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Three-step method for ultrasound-guided central vein catheterization

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Editor's key points

- The long-axis, in-plane (LAX-IP) approach has advantages and disadvantages when performing ultrasound-guided central venous catheterization.
- This study reports a new three-step technique to overcome some of the potential problems of the LAX-IP approach.
- After operator training, the new technique was used in 100 patients.
- No major complications occurred, but some difficulties were reported.

Background. The long-axis view and in-plane needle approach (LAX-IP) for ultrasound-guided central vein catheterization is considered ideal because of the quality of real-time imaging. We describe a novel technique, using a step-by-step procedure, to overcome the pitfalls associated with the LAX-IP. This study was undertaken to demonstrate the clinical utility of this approach.

Methods. All operators underwent training before participation in this study. One hundred patients were enrolled in this study and underwent central venous catheterization using this method. Using a portable ultrasound and vein catheterization kit, patients were appropriately positioned and a straight portion of the vein identified (Step 1). A needle guide was used (Step 2) and the vein imaged in real time in two directions (Step 3), to identify the true long axis and prevent damage to surrounding tissues.

Results. The overall success rate for catheterization was 100% with a median of one puncture for each patient. All catheterizations were performed within three punctures. Problems with the first puncture included difficult insertion of the guide-wire due to coiling, difficult anterior wall puncture, less experience with the procedure, and other reasons. There were no complications associated with the procedure.

Conclusions. This three-step method is not dependent on an operator's ability to proceed based on spatial awareness, but rather depends on logic. This method can prevent difficulties associated with a two-dimensional ultrasound view, and may be a safer technique compared with others. Further clinical trials are needed to establish the safety of this technique.

Keywords: axillary veins; central venous catheterization; central venous pressure; jugular veins; subclavian veins; ultrasonography

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When ultrasound imaging is used to guide central venous catheterization, the image formed by the sonographic beam can be along the axis of the vein (long-axis view) or perpendicular to it (short-axis view). The long-axis view of the vessel and in-plane needle approach (LAX-IP)[1] for ultrasound-guided central vein catheterization is performed in real time, which allows imaging of the needle and vein during the entire procedure. This benefit of the LAX-IP is ideal compared with the short-axis view of the vessel and out-of-plane needle approach (SAX-OOP). However, the LAX-IP has some pitfalls, which may lead to unanticipated injury of surrounding structures or failure to place to the catheter (Fig. 1). We describe a novel technique to prevent the pitfalls associated with the LAX-IP and show its clinical efficacy in a pilot study.

The LAX-IP has three problems that must be overcome to be more clinically useful. First, a vein that is not straight is difficult to approach using this approach. Secondly, manoeuvring a needle under the guidance of a thin ultrasound beam requires specific training and skill. The situation may be complicated by the 'side-lobe' artifact. If the needle is slightly out of the plane of the ultrasound beam, the artifact makes the needle appear to be in the plane of the sonographic beam.[2] Thirdly, it is difficult to accurately identify the true centre of the vein on the longitudinal view. A similar image can be seen with the ultrasound beam glancing near the edge of the vein. If the direction of the longitudinal view is towards the sidewall of the vein, the needle tip may go through the wall of the vein. In a typical clinical setting, a combination

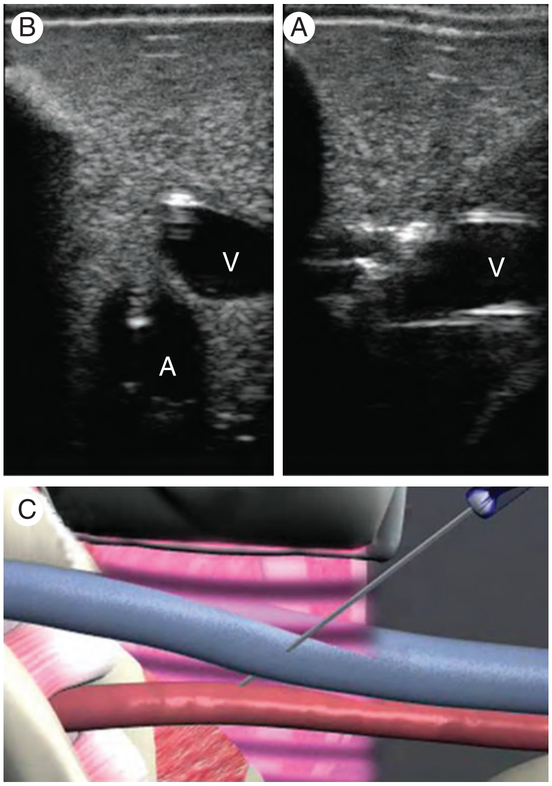

Fig 1 Pitfalls of the LAX-IP technique. Pitfalls associated with the LAX-IP are demonstrated using a simulator. V, vein; A, artery. (A) The longitudinal view shows what appears to be a correct orientation. (B) Actually, the tip of the needle is in the artery. (C) The three-dimensional graphic illustrates that the needle went through the vein into the artery.

of these problems can lead to misjudging, loss of the view of the needle on the ultrasound, or both, which could lead to failure of placement or unanticipated injury of surrounding structures. Each of these three problems can be overcome by applying this novel three-step method.

Methods

Ultrasound-guided central vein catheterization

(Step 1) Finding a straight portion of the target vein

A straight portion of the vein is selected for the puncture site, by precise and careful observation using the ultrasound transverse view. A straight portion is easily identified for the internal jugular vein. For a straight segment of the infra-clavicular axillary vein,[3 4] Sandhu[5] recommends straightening the vein by abduction of the patient's ipsilateral upper arm.

(Step 2) Using a needle guide

A needle guide is used, which decreases the training required for appropriate handling of the needle, and also prevents the 'side-lobe' artifact.

(Step 3) Set an ultrasound view along the true axis

Two scan techniques are applied to determine the true location of the long axis of the vein so that the puncture site will be in the centre of the vein.

Side-scape scan technique

Although the centre of the long axis is difficult to see on ultrasound, a view across the sidewall of the vein can be easily shown not to be the actual long axis. Since the centre of the vein is at the same distance from both sidewalls of the vein, the ultrasound probe is set furthest from both sidewalls of the vein using this logic. The procedure in detail is as follows:

(1) Stabilize the proximal edge of the probe by pinching the needle-guide wing with the right first and second fingers, while holding the distal edge of the probe with the left hand.
(2) Turn the distal edge of the probe to the right until the right sidewall of the vein is seen. Then, turn the distal edge to the left until the left sidewall of the vein is imaged.
(3) Repeat the scan (termed the 'side-scape scan'). Then, place the distal edge of the probe at the midpoint equidistant from both sidewalls of the vein.
(4) Do the same scan (1)–(3) at the proximal edge of the probe, by stabilizing the distal edge pinching with the left fingers.
(5) Finally, let both edges of the probe be placed equidistant from both sidewalls of the vein. This places the probe on a line just above the true long axis of the vein (Fig. 2).

Side-swing scan technique

One advantage of the long-axis approach is that venepuncture is performed with real-time imaging. Careful puncture may prevent puncture of the posterior wall of the vein, the so-called 'double wall puncture'. However, a large-bore needle and/or performing this in a patient with low venous pressure may lead to an unintended double wall puncture. Therefore, the ultrasound view is used to direct the needle away from surrounding structures, such as the artery, lung, or nerve, which are in close proximity to the vein (Fig. 3). The procedure in detail is as follows:

(1) Under ultrasound view, lower the probe to the right side on the skin and observe carefully whether any important structure is present.
(2) Then, lower the probe to the left side, checking carefully for important structures nearby.
(3) Repeat the same scan on both sides and set the probe so as not to be over an artery and/or lung on the ultrasound view.

By using a combination of the two techniques, the ultrasound view determines a safe direction without perforation

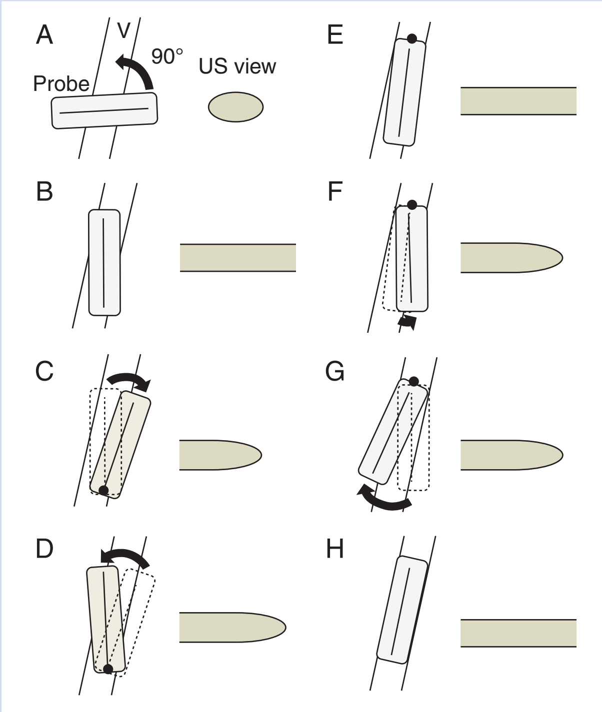

Fig 2 Side-scape scan technique. The details of the side-scape scan technique are shown in sequence, in (A–H). (A) Find the targeted vein using a short-axis view, then turn the ultrasound probe by 90°. (B) Although the ultrasound beam directed is laterally, the long-axis view looks like the long axis through the centre of the vein and parallel to the vein walls. (C) Turn the distal part of the probe to the right using the centre of the proximal edge (black dot) as the turning point till the right lateral wall can be identified (bullet shape of the walls). (D) Turn the probe to the left using the same motion described in (C). (E) Repeat the motions as in (C) and (D) to find the presumed centre of the vein (black dot). (F) Turn the proximal part of the probe to the right till the right lateral wall is identified. (G) Turn the proximal part of the probe to the left using the same motion described in (F). (H) Repeat the motions as in (F) and (G) to find the presumed centre of the vein. At this stage, both edges of the probe can be set close to the centre of the vein.

of the vein and accidental injury to surrounding structures, thus preventing the third problem. Puncture of the vein is performed under real-time ultrasound guidance (Fig. 4).

Clinical trial

This study was approved by the local ethics committee (Chiba Medical Center Ethical Committee), and written informed consent was obtained from each patient. All patients enrolled needed central venous catheter for clinical treatment, such as nutrition support, administration of cardiovascular medications, monitoring of central venous pressure, or administration of chemotherapy. Exclusion criteria were a patient's refusal to enrol in the study or the inability to clearly visualize the vein on ultrasound.

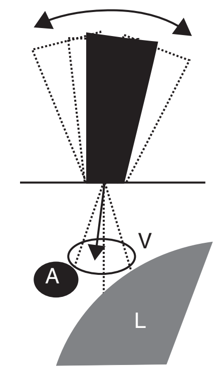

Fig 3 Side-swing scan technique. Swing the probe laterally to identify the location of surrounding structures. The dashed lines show potentially hazardous directions, but the solid arrow shows the safest direction. (A indicates the axillary artery, V indicates the axillary vein, and L indicates the lung.)

Training

Before this clinical trial, all participants underwent 1 h hands-on training using a mannequin simulator[6] to learn the techniques, especially the specific scan techniques. The instructor first showed the free-hand LAX-IP using the mannequin simulator. The importance of having the needle tip against the simulator's vein was explained, to determine whether the puncture was a success or not. The instructor then showed the scan techniques with vein puncture. The needle tip position within the vein was demonstrated. After the demonstration, participants tried the method and also evaluated the technique individually, checking the needle position within the vein. All participants demonstrated appropriate skill using this method after 1 h of hands-on training.

Equipment and central vein catheter kit

We used a 6–13 MHz, real-time, portable ultrasound device (NanoMaxx®, Sonosite Co., WA, USA) and central vein catheter kit (Safe Guide, Nippon Covidien Co., Tokyo, Japan). The kit was based on the Seldinger technique with a 22 G needle (6.7 cm in length), micro-needle system.[7] A needle guide and a disposable plastic sheath (Infiniti™ Needle Guidance System No. 674-047 & 610-1-75, CIVCO Medical Solutions, IA, USA) were used. A custom-made plastic needle guide was used from December 2010 to June 2011, until the commercial needle guide described above was available.

Preparation

Patients were placed in the Trendelenburg position at 10° in the operating theatre, or in the supine position with elevation of the lower extremities in a treatment room or X-ray fluoroscopy facility. If the axillary vein was chosen for the catheterization, the ipsilateral upper arm was abducted at 90° from the trunk to straighten the axillary vein. Pre-puncture scanning was performed to identify the infraclavicular axillary

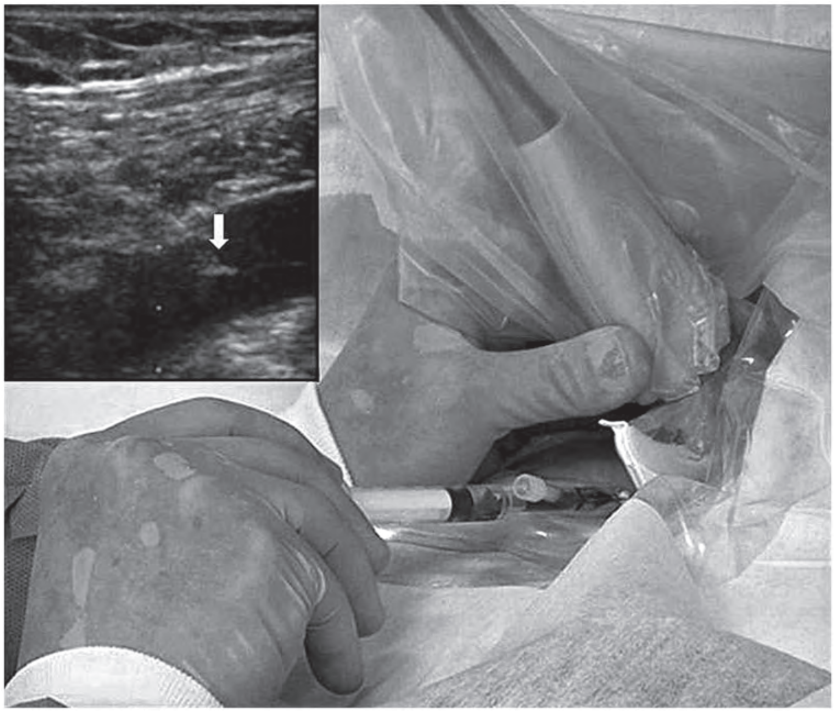

Fig 4 Real-time ultrasound-guided central venous catheterization. A needle has been introduced into the infraclavicular axillary vein utilizing ultrasound guidance with a needle guide controlling the passage of the needle in an in-plane approach. Inset: the needle tip is seen within the vein (arrow).

vein, and to exclude any vein inappropriate for catheterization (e.g. thrombosis, ectopic location, or atrophy). Chlorhexidine-alcohol was used for anti-septic skin preparation. The puncture skin site was then draped widely. Sterile ultrasound gel was used and a disposable sterilized plastic sheath covered the ultrasound probe during the procedure.

Venepuncture technique

A straight portion of the infraclavicular axillary vein was found using the transverse ultrasound view at the caudal portion of the clavicle (Step 1), and a needle guide was used (Step 2). The probe was rotated carefully through 90° to obtain the long-axis view of the vein. As mentioned above, a side-scape scan was performed to identify the centre of the long axis. The side-swing scan was then used to prevent injuries to surrounding structures (Step 3). Puncture of the vein was performed under real-time ultrasound guidance.

Results

One hundred patients undergoing central vein catheterization for a variety of indications between December 2010 and May 2012 were studied (Table 1). During the study, one patient did not consent to central vein catheterization of his neck or chest. A PICC (peripherally inserted central catheter) was placed after informed consent.

Table 1 Patient characteristics and results of vein catheterization. Data presented as median (range) or number. Age is shown as mean (range). G-W, difficult insertion of the guide-wire; tech., other technical problem

Catheter placed	Internal jugular vein	Axillary vein
Patients (M:F)	39 (25:14)	61 (35:26)
Right:left	39:0	54:7
Age (yr)	71 (42–89)	68 (34–93)
Height (cm)	159 (140–182)	159 (140–178)
Weight (kg)	56 (45–92)	54 (35–102)
No. of punctures	1 (1–3)	1 (1–3)
Multi-puncture	1 (G-W), 2 (tech.)	7 (G-W), 7 (tech.)
Complication	None	None
Total success rate	100%	100%

Nine operators (seven consultants, two trainees) performed all of the catheterizations. The first author (J.T.) has performed at least 300 ultrasound-guided central vein catheterizations using the SAX-OOP in clinical practice but had only preliminary training with a mannequin simulator before the study. The sixth author (Y.F.) also has performed at least 30 catheterizations with the SAX-OOP. The other seven operators were relative beginners in ultrasound-guided central vein catheterization. J.T. and Y.F. performed 65 of the procedures in this study; the other operators performed the procedure in the other 35 patients. There was no statistical difference between the operators with regard to success rate, multiple-puncture rate, or complication rate (χ^2 test, $P>0.05$). These data suggest that the method is quickly learned.

All vein catheterizations were achieved with three or fewer vein punctures. The overall success rate was 100%, and no complications (e.g. unanticipated arterial puncture, pneumothorax, haematoma, etc.) were encountered. Difficult insertion of the guide-wire occurred in eight patients, and these cases required a second venepuncture (six cases) or a third venepuncture (two cases). Difficult insertion of the guide-wire was caused by coiling of the guide wire at the puncture site in the vein (two cases), insertion at the site of a valve (one case), severe dehydration (one case), and an unknown reason, which prevented progress to a more central portion of the vein (four cases). Technical problems were experienced during the first month of the clinical trial, including a difficult puncture against the anterior wall of the vein (four cases), and incorrect manipulation of the probe causing loss of the view on ultrasound (five cases). In one obese patient (102 kg, 173 cm, BMI 34), a longer needle (15 cm, 20 G, TOP Co., Tokyo, Japan) was needed to reach the vein.

Discussion

The first clinical trial using two-dimensional ultrasound-guided central vein catheterization was reported in 1986.[8] Since that time, we have focused on ways to teach the skills needed for safe ultrasound-guided central venepuncture. The most difficult point is to get the trainee to understand the pitfalls[2] associated with two-dimensional imaging, since a two-dimensional view is not easily translated to the three-dimensional real world of the clinical setting. Refining the technique of the procedure and training for the technique over two decades, we concluded that a stepwise logical approach is the key to solve the problem without expecting a particular ability for spatial awareness and orientation, or 'sixth sense'. In this article, we introduce a logical method composed of three steps, and have demonstrated a high success rate and low complication rate in the clinical setting. Further clinical studies may confirm the safety of this method.

Recently, needle visualization has been improved by using technology, which resulted in development of the 'echogenic needle (or cannula)'. It is often helpful to manipulate the needle with in-plane imaging. Stefanidis and colleagues[9] reported the usefulness of the echogenic needle for ultrasound-guided subclavian vein catheterization. They showed that improved needle visibility reduced access time and the operators' perception of technical difficulty. However, they did not show that improved needle visibility reduces the incidence of mechanical complications. When we teach ultrasound-guided central vein catheterization to beginners, we sometimes notice that they confuse the shaft of the echogenic needle with the needle tip because it has almost the same brightness.

Improved needle visibility may relate to successful ultrasound-guided central vein catheterization. However, a clear image of the needle in the longitudinal view does not guarantee that the needle is in the plane of the ultrasound beam, because image clarity depends on the operator's subjective impression. Therefore, another strategy is needed to maintain the needle in the ultrasound beam plane. One approach is to use a needle guide, which can also eliminate the side-lobe artifact. Deformity of the vein being punctured by the needle must also be considered. If the needle is not directed at the centre of the vein, the off-centre pressure on the anterior wall may result in a dimple of the anterior wall pushing against the lateral wall inside the vein. Further pressure on the needle may induce a double wall puncture of the vein from the anterior wall to the lateral wall. Therefore, the direction of the needle tip is one key to safe practice.

In this study, we used a relatively small footprint ultrasound probe (40×10 mm, NanoMaxx®), and there were only four obese patients (BMI>30) in this study. Therefore, the needle used in this study was long enough except in one obese patient (BMI 34). The authors strongly suggest considering the size of the ultrasound probe, length of the needle, and wing size of needle guide before applying the method clinically. Disappointingly, if a larger ultrasound probe were used, the method could not be applied in some patients for internal jugular vein catheterization because of a lack of room to manoeuvre in the neck.

Another problem is the need for an assistant to help with insertion of the guide-wire because of the needle guide. The needle guide, an Infinity™ CIVCO Medical Solution device, has a wing to direct it into the ultrasound beam and a hole at the distal end. After puncturing the vein, the operator must be holding the probe and the needle, and an assistant must actually insert the guide-wire. A valved needle introducer or a slit type of needle guide may overcome the need for an assistant.

The cost may be increased by using a commercially available needle guide compared with free-hand techniques. Furthermore, a longer needle which is included in the usual catheterization commercial kit may be needed for an obese patient, and may increase the cost.

Although the clinical usefulness of ultrasound-guided internal jugular vein catheterization has been shown, evidence for the clinical efficacy of ultrasound-guided subclavian and infraclavicular axillary vein catheterization has also been reported. Some studies reported a success rate for subclavian and infraclavicular axillary vein catheterization from 92% to 100%, and also a low mechanical complication rate from 4% to 0%.[4 10–14] Compared with these studies, our data showed comparable or slightly better results with a 100% success rate and 0% mechanical complication rate. However, we acknowledge that further study of this method to specifically determine success rates and complication rates in a large sample of patients will be necessary to establish its true clinical value.

In summary, we have described a novel method order to facilitate ultrasound-guided placement of central venous catheters using the LAX-IP method. We found that this technique can be taught fairly easily, performed safely, and with good results in the clinical setting. These results support the conduct of further clinical trials to establish the true efficacy of this technique. We believe that this method may ultimately contribute to improved safety in central vein catheterization.

Acknowledgements

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Declaration of interest

J.T. is a technical adviser of the Nippon Covidien Co. (Japan) and has done an ultrasound-guided technical training course held by the company.

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Handling editor: J. P. Thompson

Fourth step for ultrasound-guided central vein catheterization

Editor—We read with great interest the article by Tokumine and colleagues.[1] The authors have introduced and demonstrated the safest method for central venous catheterization under real-time ultrasound guidance using the long-axis view of the vessel with the in-plane needle approach. As they have pointed out, the ultrasound-guided procedure with the short-axis view of the vessel with the out-of-plane needle approach would increase the success rate of venous puncture, although the technique will never be able to prevent unintentional penetration of other vital structures, including the carotid artery and pleura.[2] Strictly executing the three-step method, our anaesthesiologists could accomplish safe and practical catheterization.

Longitudinal ultrasound imaging is the most essential and important factor. Interestingly, the pictures demonstrated by the authors[1] were very similar to our presentations.[3] The National Institute for Clinical Excellence (NICE) guidelines of 2002 (reviewed in 2005)[4 5] recommend ultrasound guidance for central venous cannulations; however, the detailed practical description including the axis of ultrasound is not found in the text. When physicians endeavour to establish the safest methods for central venous catheterization, many practitioners would reach a similar conclusion,[6 7] that is, the long-axis, in-line real-time ultrasound guidance technique.

The three-step method could be considered to be an almost perfect way and there might be no room for discussion. However, we would like to append a fourth step. In our intensive care unit, the supervisor requires the operator to confirm appropriate i.v. guidewire placement by ultrasound examination before the insertion of a large-bore dilator and catheter. The intensivists track the guidewire as far as is possible to the limits of ultrasound visibility. The ultrasound probe is placed on a supraclavicular fossa, and when the internal jugular vein is accessed, we usually confirm the correct placement at the level of branching of the jugular vein and subclavian vein. The detection of the guidewire in the jugular vein near the entry site is never a guarantee for an appropriate placement.[1 2] The penetration of the posterior wall of the internal jugular vein and other vital structures can occur at a site more proximal than the skin puncture.

Thus, extensive tracking of the guidewire before the large-bore cannulation is recommended as the fourth step of the method introduced by Tokumine and colleagues.[1] We have no results of clinical investigation on this improvement so further study is required.

Declaration of interest

None declared.

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Reply from the authors

Editor—We appreciate the constructive comments of Dr Adachi and colleagues, and would like to further explain our message. While we greatly appreciate their kind remarks, we also acknowledge that the long-axis in-plane ultrasound guidance technique itself is not perfect. The long-axis in-plane technique also may lead to inadvertent anterior to lateral double-wall punctures.[1] This technique is restricted by the use of two-dimensional views. Dr Adachi and colleagues demonstrated the possibility of an anterior to posterior double-wall puncture with the long-axis in-plane technique in clinical settings, such as hypovolaemia.[2]

We agree that the passage of the guidewire can be a significant cause of difficulties. To prevent it, confirming appropriate i.v. position of the guidewire using ultrasound observation is effective, as recommended by Dr Adachi and colleagues. The technique they describe ('The fourth step') may increase the rate of appropriate positioning of the guidewire, and we agree that further study is indicated.

During each step of the placement process, guidewire coiling in the vein, migration into a small vein branch, tear or injury of the vein during dilation, or incorrect position of the catheter tip may occur. We would add that fluoroscopy might also be useful.[3 4] The combination of ultrasound and fluoroscopy may be ideal, but not always feasible due to the condition of the patient. In many situations, Dr Adachi and identify the exact cause of a problem such as vaginal spotting. If the patient is not bleeding heavily and a viable intrauterine pregnancy is visualized on bedside ultrasound, then any of the other etiologies for minor vaginal bleeding such as a cervical polyp may be safely left to the patient's primary obstetric provider for diagnosis. In many instances, it may even be better to have these types of diagnoses made by clinicians who are better prepared to manage a woman's longitudinal care. It is also very unlikely that a lubricated transvaginal ultrasound probe would induce severe bleeding from an occult cervical cancer. If such a lesion was in fact predisposed to significant hemorrhage from such minor trauma, then bleeding would be just as likely to occur after placement of a speculum or after bimaual examination. We agree that Papanicolaou tests can be performed on any patient undergoing a pelvic examination, pregnant or not. However, the impact of specific sampling techniques on results, the counseling needed for abnormal findings, and the required robustness of a follow-up system make this a test that few EDs feel comfortable incorporating into their routine care of women presenting to the ED with genital concerns.

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Four cases of inadvertent arterial cannulation despite of ultrasound guidance

To the Editor,

We read with great interest the publication by Stone et al [1] in the recent issue of the journal about the ultrasound detection of guidewire position for avoiding arterial guidewire placement. They demonstrated that guidewire visualization within the jugular vein predicted venous catheter placement with a sensitivity and specificity of 100% and 100%, respectively, in all 20 adult patients. As the author discussed, the use of real-time ultrasound guidance decreases complication, especially arterial puncture [2]. We are also confirming the venous placement of the wire in all cases using ultrasound sonography.

Recently, we encountered 4 cases of inadvertent arterial cannulation [3]. All procedures were performed after confirming the stria of internal jugular vein with ultrasound, and the puncture of the final case was performed under real-time ultrasound guidance. The vein was exactly punctured, and the existence of guidewire in the vein was confirmed with sonography at the pierced site. However, the guidewire might be migrated into carotid artery through the posterior vessel wall of internal jugular vein, and subsequent large-bore cannulation injured the artery at the proximal site. This risk was well documented by Blaivas and Adhikari [4]. They investigated the frequency of posterior vessel wall penetration by the needle during attempts to place central venous catheters with ultrasound imaging, and 64% of residents accidentally penetrated the posterior wall of the vein during cannulation.

We believe that the most important technique of real-time ultrasonographically guided catheterization might be visualization of both the vein and entire needle, especially the point of needle, in the same plane at the puncture [3]. The top of needle should be in the internal jugular vein completely. After the placement of guidewire, the confirmation of accurate placement would be difficult and the possibility of migration to the artery never be eliminated. At least, our experience reduced the sensitivity and specificity demonstrated by Stone et al [1].

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An unseen danger: Frequency of posterior vessel wall penetration by needles during attempts to place internal jugular vein central catheters using ultrasound guidance*

Michael Blaivas, MD, RDMS; Srikar Adhikari, MD, RDMS

LEARNING OBJECTIVES

On completion of this article, the reader should be able to:

1. Explain appropriate technique and use of ultrasound in placement of internal jugular lines.
2. Describe benefits and limitations of use of ultrasound.
3. Use this information in a clinical setting.

The authors have disclosed that they have no financial relationships with or interests in any commercial companies pertaining to this educational activity.

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Lippincott CME Institute, Inc., has identified and resolved all faculty conflicts of interest regarding this educational activity.

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Objectives: **To evaluate the frequency of unsuspected posterior vessel wall penetration of the internal jugular vein during ultrasound-guided needle cannulation.**

Design: **Prospective, single-blinded observational study.**

Setting: **Urban level I emergency department with an annual census of 80,000.**

Patients: **Residents who had previously completed a 2-day ultrasound course including a 3-hr didactic and hands-on session on ultrasound-guided central venous cannulation.**

Interventions: **Residents were asked to place an ultrasound-guided catheter on a human torso mannequin. Residents used a short-axis approach for ultrasound guidance. During the procedure, an 8–4 MHz convex (endocavity) transducer was used to observe the path of the resident's needle without interference with the placement procedure.**

Measurements and Main Results: **Unknown to residents, researchers tracked the frequency of posterior wall penetration and the final needle location when the resident felt that optimal needle placement was achieved in the lumen of the internal jugular. Residents were also asked to rate their confidence regarding appropriate final needle position on a 10-point Likert scale. Statistical analysis consisted of descriptive statistics and Spearman correlation analysis. A total of 25 residents participated. All had placed at least one ultrasound-guided central catheter previously. The median number of previous ultrasound-guided cannulations was 8.0. Sixteen (64%) residents accidentally penetrated the posterior wall of the internal jugular vein during cannulation. The median number of posterior wall penetrations was 1.0 for all residents. In six cases the final location of the needle was through the posterior wall and deep to the venous lumen. In five of these cases the carotid artery was actually mistakenly penetrated. Median confidence by residents regarding appropriate needle placement was 8.0 out of 10. More training and more ultrasound-guided catheters placed were associated with fewer posterior wall penetrations ($p = .04$).**

Conclusions: **In this study, residents accidentally penetrated the posterior vessel wall of the internal jugular in a lifelike vascular access mannequin in the majority of cases. These results suggest that care must be taken even with ultrasound-guided central catheter placement and that alternative ultrasound guidance techniques, such as visualization of the vein and needle in longitudinal axis, should be considered. (Crit Care Med 2009; 37:2345–2349)**

Key Words: emergency ultrasound; ultrasound-guided catheter placement; ultrasound; ultrasound-guided procedures; ultrasound education; central venous access

***See also p. 2473.**

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Central venous access under ultrasound guidance is widely supported in current medical practice. The use of ultrasound guidance for central venous cannulation has been endorsed by several medical societies and supported by a large number of favorable studies in the literature (1–5). Typical central venous catheter sites include the internal jugular, femoral, and subclavian veins. Internal jugular (IJ) cannulation is perhaps the most popular method given the ready access of relatively superficial vessels (3, 6, 7). Good visualization under ultrasound and the possibility of compressing the jugular and carotid vessels to affect hemostasis also contribute to its popularity as a site of choice.

There are two basic methods of using ultrasound to assist central venous cannulation. The first and least effective is static ultrasound assistance, where ultrasound is used to identify the vessel, a temporary mark is placed on the skin, and then the procedure is performed blindly (1, 5). This approach does little to improve success, and likely safety, in challenging patients (1, 5). In the dynamic ultrasound-guidance approach, the operator directs a needle into the desired vessel underneath an ultrasound transducer and uses the real-time image on the ultrasound machine screen to guide cannulation. This is the sole method recommended by the Agency for Healthcare Research and Quality (1). Studies by Nadig et al (4) and Milling et al (5) comparing these two methods confirmed that dynamic ultrasound assistance outperformed static ultrasound, resulting in significantly fewer unsuccessful attempts at central venous access.

Most studies report the use of real-time guidance using a transverse approach where the ultrasound transducer is placed perpendicular to the length of the vein and the venous lumen is seen in cross section as a circle on the ultrasound machine screen (Fig. 1). The vessel is then centered under the transducer and the midpoint of the transducer becomes a reference point for insertion of the needle. The needle is introduced through the skin, under the transducer, and is seen as a dot (cross section) on the ultrasound image. This approach is the most common and is favored by novice sonologists (6). However, because the entire length of the needle is not visualized and only a cross section of the needle is seen, extra care has to be taken to not lose track of the needle tip and penetrate deeper structures that are out of sight.

We sought to evaluate the number of penetrations that sonologists made of the posterior vessel wall while attempting to cannulate the IJ vein on a commercially available ultrasound phantom. As a secondary measure, we evaluated the accuracy with which novice sonologists determined the final location of their needle within the IJ when they were ready to feed a guide wire into the vein.

METHODS

Study Design. This was a prospective, single-blinded study for the evaluation of IJ catheter placement in a synthetic human torso ultrasound mannequin. This study was approved by institutional review board, and verbal consent was obtained from each participant. The study subject's performance during the study was recorded anonymously.

The study occurred at an urban level I emergency department with an emergency medicine residency, an active ultrasound education program, and annual census of 80,000 patients. Twenty-five emergency medicine residents, all of whom had undergone training in ultrasound-guided vascular access (a 2-day ultrasound course including a 3-hr didactic and hands-on session on ultrasound-guided central venous cannulation), had previous experience placing ultrasound-guided catheters, and used the short-axis approach, were asked to participate in the study. The investigators of this study were board-certified emergency physicians with hospital credentialing in emergency ultrasound. All had ≥2 yrs of ultrasound experience in the emergency department before the study, and each had performed ≥100 ultrasound-guided vascular access procedures before the study.

Study Protocol. Each emergency medicine resident was asked to perform an IJ cannulation under ultrasound guidance in the typical short-axis approach. None of the residents were aware of the goals of the study or that variables being recorded. Residents were given the following clinical scenario: An ill patient in a critical care setting required a central catheter but was not unstable or in cardiac arrest, so the central catheter could be placed semi-electively. The patient was anticoagulated with an international normalized ratio of 3.5 so special care was requested to avoid penetration of the carotid and posterior wall of the IJ. Each resident was asked to carefully position the needle tip into the center of the internal jugular vein. Red fluid simulating blood could be withdrawn with the syringe similar to what would occur with a live patient.

We used a life-sized torso model containing a realistic IJ, carotid, clavicle, and subclavian vein and artery (Blue Phantom, Kirkland,

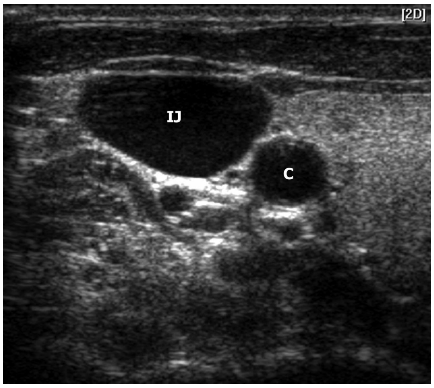

Figure 1. Short-axis view of the right internal jugular vein (*IJ*) and adjacent carotid artery (C).

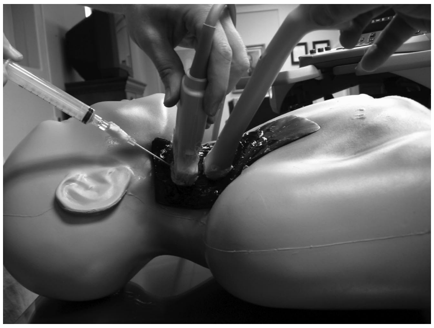

Figure 2. A short-axis approach is being used by a resident to access the internal jugular vein on a synthetic torso mannequin. A convex endocavity transducer is being held near the resident's transducer to observe progress. The endocavity transducer was adjusted constantly to observe the path of the needle and avoid contact with the residents transducer.

WA). The vessels in the mannequin allow for compression as part of the identification process. Residents used a short-axis approach for ultrasound guidance. No time pressure was put on the study subjects, and they were allowed to adjust their ultrasound transducer positioning and image as desired as long as a transverse view of the IJ was maintained during cannulation. A Sonosite Titan ultrasound system with a 10–5 MHz linear transducer was used by residents for vascular access. A Sonsoite Micromaxx with a 8–4 MHz endocavity transducer was used by investigators, at the same time, to track the needle. Once the resident was ready to attempt cannulation, a high-resolution convex (endocavity) transducer was placed proximal to the linear transducer being used by the resident (Fig. 2). The endocavity transducer was adjusted constantly to observe the path of the needle and avoid contact with the resident's transducer. The convex transducer's orientation allowed visualization of the target vein in long axis without interfering with the resident's attempts at cannulation. Because of the wide convex image delivered by the endocavity array, investigators were able to see directly under the linear transducer being used by the residents without interference.

Unknown to residents, one of the investigators tracked the needle's progress in long axis, recording any penetration of more than one wall of the internal jugular, penetration of the adjacent carotid artery, and final location of the needle tip in the venous lumen as seen in long axis when the resident was ready to feed the guide wire. Residents were not asked to actually feed a guide wire.

Main Outcome Measures

Study physicians filled out standardized data collection sheets. They recorded the number of times each resident penetrated the posterior wall of the vessel. The "posterior wall" was defined as the second wall penetration by the needle after having penetrated the vessel once and still having the needle shaft through the wall at the original site of vessel penetration (Fig. 3). Thus, if the needle was driven in at an angle and initially penetrated the anterior wall and then the side wall, this was considered a posterior wall penetration. One physician tracked posterior wall penetrations (MB). The physician had 15 yrs of point-of-care ultrasound experience and >1,000 ultrasound-guided vascular access procedures as well as extensive teaching and research experience in ultrasound vascular access.

For secondary study outcome measures, physicians recorded the final position of the needle tip in or out of the vein. This was believed to be important because falsely placing the needle outside of the internal jugular can occur after passage through the vessel and concomitant blood withdrawal into the syringe. In addition, the closer the needle tip is to the posterior wall, the more likely it is to migrate through the wall when the physician takes the probe off the skin and reaches for the guide wire. Having the needle in the center is the desired location under ultrasound. Quality assurance ultrasound video review had previously revealed that needle drift sometimes occurs when eyes are taken off the needle and syringe and the physician reached for a guidewire. Thus, precision of needle placement within the vessel may decrease the likelihood of malpositioning and gives more room for error with any needle drift during changeover and wire insertion. In addition, researchers recorded whether the carotid artery was penetrated. Finally, residents used a 10-point Likert scale to indicate their level of confidence that the needle tip was in the middle of the vein. Ten was highest confidence level.

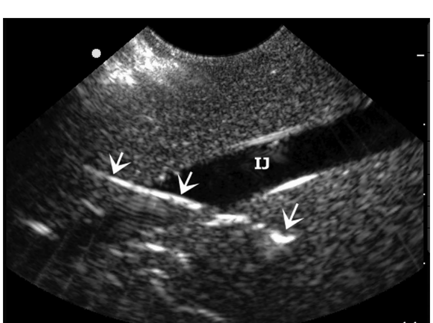

Figure 3. An image from the convex array transducer used to monitor resident needle progress shows the needle (*arrows*) penetrating through the mannequin's internal jugular vein (IJ).

Statistical Methods. Statistical analysis included descriptive statistics and correlation analysis to evaluate for effect of experience level. Spearman correlation coefficients were calculated to evaluate for any relationship between posterior wall penetration and year of training or ultrasound-guided catheter placement experience. Medians and interquartile ranges were used to evaluate Likert scale ratings by subjects for total central catheters before the study, blind central catheters before study, and confidence in needle placement. We used 95% confidence intervals and ranges to report frequencies and percentages. Sample size was not calculated before the study given the absence of available data on posterior wall penetration frequency and needle location frequency for central catheter placement under ultrasound. Data were analyzed by a professional statistical consultant using PC SAS 9.1.3.

RESULTS

A total of 25 residents were enrolled in the study. All of the residents were able to complete the procedure and draw simulated blood from the mannequin. Sixteen (64%) residents accidentally penetrated the posterior wall of the IJ during cannulation. In six cases the final location of the needle was through the posterior wall and deep to the venous lumen. In five of these cases the carotid artery was actually mistakenly penetrated. Summary data are presented in Tables 1, 2 , and 3. Table 1 shows distribution of training year among the participants, frequency of posterior wall penetration, and final location of the needle when the resident finished the cannulation and was ready to feed the wire through the needle. Penetration of the posterior wall ranged from 0 to 10 times. Table 2 shows subjects' experience at the time of the study with catheter placement. Experience ranged broadly; all subjects reported placing ultrasound-guided catheters previously. Table 3 shows Spearman correlation analysis examining the relationship between training year and ultrasound-guided catheter experience with posterior wall penetration. More training and more ultrasound-guided catheters placed were associated with fewer posterior wall penetrations ($p = .04$)

Comment. Ultrasound guidance of central venous cannulation is endorsed

Table 1. Frequencies and percentages of resident training, wall penetration, and final needle location when resident felt it was time to feed in the guide wire

	Frequency, n (%)
Training year	
1	7 (28)
2	8 (32)
3	10 (40)
Ended through posterior wall	
No	19 (76)
Yes	6 (24)
Posterior wall penetration	
0	9 (36)
1	6 (24)
2	6 (24)
3	1 (4)
4	1 (4)
7	1 (4)
10	1 (4)
No	9 (36)
Yes	16 (64)
Ended in carotid	
No	20 (80)
Yes	5 (20)
Final needle location in short axis	
Near anterior wall	3 (12)
In center of vessel	16 (64)
Near posterior wall	6 (24)
Final needle location in long axis	
Near anterior wall	5 (20)
In center of vessel	11 (44)
Near posterior wall	3 (12)
Through posterior wall	6 (24)

Table 2. Descriptive statistics of count data and Likert scale

	Median (Interquartile Range)
Ultrasound-guided catheters placed prior to study	8 (2, 15)
Blind central catheters placed prior to study	20 (15, 40)
Posterior wall penetration	1 (0, 2)
Confidence in needle placement	8 (7, 9)

Table 3. Spearman correlation coefficients and p values

	Training Year	Ultrasound-Guided Catheters
Posterior wall penetration	–.41 ($p = .04$)	–.54 ($p = .01$)

by a number of organizations, and there is compelling evidence that it decreases the frequency of complications (1–3). Ultrasound-guided vascular access has been associated with higher success rates, reduction in mean insertion attempts, and placement failure rates. This technique has been shown to ensure safety and reduce many of the potential complications associated with landmark methods (7–12). One reason complications may occur during blind cannulation is the unreliability of the traditional belief that anatomically the carotid and internal jugular are always located side by side, a basis of the landmark technique. In fact, the carotid is frequently partially overlaid by the internal jugular or even sits directly deep to it (13–15). Ultrasound-guided catheterization is thought to be safer in high-risk patients, such as those with disorders of hemostasis (16, 17). Ultrasound guidance has been shown to be significantly safer and have a higher success rate compared with the blind technique for hemodialysis patients (18–20). However, anecdotal reports note accidental arterial cannulation and other associated complications despite the use of ultrasound guidance for central catheter placement.

The most common approach to ultrasound guidance is a short-axis or transverse visualization of the central vein (Fig. 1). With this technique, the vein is seen in cross section as a circle and the needle is also seen in short axis as a bright dot. The bright dot of the needle can distort the tissue and cause classic metallic artifacts on ultrasound. Regardless of the exact image created, the needle is first seen superficial to the vein and is guided into the venous lumen by moving the transducer away from the point of skin penetration, thereby following the progress made by the needle tip. In the long-axis approach, the vessel appears as a dark, thick line and the entire length of the needle can potentially be tracked on the ultrasound screen as it enters the blood vessel (Fig. 4) (21). The short-axis technique appears to be favored by novice sonologists and is described as being easier to perform and taking less time than the alternative longitudinal guidance approach (6). Most physicians find the longitudinal-axis approach, in which the needle can easily move out of plane and vanish from the screen, more cumbersome and time consuming. A large portion of studies on ultrasound-guided vascular access in the literature also use the short-axis approach (22–24). Researchers have not yet determined which approach is the more accurate and precise one. Anecdotally, it is has been our experience that as novice ultrasound users' expertise grows, they tend to gravitate to the long-axis approach for vascular access. This is attributable to a perceived increased precision in needle guidance that appears more important in the more difficult access patients. The serious consequences of accidental posterior wall penetration or poor needle tip visualization are likely to be underreported, as a search of MEDLINE suggests (25). We are aware of six in-house cases of carotid artery cannulation ultrasound guidance in short axis, one resulting in airway loss and death. Again, the impact that use of the long axis has on carotid artery puncture rates is unknown. A carotid artery positioned directly underneath or deep to the internal jugular may increase the risk of carotid penetration from posterior IJ wall. However, in cases where the carotid is lateral to the IJ, this risk should be decreased.

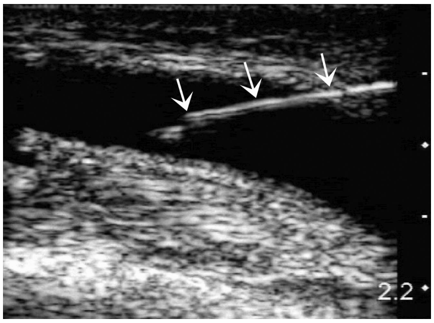

Figure 4. A needle is visualized in its length (*arrows*) entering a vessel, also visualized in its length or long axis.

In an earlier study, short- and long-axis approaches with vascular access were compared in an inanimate model (6). This prospective, randomized, observational study found that novice users could perform cannulation more quickly using the short-axis approach. There was, however, no statistically significant difference in terms of ease of use, number of skin breaks, and mean number of needle redirections (6). No prior studies comparing the complication rates of these two approaches have been reported in the literature.

Our data indicated that despite the appearance of real-time cross-sectional visualization of the needle as it approaches a vessel, inadvertent penetration of the posterior vessel wall occurred in the majority of attempts. We hypothesize that this, in all likelihood, occurs in blind cannulation attempts with some regularity. We were surprised by the pattern of the results, especially given that all subjects were residents with ≥1 yr in training who had undergone at least one ultrasound-guided vascular access training session. Furthermore, all of the residents reported placing at least one ultrasound-guided central catheter (IJ specifically) since their training course. The mean number of catheters placed was nearly ten and suggests at least a moderate level of trainee experience. Because the range of previous ultrasound-guided catheters placed was narrow (1–25), it is difficult to say whether residents with 50 or even 100 catheter experience would still penetrate the posterior vessel wall as frequently.

Our data also suggest that physicians placing ultrasound-guided central venous catheters using the short-axis approach should be careful about the location of the needle tip and maintain a healthy concern that it may have already gone through the posterior vessel wall. The institution of monitoring by more experienced sonologists, with a high-resolution microconvex transducer, to track the needle's position for novice sonologists in a training setting may be beneficial. The short-axis approach is the preferred and most frequently used method in our emergency department by residents and attending physicians, and we have noted several carotid artery penetrations. Using the longitudinal approach where the entire length of the needle can be visualized and, at least theoretically, the needle tip never blindly penetrates tissue is hypothetically advantageous. The fact that previous data indicate that novice sonologists find this approach less appealing may need to be weighed against the theoretical potential for improved success rates and fewer complications when using the longitudinal method of needle guidance. There is no evidence to support that posterior wall penetration results in clinically significant adverse events to the patient or the patient's outcome. However, that has not been specifically studied before, either in an experimental or a clinical setting.

This study has several limitations, including the use of an ultrasound phantom instead of actual patients. However, the use of actual patients would have been quite difficult for this study. Furthermore, the use of one phantom allowed us to standardize the level of difficulty each resident faced. The distance between the IJ and carotid in the mannequin model is greater than in many actual patients. This means that in actual patients, penetration of the posterior wall may be more likely if the vessels are closer together. From the data it is apparent that the model is not unrealistically easy and provides an adequate challenge for vascular access similar to that of a live patient. The ultrasound phantom did not move and was not in distress, thus removing some of the real-life difficulties occasionally encountered when placing catheters. It is likely that in real patients, some of the residents would have realized a carotid was cannulated before dilating the tract and inserting the catheter. This would occur if blood pressure and oxygenation are adequate and the syringe is taken off from the hub of the needle, showing arterial pulsation. The residents had a range of experience, but it would not be possible to standardize experience levels unless we used interns immediately after their training. We specifically sought physicians in training would who have placed both blinded and ultrasound-guided catheters and would be expected to do so in the emergency department and intensive care rotations without the supervision required for a first-time user. Finally, there is the possibility of bias introduction through the use of an investigator, nonblinded to hypotheses, as the main determiner of outcomes.

In this study, residents accidentally penetrated the posterior vessel wall of the internal jugular in a life-like vascular access mannequin in the majority of cases. Although the percentage of residents penetrating the posterior wall was not statistically significant, it is clinically significant given the danger of unintentional penetration of the carotid artery. These results suggest that care must be taken even with ultrasound-guided central catheter placement and that alternative ultrasound guidance techniques, such as visualization of the vein and needle in longitudinal axis, should be considered.

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