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REVIEW

Ultrasound-guided vascular access in critical illness

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Abstract
Over the past two decades, ultrasound (US) has become widely accepted to guide safe and accurate insertion of vascular devices in critically ill patients. We emphasize central venous catheter insertion, given its broad application in critically ill patients, but also review the use of US for accessing peripheral veins, arteries, the medullary canal, and vessels for institution of extracorporeal life support. To ensure procedural safety and high cannulation success rates we recommend using a systematic protocolized approach for US-guided vascular access in elective clinical situations. A standardized approach minimizes variability in clinical practice, provides a framework for education and training, facilitates implementation, and enables quality analysis. This review will address the state of US-guided vascular access, including current practice and future directions.

Keywords: Central venous catheter, Vascular access, Ultrasound, Education, Complications

Introduction

Over the past two decades, ultrasound (US) has become widely accepted to guide safe and accurate insertion of vascular devices in critically ill patients. This review will address the state of US-guided vascular access, including current practice and future directions. We emphasize central venous catheter (CVC) insertion, given its broad application in critically ill patients, but also review the use of US for accessing peripheral veins, arteries, the medullary canal, and vessels for institution of extracorporeal life support (ECLS). Intensive care units (ICUs) should adopt standard practices for training in US guidance, a procedural algorithm, and recommendations for preventing and detecting complications and malposition.

US-guided vascular access relies on high-frequency linear transducers, generally in the 5–12 MHz range (with exceptions noted below). Color Doppler and pulse-wave capabilities are useful in some situations. The transducer is contained within a sterile sleeve to facilitate real-time guidance, without interfering with the sterile field. The same transducer can be employed to detect some complications, such as pneumothorax, but more complete post-procedure examination may benefit from low-frequency, phased array probes as described below. A capability to save or print images may be useful for documentation, quality control, or billing purposes.

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Prevalence of US-guided CVC insertion

Highly capable US machines are nearly ubiquitous in ICUs in resource-intensive parts of the world. In large part this has been driven by the advantages of US for CVC insertion; at the same time, ready availability of US machines has enhanced adoption of US for vascular access. Three studies give information on the frequency of ultrasound guidance in ICUs, ranging from 45% to 80% for catheterization of the internal jugular vein (IJV) [1–3] (ESM Table A). A prospective audit from Great Britain, published in 2018, showed that US was used for 93% of CVC insertions, mostly in the IJV [4]. Data regarding how often US is used for vascular access is scarce and of uncertain reliability: point-prevalence surveys would be valuable to inform educators, ICU directors, and professional societies.

Evidence supporting US-guided CVC practice

Recent systematic reviews show clear advantages for US guidance versus anatomic landmark techniques at the IJV site, demonstrating fewer complications and higher success rates (ESM Table B) [5, 6]. These findings have led to practice guidelines recommending that US be used routinely [7]. Dynamic US guidance for IJV cannulation is superior when compared with using US solely to identify the anatomy (static guidance) [8]. Plastic devices can be attached to the US transducer to guide the needle at a proper angle to enter the vein, but these have not seen widespread uptake [9]. Real-time ultrasound for the subclavian vein (SCV), axillary vein (AxV), and femoral vein (FV) is increasingly supported by evidence [10]. In light of these findings, we recommend that real-time ultrasound guidance be used routinely for CVC insertion at all sites. An exception might be in emergency settings when an ultrasound machine is not readily available [11], although intraosseous access may be safer and faster than landmark-based CVC insertion. Common sense suggests the use of US especially in patients with clotting abnormalities, obesity, hypovolemia, distorted anatomy, previous CVC placement, and after failed attempts using landmark techniques.

Given the advantages of US-guided CVC insertion at the IJV site, it is remarkable that routine US use still faces barriers and resistance [12–15]. For example, in one survey, 36% of operators believe that landmark techniques are a reasonable alternative, even when US is available [3]. Additional training and education may serve to enhance uptake. Further, younger intensivists are more likely to adopt US routinely.

An algorithmic approach to US-guided vascular access

To ensure procedural safety and high cannulation success rates we recommend using a systematic protocolized approach for US-guided vascular access in elective clinical situations. A standardized approach minimizes variability in clinical practice, provides a framework for education and training, facilitates implementation, and enables quality analysis. Several algorithms describing US-guided CVC placement—with varying degrees of complexity—have been suggested [15–17]. We recommend a pragmatic protocol comprised of six obligatory steps (Table 1; Fig. 1) [15].

Take-home message

This review addresses the state of ultrasound-guided vascular access in the ICU, including current practice and future directions.

Table 1 Protocol for CVC insertion

1. Choose site, identify anatomy, select appropriately sized catheter (pre-scanning)
2. Confirm patency of the target vessel (compression)
3. Insert needle using real-time US guidance
4. Confirm correct needle position
5. Ensure that wire is in the desired vessel
6. Verify catheter location

Step 1: Choose site and identify anatomy

Pre-scanning is a cornerstone for successful cannulation. Systematic evaluation of the possible locations for central venous cannulation has been proposed as the Rapid Central Venous Access (RaCeVA) protocol [18]. This brief, step-by-step evaluation scans the main cervical and thoracic veins, starting from the IJVs at the mid-neck to their junctions with the brachiocephalic vein, then proceeds to the supraclavicular area to scan the subclavian vein and concludes with infraclavicular imaging to interrogate the axillary and cephalic veins.

The choice of vessel should be guided by the following factors: size (cross-sectional diameter, cross-sectional area), depth (distance from skin surface), contiguity with potentially dangerous structures (artery, nerve, pleura), respiratory variation, catheter-to-vessel ratio (venous catheters should generally not exceed 30% of the cross-sectional diameter of the vein) [19, 20], and operator experience. Both short-axis and long-axis views help create a comprehensive picture of the target vessel and surrounding structures. Color Doppler imaging and Doppler flow measurements may help to identify the vein and the artery in challenging circumstances. Once a site is chosen, US should be used to confirm lung sliding prior to needle insertion to provide a comparison for the post-procedure assessment.

For CVC insertion the IJV remains the most commonly used site, both in elective and emergency settings. Although associated with an increased risk for infection [2], it is the safest approach in terms of mechanical complications when conducted with US. Often a mid-neck location is chosen (Fig. 2), as far as possible from the carotid artery and generally without rotating the neck [21]. For long-term central venous access, alternative locations are preferred because of the risk of thrombosis and infection [2].

The supraclavicular approach to the subclavian vein (SCV) is technically challenging as the posterior wall of

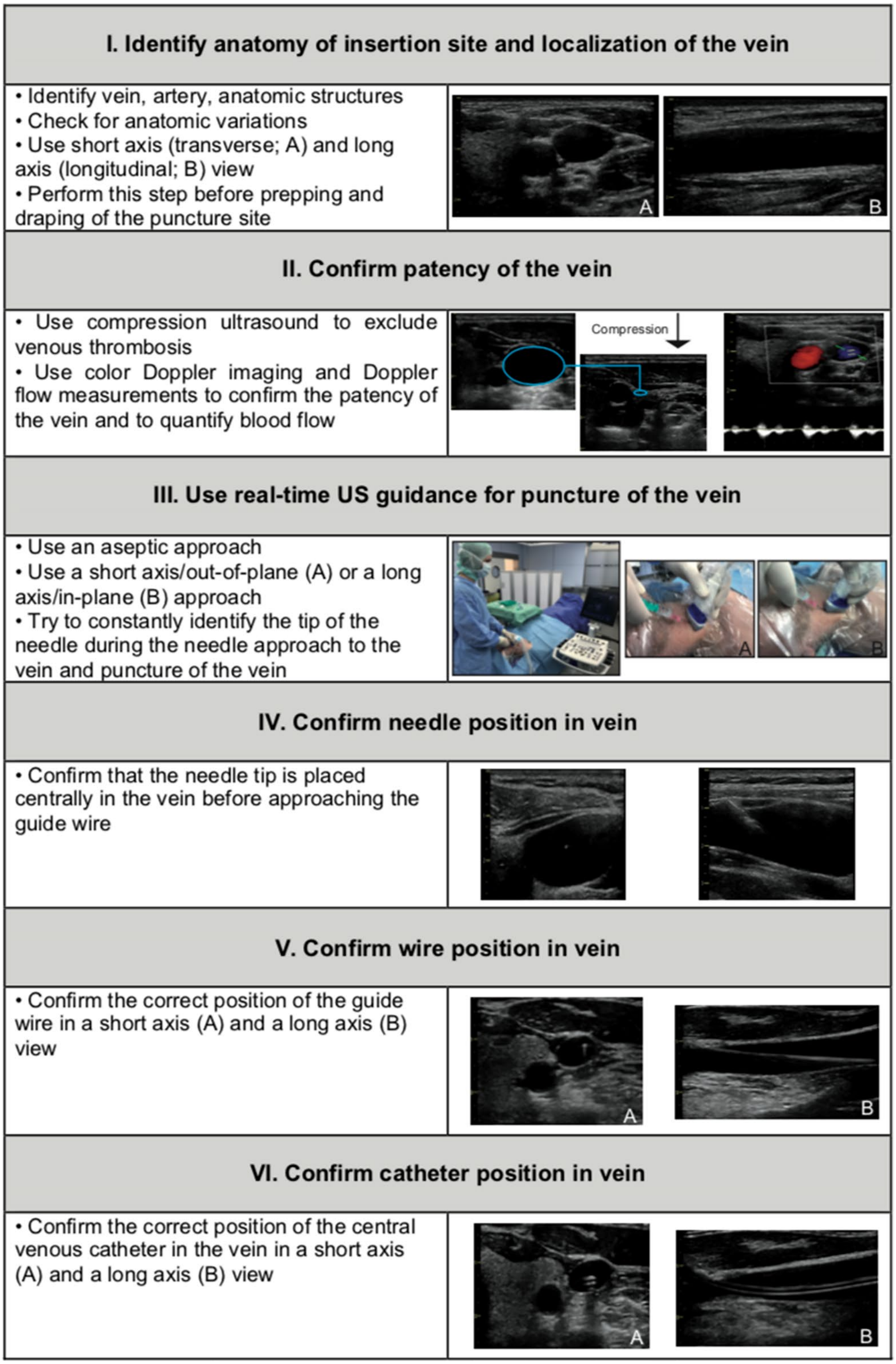

Fig. 1 Basic six-step approach to ultrasound-guided central venous catheter placement with permission from Ref. [15] Saugel; http://creativecommons.org/licenses/by/4.0/, no changes made)

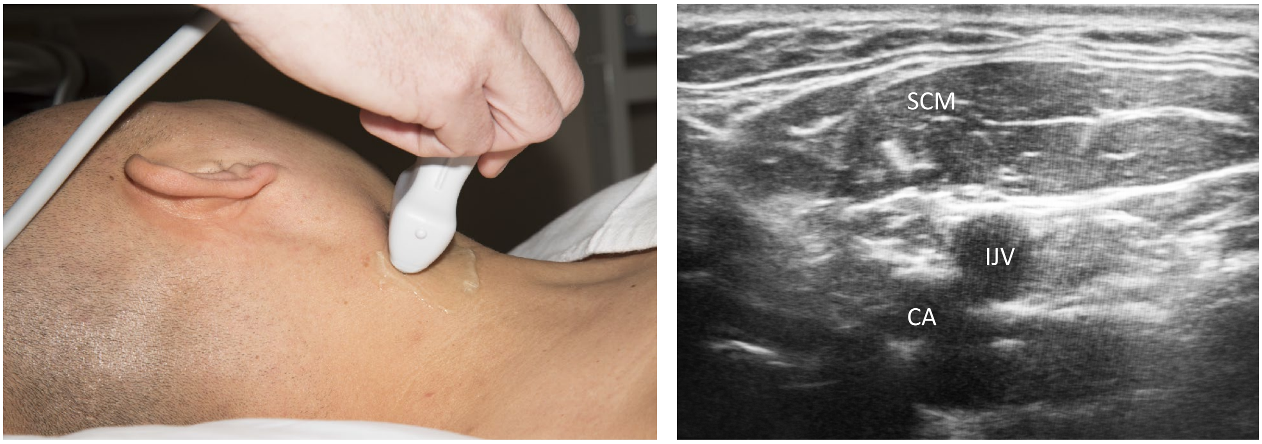

Fig. 2 Ultrasound probe position and visualization of the IJV at mid-neck. IJV is lateral to the carotid artery (CA) and behind the sternocleidomastoid muscle (SCM). For Figures 2 through 7 we acknowledge photographer Amanda Perry

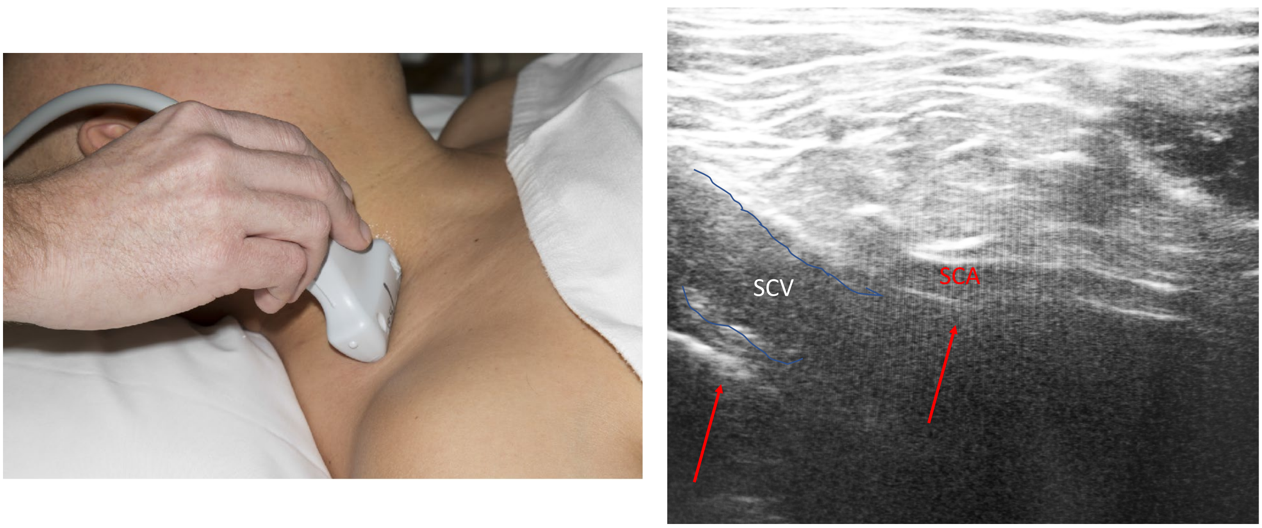

Fig. 3 Ultrasound probe position and visualization of the SCV (supraclavicular view). The SCV is visualized in longitudinal view just in front of the subclavian artery (SCA) but the pleura (indicated by red arrows) is just behind the posterior wall of the vein. The cephalic vein (CephV) is just crossing and reaching the SCV

the subclavian vein is adjacent to the pleura (Fig. 3). The subclavian vein cannot be visualized by ultrasound in the infraclavicular area [22] as the first rib creates an acoustic shadow (Fig. 4). The transition between the subclavian vein and the axillary vein occurs at the lateral margin of the first rib and thus the vessel being visualized and cannulated technically will vary according to probe positioning and angle. The veins most easily visible by ultrasound in the infraclavicular area are the axillary and cephalic veins. The axillary vein can be approached from the infraclavicular area: it may be deep (especially in obese patients) and collapsible with inspiration (Fig. 5) [23]. It is a reasonable approach, especially at the mid-clavicular level where it is best visualized, using a transverse or longitudinal view to avoid posterior wall puncture. Smaller vascular probes that facilitate entry close to the clavicle may be especially useful here. The brachiocephalic vein (BCV) is an alternative, being easy to visualize, far from the subclavian artery and pleura, and not subject to inspiratory collapse (Fig. 6).

Although the femoral vein (FV) is not truly a central vein, it is easily visible by US just below the inguinal ligament, especially if the thigh is externally rotated. Care is

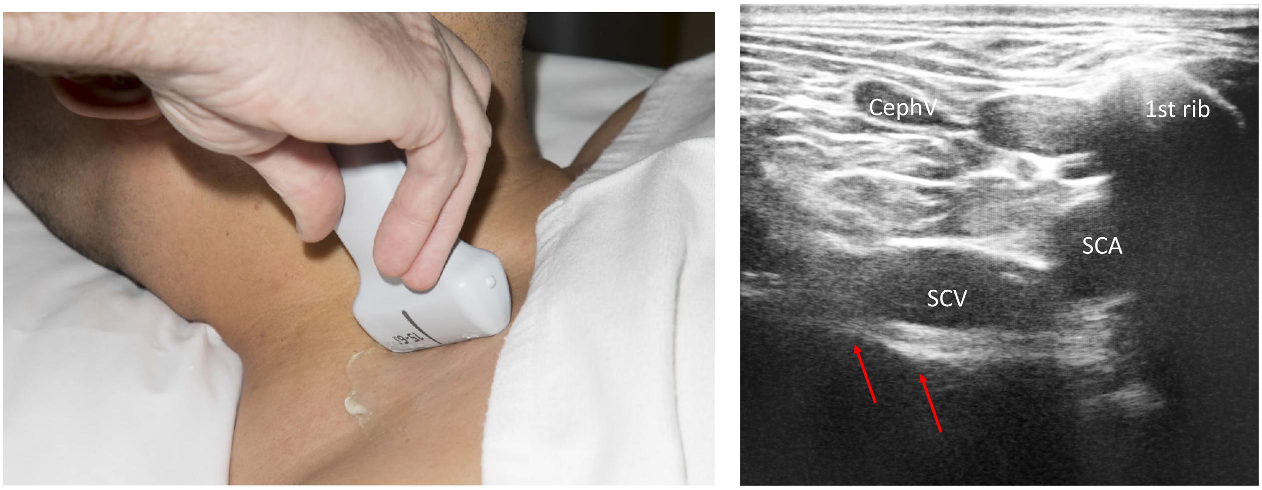

Fig. 4 Ultrasound probe position and visualization of the SCV (supraclavicular view). The probe is placed in transverse view. SCV and subclavian artery are located near the first rib, which creates an acoustic shadow, impeding visualization. The red arrow indicates the pleura. The cephalic vein (CephV) just crosses over the subclavian vein

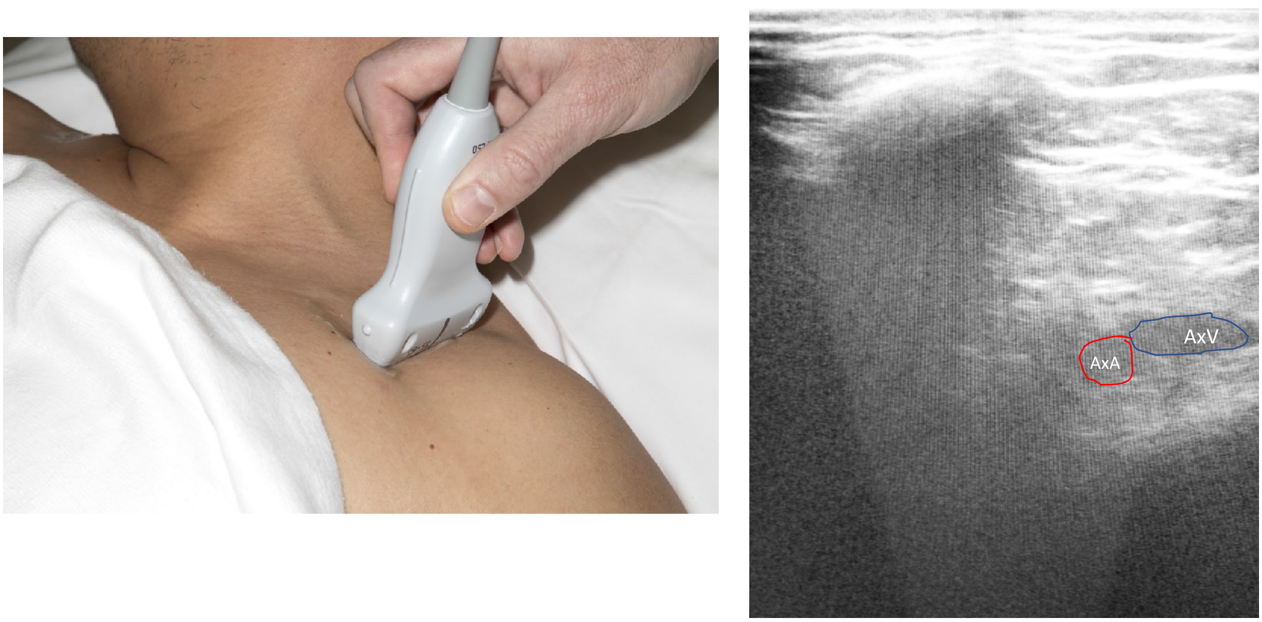

Fig. 5 The probe is positioned at the mid-clavicle showing a transverse view of the axillary vein (AxV). AxV and axillary artery (AxA) are located deeply and the posterior wall of the AxV is not continuous with the pleura

required during cannulation when the femoral vein lies behind the femoral artery (Fig. 7).

Step 2: Confirm patency of the target vessel

The patency of veins can be confirmed using compression US. When intraluminal thrombus is evident, compression is avoided so as not to provoke embolization, and an alternative site is chosen. For both arteries and veins, color Doppler imaging and Doppler flow measurements provide additional verification of patency.

Step 3: Insert needle using real-time US guidance

While steps 1 and 2 are part of pre-cannulation scanning, performed before preparing a sterile field, the remaining steps are conducted under aseptic conditions. Real-time US enables the needle shaft (long-axis/in-plane view)

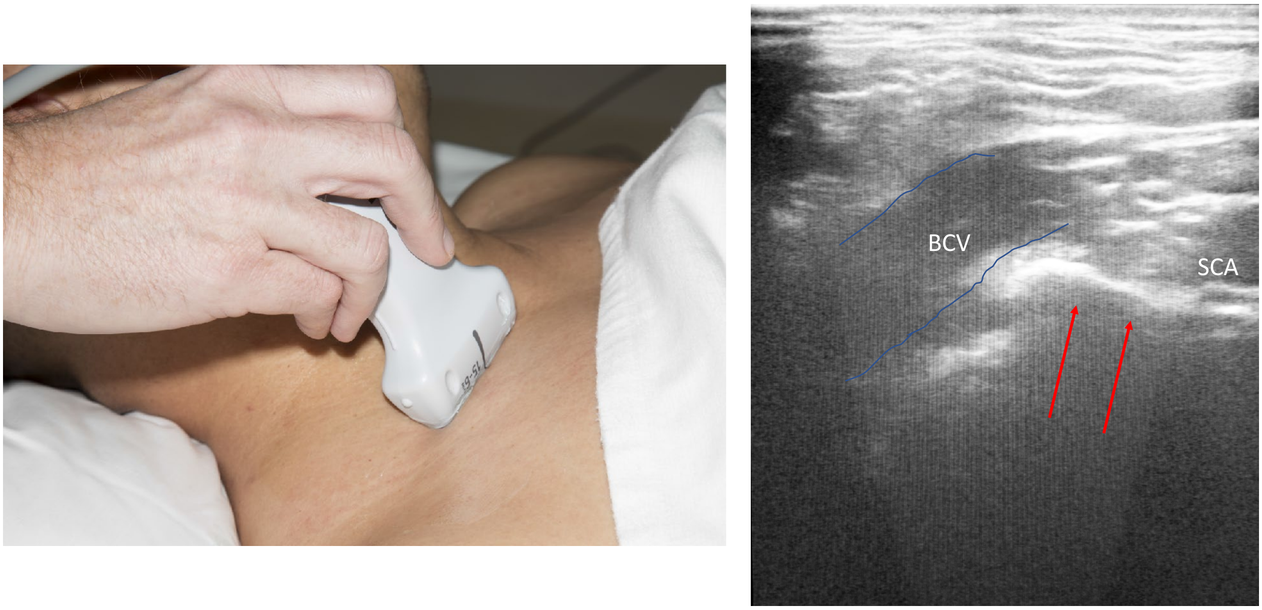

Fig. 6 Ultrasound probe position and visualization of the brachiocephalic vein (BCV). The probe is tilted down and parallel to the major axis of the clavicle to allow a longitudinal view of the BCV. The subclavian artery is far behind the BCV and its puncture angle. The red arrows mark the pleura

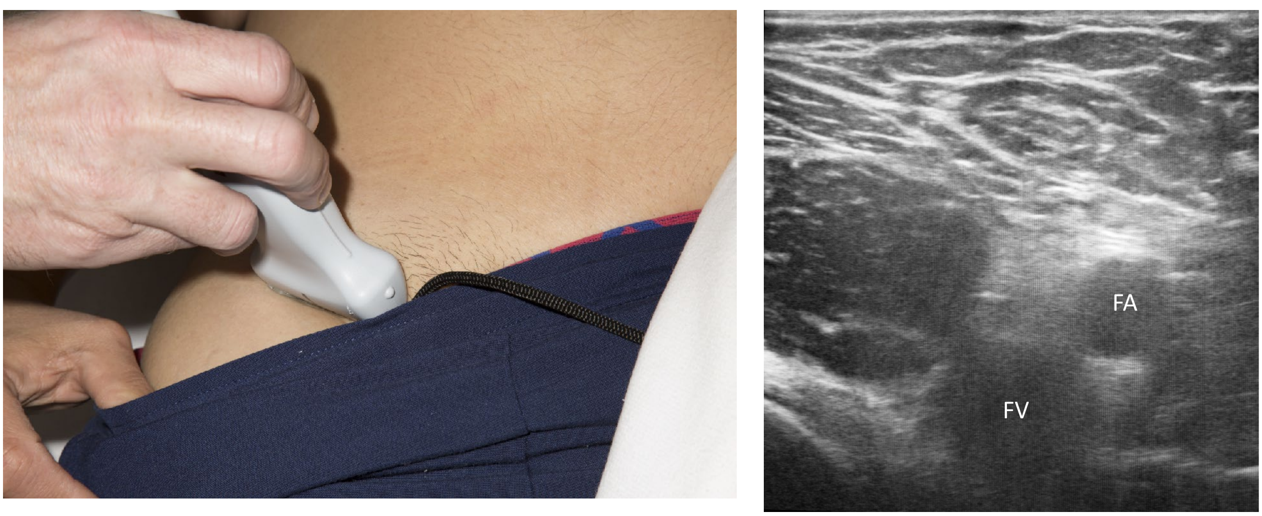

Fig. 7 Ultrasound probe position for the femoral vein (FV). The probe is placed in the groin at 30° to the hip. The FV is deep and just behind the femoral artery (FA)

or the needle tip (short-axis/out-of-plane view) to be visualized during needle insertion, allowing the operator to choose a path that minimizes risk to surrounding structures and optimizes the chances of successful cannulation. When the short-axis/out-of-plane method is chosen, it is essential to slide or tilt the transducer in order to follow the needle tip in real time as it enters the vessel. Specific approaches to CVC insertion are discussed below.

Step 4: Confirm correct needle position

Before insertion of the guidewire, the correct position of the needle in the center of the vein should be confirmed in a short-axis and a long-axis view. Alternative means of determining needle position, such as ability to pull blood into a syringe or advance a wire into the vessel, are often used: these approaches have not been compared with regards to accuracy.

Step 5: Ensure that wire is in the desired vessel

When using the Seldinger technique, proper wire position should be confirmed by both long- and short-axis US imaging, before a dilator is advanced.

Step 6: Verify catheter location

Long- and short-axis imaging should be used to verify the placement of the catheter. Although the chest radiograph (CXR) has been considered the standard means of post-procedure assessment, US may be a safe and effective alternative for corroborating correct positioning of the tip and excluding iatrogenic complications. The radiographic boundaries of the superior vena cava (SVC) and the SVC–right atrial (SVC–RA) junction are not well defined on CXR. A study using MRI revealed errors using common radiographic landmarks to define the SVC–RA junction [24] and a study using transesophageal echocardiography concluded that CXR is not accurate in identifying intra-atrial catheter tip positioning [25]. Moreover, CXR has low sensitivity (27–82%) and appears less accurate than ultrasound in detecting the occurrence of pneumothorax [26]. These data suggest that ultrasound be generally preferred for detecting post-procedure complications and CXR be limited to cases where ultrasound is not technically feasible, such as in the presence of physical barriers to sound transmission. A complete post-procedure assessment requires an additional low-frequency transducer (such as a phased-array echocardiography probe) and, if conducted before the sterile field is taken down, a second operator.

Normal saline (with or without agitation) can be used to confirm catheter position in vascular and cardiac views. A recent systematic review and meta-analysis identified 15 studies with 1553 CVC insertions, showing a pooled sensitivity and specificity of catheter malposition by ultrasound of 0.82 and 0.98, respectively [27]. The overall diagnostic yield for pneumothorax detection was nearly 100%. The average time required for bedside ultrasound confirmation of CVC was 6 min, significantly shorter than the time for chest radiograph completion (64 min) and interpretation (143 min). Thus, adequate ultrasound confirmation of CVC placement appears to be feasible, with good interobserver reliability independent of operator experience [27]. The use of contrast agents for ultrasound has also been studied, but cost is high and there is a risk of contrast-related adverse events.

Ultrasound protocols with vascular and cardiac views demonstrated greater accuracy than with cardiac views only [27], suggesting that both internal jugular veins, both subclavian veins, and the inferior vena cava should be imaged for errant catheters, followed by cardiac ultrasound. Echocardiography should include the subcostal acoustic views along the short heart axis to obtain the subcostal bicaval acoustic window, showing the superior vena cava–right atrial junction (Videos 1, 2, 3, Online Resource). Combining B-mode ultrasound with agitated–saline mixture allows detection of correct catheter position at the junction more accurately than visualization of the right heart chambers only. Detection of the catheter tip is facilitated by using air–saline or air–blood–saline mixture [28], as when detecting foramen ovale patency [29]. The contrast obtained by mixing saline (80%) with air (10%) and blood (10%) has been shown to be superior in some settings [30, 31], because air has a very different acoustic impedance than blood and is therefore highly echogenic. Blood mixed with normal saline produces smaller, more uniform, and numerous stable microbubbles with the same amount of air. Although current scientific evidence supports the use of ultrasound for the confirmation of CVC position, many physicians still consider CXR as standard of care [32]. We believe ultrasound should be the first-line method to confirm catheter malposition, with CXR being limited to specific situations.

Specific CVC insertion techniques

Considering the space relationship between the vein and the transducer, the vessel can be visualized either in short or long axis. In contrast, the relationship between needle and the plane of the US beam is described as in-plane or out-of-plane [14]. Any US-guided venipuncture will result in three possible combinations: (1) short axis, out-of-plane; (2) short axis, in-plane (meaning that the transducer is oriented along the vessel's short axis while the needle punctures the vessel from the side, parallel to the transducer); and (3) long axis, in-plane. Experienced operators may utilize a combination of these techniques by imaging the vessel obliquely with the cannulation needle remaining in-plane to facilitate an optimal trajectory in especially challenging situations.

There is lack of evidence as to whether one approach is superior for central vessel cannulation [33], but each has advantages and disadvantages (Table 2). Common sense suggests selecting a trajectory that reduces the risk of inadvertent damage to the posterior or lateral wall of the vein, or to adjacent arteries, nerves, or pleura.

US guidance for cannulation at other sites

Growing evidence suggests that routine utilization of ultrasound guidance is beneficial for all types of vascular access [3]. Many of the principles relevant during CVC insertion can be translated also to use of US in other settings.

Table 2 Approaches to CVC insertion

Vein	Visualization	Cannulation	Advantages	Disadvantages
Internal jugular vein	Longitudinal Transversal Oblique	In-plane (especially if the carotid artery is under) Out-of-plane	Easy to visualize Easily compressible Usually large cross-sectional diameter Less respiratory variations	Increased risk for infections Increased risk for thrombosis Not ideal in case of tracheostomy
Brachiocephalic vein	Longitudinal	In-plane	Easy to visualize Not dependent on respiratory variations Large cross-sectional diameter	Less visible and accessible in obese patients Requires advanced training
Subclavian vein (supraclavicular approach)	Longitudinal	In-plane	Not dependent on respiratory variations	Can be overlapped by subclavian artery Near to pleura Requires advanced training Risk for pneumothorax
Axillary vein	Longitudinal Transversal	In-plane Out-of-plane	↓ risk for infections ↓ risk for thrombosis	Dependent on respiratory variations Deep position Requires advanced training Risk for pneumothorax
Femoral vein	Transverse (longitudinal)	Out-of-plane	Easily visible Ideal for emergency situations or when the head and neck area are not accessible	High risk for infections High risk for accidental removal Catheter tip will not be centrally placed

Peripheral veins

For peripheral intravenous catheter (PIV) access, US guidance using a high-frequency vascular transducer in real time is superior to conventional insertion with regards to success rate, time to cannulation, and number of skin punctures [34, 35]. Short- and long-axis approaches to direct catheter insertion as well as wire-assisted insertions (using the modified Seldinger technique, MST) produce better results than landmark techniques [36]. In addition, catheters inserted using US may be longer-lived than those placed conventionally [37], perhaps because of less trauma to the vessel. This is especially true when MST and a guidewire are used, and when longer catheters are employed [38, 39]. In one emergency department study of patients judged to have difficult veins, a long catheter (6 cm, 19.5 G, built-in guidewire) compared to a shorter one (4.78 cm, 20 G) was usable for 4.04 vs 1.25 days [39].

A long-axis approach allows good visualization of the catheter over the needle throughout placement. However, a near-perfect on-axis image must be maintained throughout insertion and this requires substantial operator skill (Videos 4 and 5, Online Resource). Short-axis placement allows easier visualization of the target vessel but skill in following the advancing needle requires practice. Various ultrasound task trainers are available to facilitate mastery of PIV insertion.

Vasoconstricting medications are typically given through central veins to reduce the risk of extravasation and tissue damage. By reducing insertion trauma and facilitating confirmation of correct catheter placement, US guidance of peripheral cannulation may allow safe infusion of vasoconstrictors. In one study, US was used to guide cannulation, then to confirm the location by directly imaging the catheter and visualizing saline infusion into the vein [40]. Out of 734 PIVs placed, extravasation occurred in only 2%, or 19 PIVs, without any tissue injury. This has led numerous hospital systems in the USA to adopt this technique to reduce the number of CVCs placed solely for short-term vasopressor infusion.

Arteries

As with PIV cannulation, US-guided placement of peripheral arterial cannulas has been shown to be superior to the palpation technique, especially for the radial artery [41, 42]. Numerous studies show a decrease in the number of attempts and time needed for successful cannulation, using either short- or long-axis approaches. One meta-analysis included 12 trials and 1992 subjects [43]. Compared to the traditional palpation technique, ultrasound-guided insertion of radial arterial cannulas was associated with decreased first attempt failures. Insertion technique is similar to that for PIVs and the use of the MST with a guidewire may facilitate insertion.

For femoral artery cannulation, a meta-analysis comparing US guidance to traditional palpation showed a substantial reduction in accidental venipuncture, hematoma formation, and first-pass failure [44]. Cannulation of the axillary artery is also facilitated by US, yielding high success rates even for inexperienced operators [45].

Intraosseous needle insertion

Intraosseous (IO) cannulation is used increasingly, especially for patients with difficult access, in urgent crises, and in pediatric populations. The basic IO technique consists of inserting a metal needle through the skin and outer bony cortex into the highly vascular medullary space, using manual twisting or a powered drill (Video 6, Online Resource). The proximal tibia is a preferred site, but IO insertion is also used for the proximal humerus, femur, sternum, and clavicle. A basic challenge is to correctly position the needle tip in the medullary cavity, neither straying off target in heavily adiposed areas nor penetrating entirely through the bone into deeper tissues. IO lines that are not well secured or are marginally positioned may fail in critically ill patients during movement or resuscitation efforts [46]. Malpositioning may be challenging to detect clinically as fluid is forced into soft tissues, potentially increasing the risk of compartment syndrome and other complications.

US guidance of IO needle insertion is possible in areas where landmark identification is impossible, such as in obese patients. A linear array or high-resolution microconvex transducer is placed adjacent to the IO needle such that the needle is in-plane with the ultrasound beam. Identification of the needle shaft penetrating through the bony cortex is possible (Fig. 8). Linear transducers with side-scanning capability are also useful. If side-scanning or a high-resolution microconvex probe is not available, a linear transducer can be angled to scan under the IO needle, especially with ample sterile gel to ensure an acoustic window. Needle position can be confirmed by direct visualization or color Doppler imaging of a fluid bolus, which shows a blush just deep to the cortex (Fig. 9). Similarly, color Doppler detection of flow deep to the bone, above the cortex, or into adjacent soft tissue detects malpositioning (Video 7, Online Resource).

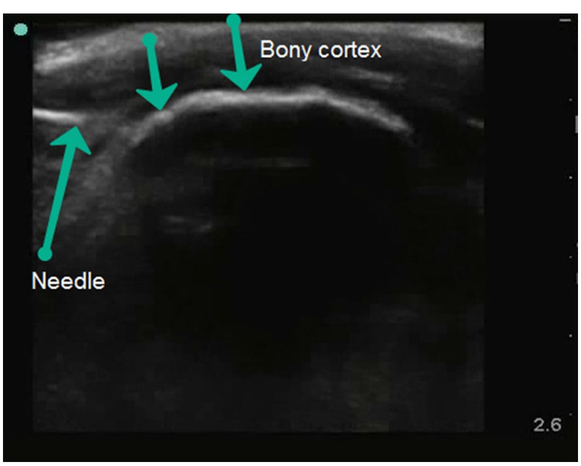

Fig. 8 IO needle traveling toward humeral cortex: a bright, thick needle (long arrow) is seen approaching the bony cortex (short arrows) of the humerus. The needle is caught slightly off axis and the penetration site into the bone is poorly seen

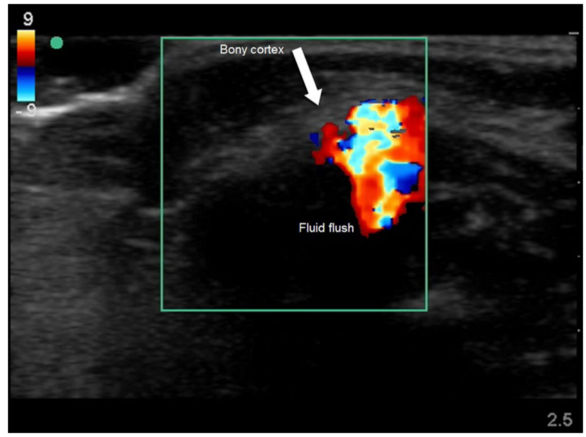

Fig. 9 Fluid flush on color Doppler easily seen below bone: bright flash of color Doppler flow is seen just deep to the bony cortex, denoting correct placement

Using a porcine model and emergency medicine physicians, IO needle tip location was assessed by physical examination, syringe aspiration, and US. Physical examination was correct 100% of the time, aspiration only 68.5%, and US 93.8%. The two US errors appeared to be due to inadequate experience [47]. US is also useful for detecting bony landmarks when they cannot be directly palpated [48].

ECLS cannulation

Successful ECLS requires adequate vascular access to provide full extracorporeal support of systemic blood flow, oxygen delivery, and carbon dioxide removal. The traditional approach to cannulation for ECLS was through surgical cutdown with vessel access through arteriotomy or venotomy, but the development of flexible, thin-walled, wire-reinforced cannulas has permitted a shift to percutaneous cannulation, albeit with different techniques and potential complications. These complications can be minimized with US imaging [49].

A critical decision in initiating ECLS is the choice of the support mode that will dictate cannulation configuration, e.g., venoarterial (VA), venovenous (VV), or veno-venoarterial (VVA). The need for venoarterial cardiac support in patients with cardiogenic shock is usually obvious, but patients presenting with respiratory failure, typically managed with peripheral VV support, may have sufficient co-existent cardiac failure to warrant circulatory support. Focused echocardiography (transthoracic or transesophageal) plays a pivotal role in this decision.

The vessels most commonly accessed for percutaneous cannulation are the right internal jugular (RIJ) and a femoral vein for dual-site venovenous support; the RIJ for single-site, dual-lumen venovenous support; and the RIJ or a femoral vein and a femoral artery for venoarterial support. Other cannulation configurations may be required.

Once a peripheral cannulation approach is identified, a pre-cannulation survey of anticipated access vessels with a linear transducer at a frequency of at least 10 MHz will serve to confirm suitability of the vessel and select an appropriate cannula diameter. The vessel should have a direct path from the skin for needle access, be free of thrombus on color Doppler imaging, free of atherosclerotic plaques if an artery, and have adequate flow velocity on pulse wave Doppler. In the femoral region the survey should extend both proximal and distal to the anticipated needle puncture site to identify the saphenous vein takeoff, and for arterial access, the location of the takeoff of the superficialis and profunda branches.

Since cannula diameter is the major determinant of flow, determination of vessel size allows selection of the largest cannula that can be inserted while minimizing risk of vessel injury. The external diameter of cannulae are reported in French (Fr) units which are defined as 1/3 mm (Fig. 10). A vessel with an inner diameter of 1 cm can accommodate up to a 30-Fr cannula, although a slightly smaller cannula diameter is chosen to reduce risk of endothelial injury and allow some flow around the cannula.

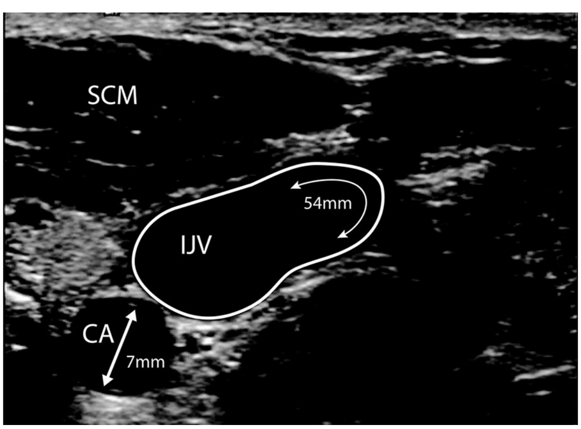

Fig. 10 Measurement of vessel size by ultrasound prior to percutaneous cannulation. In a round vessel such as the carotid artery (CA), the measured 7 mm diameter corresponds to a 21-Fr lumen (7 mm × 3). In an asymmetric vessel such as the internal jugular vein (IJV), the measured circumference of 54 mm corresponds to an approximate lumen size of 54 Fr. A cannula smaller than the lumen should be chosen to allow blood flow around the cannula. SCM sternocleidomastoid muscle

Percutaneous venous cannulation is guided as above, using a linear vascular transducer. For femoral vein access the needle should enter proximal to the saphenous vein if possible. The vessel is entered with a needle using a short-axis, out-of-plane approach to ensure needle entry into the center of the vessel, as off-center entry can result in vessel injury with large dilators. Following guidewire insertion, a long-axis view can be used to verify intraluminal placement of the wire. Final cannula position can be judged using color Doppler imaging to identify reinfusion jets. This is of paramount importance in adjusting the final position of bi-caval dual-lumen cannulae, or to troubleshoot drainage insufficiency. For femoral arterial access, the needle should enter the common femoral artery proximal to the profunda takeoff and distal to the inguinal ligament.

Training in US-guided vascular access

US guidance improves skill and success rates for CVC insertion [50, 51]. Trainees have adopted US almost universally, yet 33% of senior intensivists have not [3]. The main reason why physicians do not use ultrasound for CVC placement is that they think that this is unnecessary and are already comfortable using anatomic landmarks. To overcome barriers and increase uptake of US-guided technique, many ICUs have incorporated US training into the curriculum, instituted mandatory simulation training, and offered hands-on training to more senior clinicians [52–59]. Typical learning programs consists of short (few hours) didactic presentation using slides, web-based instruction, or video modules to cover principles of US, "knobology", image acquisition, normal anatomy, identification of artifacts, and the recognition of deep vein thrombus.

In concert with this didactic program, simulation training at IJV, AxV, and FV sites is recommended. Many studies demonstrate that simulation combined with didactic training is superior to didactic training alone for acquisition of clinical skills for US-guided CVC insertion [53–58]. The learning curve for US-guided IJV CVC placement was evaluated in 30 novice intensivists, showing that optimal technical skill was obtained after 6–8 procedures [60]. In another study after a simulation workshop and five supervised insertions, residents achieved optimal clinical outcome after performing seven procedures. In yet another, inexperienced ICU residents had to perform 7–9 US-guided procedures before reaching a success rate of 90% [61].

A remaining question is whether the landmark-based technique for CVC insertion should still be taught. In our opinion, anatomic landmark training is important since an ultrasound device may not always be available, especially in urgent situations. Even in this setting, IO access may be preferable to CVC insertion. Specific landmark training appears necessary because, even after 6 months during which residents inserted CVCs using US, their success rate with the landmark approach was dramatically low.

Time to procedural competence for US-guided PIV insertion has been well studied. Typically, a three-part training program is used, consisting of (a) didactic teaching on knobology and technique, (b) hands-on experience with vascular access gel models, and (c) direct procedural supervision for several (often five) insertions [62, 63]. In one study of emergency medicine nurses and paramedics, the success rate using US guidance was 70% after four procedures, increasing to 88% after 15–26 [62]. In another study, following initial training, emergency room technicians were successful on the first pass 86.8% of the time, second pass in another 11.6%, and the remaining 1.6% of subjects on the 3rd attempt [63].

Research questions

We identified three key questions about which there remains substantial controversy. First, are there meaningful differences in outcomes depending on whether the short-axis, out-of-plane or long-axis, in-plane method (or less common alternatives) is used for vascular cannulation? Does this differ for novice compared to experienced operators? Which is easier to teach?

A second area of uncertainty relates to procedural complications. Is the CXR still necessary or useful to detect complications and malposition or can US imaging suffice [27, 64–66]? Why are there still substantial incidences of mechanical complications [4]? Can these be reduced by better training? By specific techniques?

Finally, how can training, which is expensive and time-consuming, be optimized? How is US-guided vascular access best learned? How can skills-retention be assessed and sustained?

Electronic supplementary material

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Compliance with ethical standards

Conflicts of interest

Dr. Blaivas consults for and receives consulting fees from EchoNous, Inc. Dr. Lamperti is a scientific advisor of MEDTRONIC, received travel support from Fesenius Kabi and VYGON and honoraria from Draeger, Masimo, and MEDTRONIC. None of these relationships presents conflicts with regards to the content of this manuscript.

Ethical standards

An approval by an ethics committee was not applicable.

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