placed central venous catheters. Longitudinal scanning of the basilic and cephalic vein allows both visualization of the catheter and guidewire insertion. This can be helpful if difficulties are encountered with advancing the catheter (e.g., thrombosis) (47). To reduce complications (e.g., nerve damage and arterial puncture), depiction of the median nerve and the brachial artery should be obtained in transverse section when cannulation of the basilic vein is performed.

Cannulation of the axillary vein can be an alternative to subclavian vein puncture. Axillary vein access is easier to visualize with ultrasound because of the more laterally located puncture site and the consequently greater distance between clavicle and ultrasound probe (50). Complication rates of guidewire and catheter misplacement are comparable with the traditional landmark technique

(49). Although results of large prospective studies for axillary vein access are lacking, complications like arterial punctures with ultrasound-guided access of the axillary vein were reported to be lower than when using the landmark technique (0 to 1.5%) (49, 50). High-resolution ultrasound (>10 MHz) is excellent for veins located in the cubital fossa because surrounding structures can easily be identified (e.g., nerves). In contrast, access of the deeply located axillary vein is preferably performed with 5- to 7.5-MHz ultrasound probes. This is particularly necessary for the obese patient. Due to the deep location, difficulties with introducing the guidewire or catheter can also occur because of the steep angle of needle and vein.

Ultrasound-Guided Arterial Catheterization

A prospective, randomized study by Levin et al. (51) compared ultrasound-guided radial artery cannulation vs. the palpation technique. Two-dimensional ultrasound-guided catheterization was superior to palpation for first insertion attempt ($p = .03$) and number of attempts ($p = .003$). Although the time for successful cannulation was longer in the ultrasound group (26.1 secs vs. 17.3 secs, $p = .0001$), mean time for each patient was shorter (55.5 secs vs. 111.5 secs, not significant). Furthermore, many of the participating anesthesiologists were using ultrasound for the first time for arterial catheter insertion, thus demonstrating the ease of use of this technique.

Puncture of the radial artery is frequently chosen because of the dual arterial supply to the hand by the ulnar artery (Fig. 5, radial artery; Fig. 6, axillary artery). After multiple unsuccessful attempts at radial artery cannulation, vasospasm or hematoma formation may make subsequent successful catheterization almost impossible. Sandhu and Patel (52) have described a method using two-dimensional ultrasonography for radial artery access at the mid-forearm as a rescue technique. The artery can be identified beneath the brachioradialis muscle at the mid-forearm level. Transversal or longitudinal images were used for cannulation. The needle can be redirected safely for best viewing results, because no nerves are adjacent to the artery at this level.

Similar to the adult study by Levin et al. (51), a prospective, randomized trial by Schwemmer et al. (53) demonstrated a clear benefit of ultrasound use for radial arterial cannulation in children. Ultrasound-guided catheterization was superior to the traditional palpation method for successful first attempt ($p < .05$) and total number of attempts ($p < .05$). In contrast to the adult findings of Levin et al. (51), time for successful cannulation was shorter in children.

Discussion and Examples of Clinical Application

A meta-analysis of ultrasound guidance for central venous catheter placement, published in 1996 by Randolph et al. (54), included eight randomized, controlled trials. This study group concluded

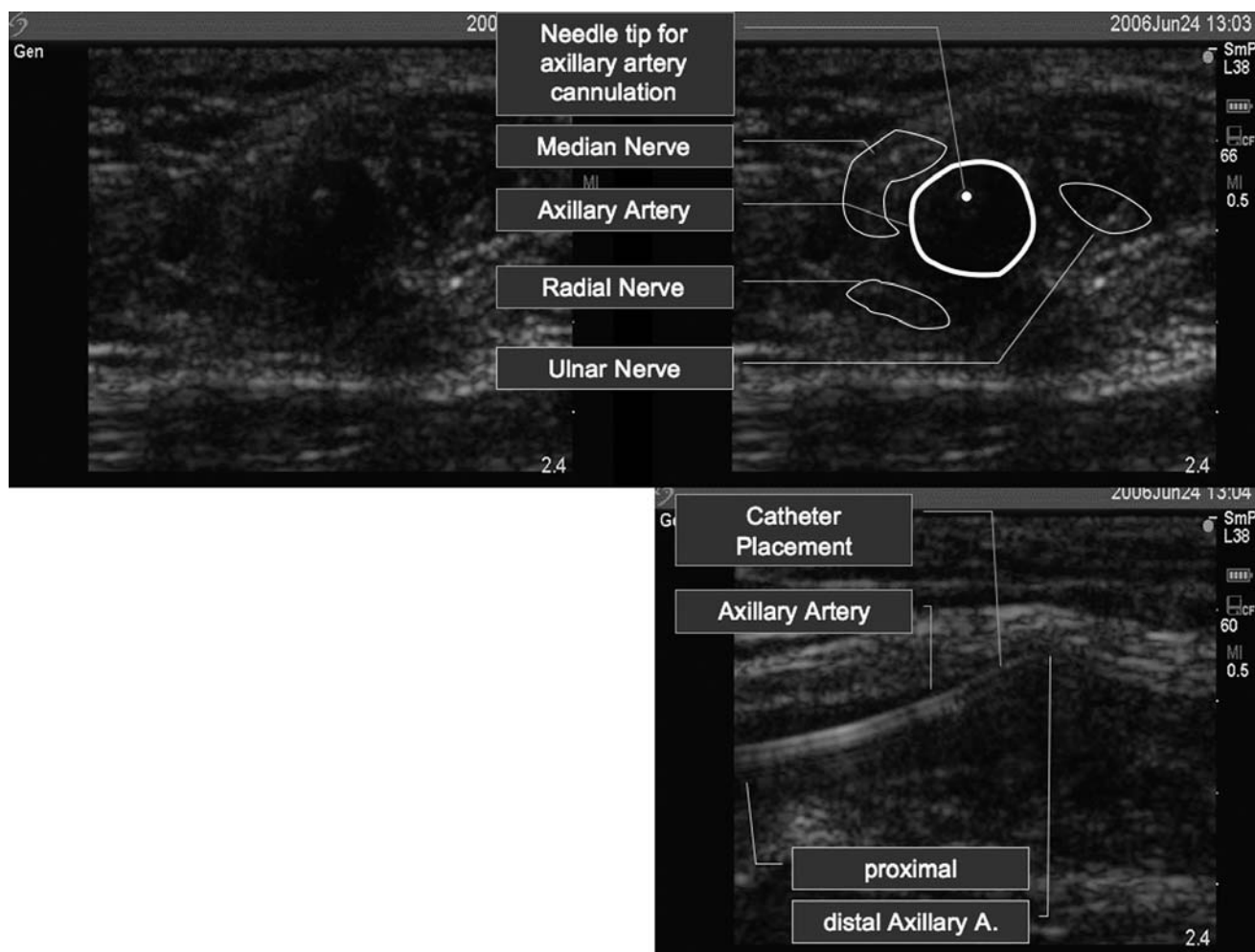


Figure 6. Cannulation of the axillary artery (A.). Cross-sectional scan with depiction of the median, radial and ulnar nerve. White spot represents the needle tip. The longitudinal scan shows a catheter inserted by Seldinger technique.

that the use of ultrasound significantly reduced “internal jugular and subclavian catheter placement failure” compared with the traditional landmark method (relative risk, 0.32; 95% confidence interval, 0.10–0.45). Complications of catheterization and the number of catheterization attempts were also reduced. Randolph et al. (54) included Doppler ultrasound-guided studies in their analysis. Hind et al. (55) subsequently excluded these trials in another meta-analysis. Data from 18 studies were evaluated. Two-dimensional ultrasound showed a clear benefit for central venous access when compared with the landmark methods. This technique was more effective in avoiding failures in the first attempt, for failed catheter placements, and for complications of venous cannulation. Evidence for IJV access was good but sparse for subclavian or femoral venous access. We have found no study of ultrasound-guided cannulation of the innominate vein (Fig. 7). Only one study reported a

significantly higher success rate for IJV cannulation in the landmark group when compared with two-dimensional ultrasound (56). This study has been commented on by Grau et al (57).

Disadvantages to the use of ultrasound must also be mentioned. There can be a time-consuming learning process (especially for the free-hand technique). There is an initial time demand to power and set up the device and to cover the probe with a sterile sheath. There is a real expense of the ultrasound devices and valid concerns that operators will become less experienced in the field of vascular access using the traditional landmark technique.

We think that all these potential disadvantages are easily outweighed by the above-mentioned advantages: visualization of the precise target location, visualization of needle progression, reduced puncture attempts, improved success rates, minimizing or preventing puncture and catheter-related complications, and control of catheter location. In addition,

we would like to emphasize potential efficiencies to the process in the operating room or intensive care unit. Despite an increased lead time for ultrasound usage, the effective time for successful cannulation can be shortened, especially for those with difficult vascular access.

Perspectives

As mentioned in the previously discussed meta-analysis, more clinical trials are required to prove effectiveness, especially for access sites other than the IJV. To compare results of clinical investigations for ultrasound and vascular access, not only the number of success rates and complications should be reported but also the number of the puncture attempts through skin, number of needle advancements, patient anatomy, positioning of patient and ultrasound probe, and the number of previous catheterizations. Furthermore, reports of lesions of the

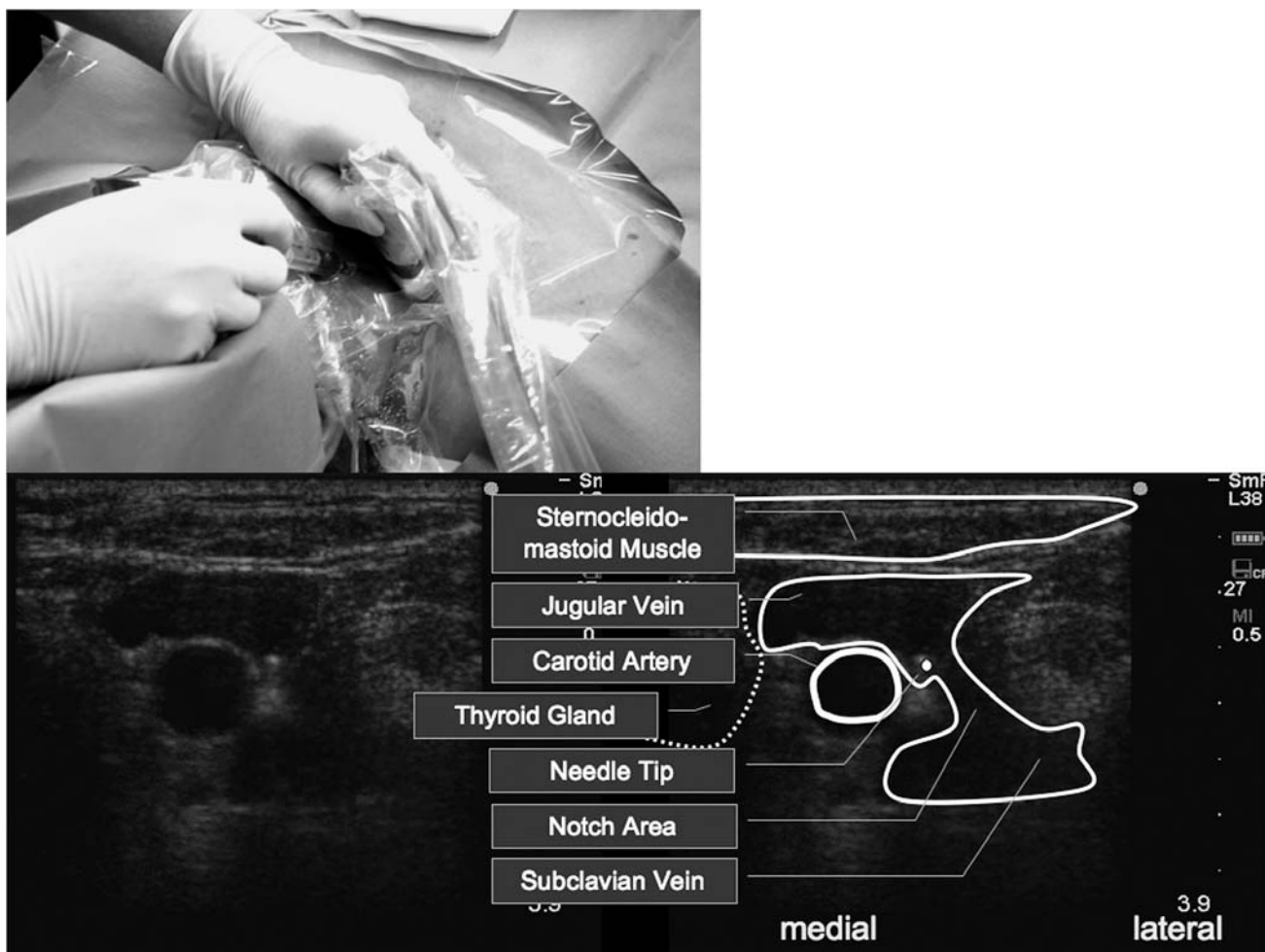


Figure 7. Ultrasound-guided central venous puncture in “notch-position” in an obese adult patient with short neck scheduled for cardiac bypass surgery. The scan depicts the confluence of the right internal jugular and subclavian vein in an adult patient. High-of-needle insertion is more proximal than described by Rao et al. (58) because of the diameter of the ultrasound probe. Effective needle placement is the same.

vascular intima or history of vascular disease could be useful to demonstrate the beneficial aspects of ultrasound usage. It should be noted that medical material used for venous cannulation still is not optimized for ultrasound visualization. We believe that there is a potential for technical improvements in the needles and catheters used for ultrasound imaging.

CONCLUSION

Ultrasound-guided vascular access has been shown to shorten time of the procedure, reduce the number of failed puncture attempts, and to minimize complications of central venous catheterization. Ultrasound combines the puncture process with diagnosis and detection of anatomic variations, lesions, and complications, which makes it a powerful tool for vascular access. Patients thus benefit from a reduced rate of complications.

Fast and successful central venous access thus lowers costs by reducing complications and optimizing the process and conduct in the operating room and in intensive care units [32–35, 46].

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