

CARDIOVASCULAR

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 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

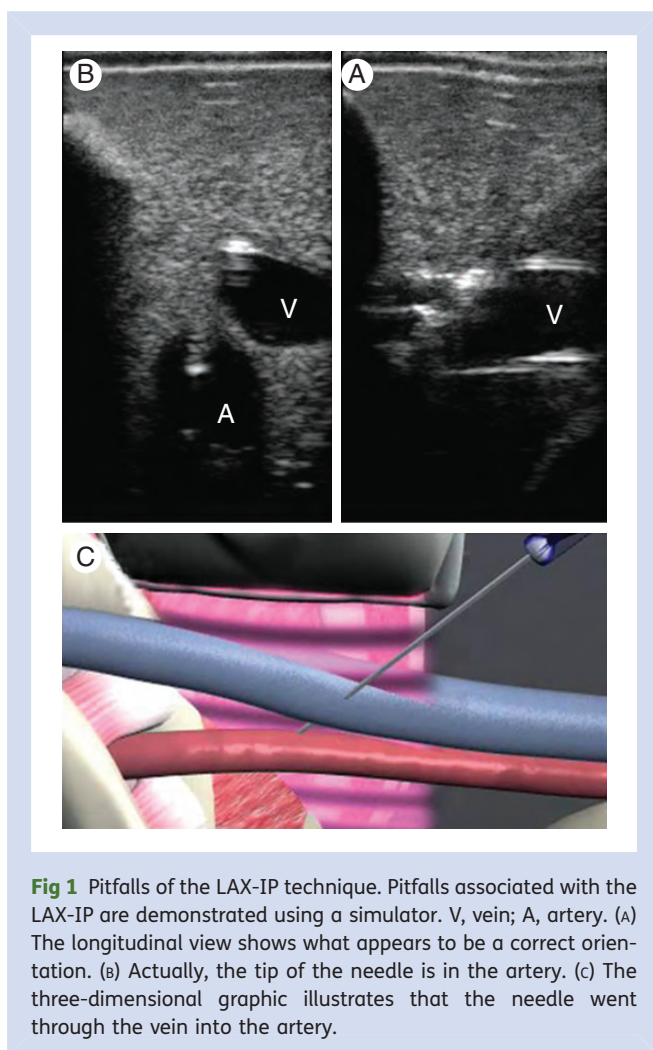


Fig 1 Pitfalls of the LAX-IP technique. Pitfalls associated with the LAX-IP are demonstrated using a simulator. V, vein; A, artery. (A) The longitudinal view shows what appears to be a correct orientation. (B) Actually, the tip of the needle is in the artery. (C) The three-dimensional graphic illustrates 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} Sandhu⁵ 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

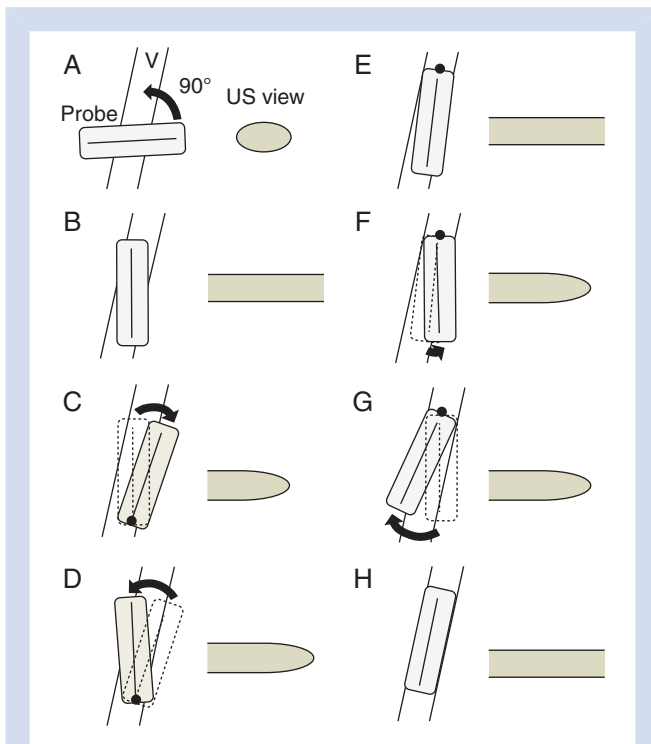


Fig 2 Side-scape scan technique. The details of the side-scape scan technique are shown in sequence, in (A–H). (A) Find the targeted vein using a short-axis view, then turn the ultrasound probe by 90°. (B) Although the ultrasound beam directed is laterally, the long-axis view looks like the long axis 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.

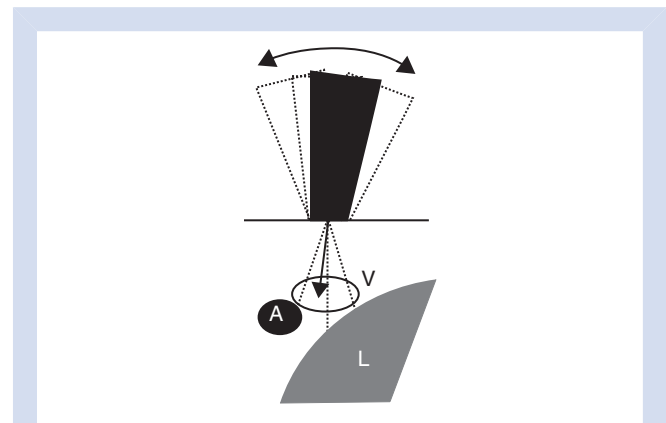


Fig 3 Side-swing scan technique. Swing the probe laterally to identify the location of surrounding structures. The dashed lines show potentially hazardous directions, but the solid arrow shows the safest direction. (A indicates the axillary artery, V indicates the axillary vein, and L indicates the lung.)

Training

Before this clinical trial, all participants underwent 1 h hands-on training using a mannequin simulator⁶ 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

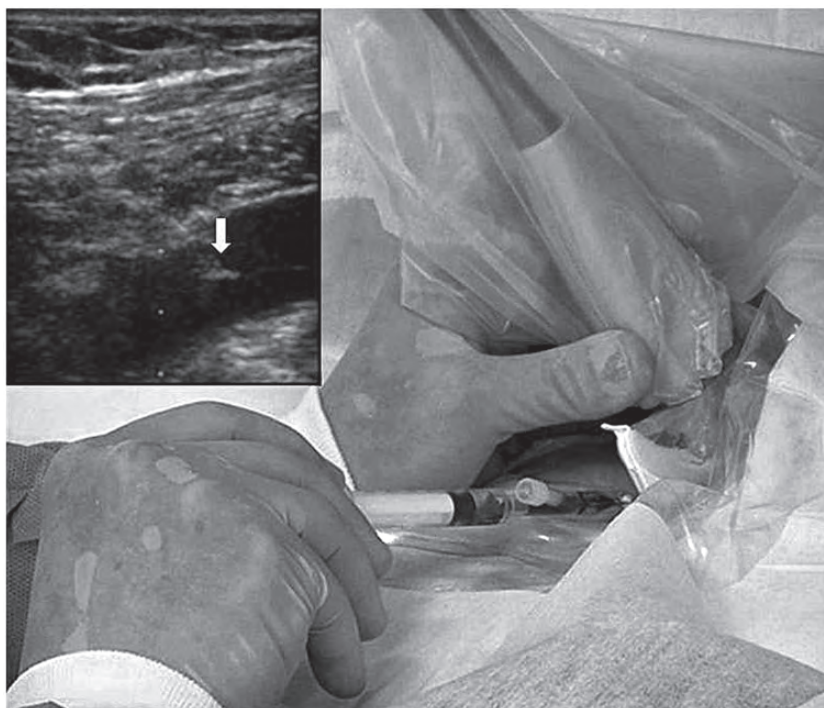


Fig 4 Real-time ultrasound-guided central venous catheterization. A needle has been introduced into the infraclavicular axillary vein utilizing ultrasound guidance with a needle guide controlling the passage of the needle in an in-plane approach. Inset: the needle tip is seen within the vein (arrow).

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

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%

his neck or chest. A PICC (peripherally inserted central catheter) was placed after informed consent.

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 pitfalls² 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 colleagues⁹ 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.

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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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