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

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Abstract
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 1 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.

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.

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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, 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 Sonosite 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.

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**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.

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 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.

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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REFERENCES

1. Agency for Healthcare Research and Quality. Making health care safer:
a critical analysis of patient safety practices [Summary]. Evid Rep
Technol Assess 2001; (43):i-x, 1-668 [Context Link]

2. National Institute for Clinical Excellence: Guidance on the use of
ultrasound locating devices for placing central venous catheters.

placement of central venous catheters: a meta-analysis of the literature.
Crit Care Med 1996; 24:2053-2058 Ovid Full Text | Request Permissions
Bibliographic Links [Context Link]

Bibliographic Links [Context Link]

trial of point-of-care limited ultrasonography assistance of central venous
cannulation: the Third Sonography Outcomes Assessment Program (SOAP-3)
Bibliographic Links [Context Link]

approaches for teaching ultrasound-guided vascular access on a new
inanimate model. Acad Emerg Med 2003; 10:1307-1311 Bibliographic
Links [Context Link]

central venous cannulation: meta-analysis. BMJ 2003; 327:361 Ovid Full
Text | Bibliographic Links [Context Link]

improves the success rate of internal jugular vein cannulation: a


*See also p. 2473.

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

**IMAGE GALLERY**

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

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Table 2

Table 3

Table 1

Figure 4