A Training Program for Real-Time Ultrasound-Guided Catheterization of the Subclavian Vein

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ABSTRACT

PURPOSE: To develop and implement a comprehensive program to train providers to place subclavian central venous catheters (CVCs) using real-time ultrasound guidance.

STUDY DESIGN: Simulation-based prospective study at an academic medical center. Of 228 anesthesia providers and intensivists eligible to participate, 106 participants voluntarily enrolled. The training program consisted of a didactic module, hands-on instruction and practice using a CVC simulator and a standardized patient. The success of the program was measured by pre and post knowledge tests and direct observation during the hands-on sessions.

RESULTS: Of 106 participants who enrolled, 70 successfully completed the program. Out of 20 possible procedure steps, an average of 17.8 ± 2.9 were correctly performed in the simulated environment. The average time to needle insertion, defined by positive aspiration of stained saline, was 3.35 ± 3.02 min and the average time to wire insertion with ultrasound confirmation was 3.85 ± 3.12 min.

CONCLUSIONS: Participants learned how to successfully perform ultrasound-guided catheterization of the subclavian vein. Since ultrasound-guided subclavian CVC placement is a useful clinical skill that many practitioners are unfamiliar with, increasing competence and comfort with this procedure is an important goal. Other centers could consider adopting an approach similar to ours to train their providers to perform this technique.

KEYWORDS: central line, subclavian, ultrasound, education, simulation, venous access

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Introduction

Hospitalized patients frequently require central venous catheters (CVCs), but these are associated with a variety of serious complications.[1] Common approaches to central venous catheterization include the internal jugular, subclavian, and femoral veins. In adults, the subclavian site is recommended by the Centers for Disease Control and Prevention (CDC) because it is associated with fewer infectious and thrombotic complications.[2] However, in some centers the subclavian is considered the approach of last resort, because subclavian CVC insertion is technically more challenging and can be associated with substantially more mechanical complications (ie, pneumothorax).[2-4] Furthermore, reducing the incidence of iatrogenic pneumothorax from CVC placement is a critical initiative for many hospitals since this complication is a Department of Health and Human Services Agency for Healthcare Research and Quality "patient safety indicator." Because fewer subclavian CVCs are being inserted, practitioners and trainees are becoming less experienced and less comfortable with this approach, and may not be able to competently perform it when it is indicated or even absolutely necessary.

Ultrasound guidance is frequently used for the internal jugular approach but still rarely used for the subclavian approach, despite increased cannulation success rates, increased ability to identify vascular anomalies and pathologies, and fewer complications during CVC insertion with ultrasound.[2-7] For example, in a large prospective randomized study that evaluated complications of CVCs by insertion site, an anatomical landmark technique was used in 86% of subclavian insertions but in only 33% of internal jugular insertions.[1] This discrepancy is likely due to a lack of familiarity with the use of ultrasound for subclavian CVC insertion and the perception that ultrasound guidance is technically challenging to perform. Consequently, we developed and implemented a comprehensive program to teach providers how to perform ultrasound-guided catheterization of the subclavian vein, more specifically using a lateral subclavian (axillary) vein approach.

Methods

The training program was offered to all 228 providers in our department who place CVCs, including anesthesiologists, anesthesiology residents and fellows, certified registered nurse anesthetists, intensivists, and advanced practice providers working in an intensive care unit. Participation was voluntary. Most providers had little to no prior familiarity with the ultrasound-guided subclavian technique. The program consisted of 3 phases.

Phase 1 included a written assessment and online didactic module. A ten-question multiple-choice pre-test evaluated baseline knowledge of requisite sonographic anatomy, indications, contraindications, and potential complications of CVC placement. No score or feedback was offered to participants at that time. Next, a didactic module consisting of slides describing the aforementioned topics in more detail, and a video demonstrating the technique, was presented (the video can be found at https://www.nejm.org/doi/full/10.1056/nejmvcm1406114).[3]

In phase 2, participants completed a hands-on training module. First, a preceptor experienced with CVC placement demonstrated the relevant surface and sono-anatomy using a standardized patient. Next, participants practiced patient positioning, skin preparation and draping, and identification of relevant surface and sono-anatomy on a standardized patient. Using ultrasonography (Sonosite X-PORTE with probe Model HFL38xp, bandwidth 13-6 MHz Linear), subclavian artery and vein positions were identified, and then both structures were interrogated with color flow Doppler. The location of the clavicle and pleural line relative to the vein were noted, and the optimal site and trajectory for needle entry was selected.

In phase 3, participants practiced the CVC placement procedure on a task trainer (Blue Phantom®, Gen II ultrasound central line training model, CAE Healthcare, Sarasota, FL). A preceptor (EAD) was present to provide coaching and feedback to the participants. They had to successfully verbalize and demonstrate the pre-procedural steps and successfully acquire ultrasound images on the standardized patient. Participants then were observed while performing the procedure on the task trainer. Key portions of the procedure were recorded, including needle stick, venous access, guide wire insertion and confirmation, insertion of the catheter, and removal of the guide wire. Any observed errors were recorded. During phase 3, feedback was not provided until the procedure was completed. Finally, a post-test questionnaire was administered and graded.

Results

Of 228 invited participants, 106 (47%) accessed the online didactic module, and 70 (31%) completed the entire training program. The majority of participants (94%) reported having placed at least 1 internal jugular CVC during the prior 12 months, and only a minority (28%) had placed at least 1 subclavian CVC during the prior 12 months (Table 1).

The post-test revealed that participants learned key information about subclavian CVC placement (Table 2).

Specifically, post-training assessment revealed significant improvement in key learning points including incidence of central line associated bloodstream infection (CLASBI) and

Table 1. Respondents' characteristics and experience with central venous catheter placement.*

RESPONDENTS' CHARACTERISTICS AND EXPERIENCE	RESPONDENTS COMPLETING PRE-ASSESSMENT (N = 106)
Provider title, N (%)	
Attending	37 (35)
Fellow	7 (6.6)
Resident	25 (24)
CRNA	30 (28)
Advance practice provider	7 (6.6)
Not answered	1 (0.9)
N of internal jugular CVC in last 12 mo	
0	4 (3.8)
1-10	42 (40)
11-20	21 (20)
>20	0 (0)
Not answered	39 (37)
N of subclavian CVC in last 12 mo	
0	76 (72)
1-10	28 (26)
11-20	1 (0.9)
>20	0 (0)
Not answered	1 (0.9)
N of subclavian CVC placed with US	
0	68 (64)
1-10	9 (8.5)
11-20	1 (0.9)
>20	0 (0)
Not answered	28 (26)
N of femoral CVC in last 12 mo	
0	59 (56)
1-10	43 (41)
11-20	0 (0)
>20	0 (0)
Not answered	4 (3.8)
Rationale for subclavian CVC placement	
Ease of placement	4 (3.8)
Alternate sites unavailable	25 (24)

(Continued)

Table 1. (Continued)

RESPONDENTS' CHARACTERISTICS AND EXPERIENCE	RESPONDENTS COMPLETING PRE-ASSESSMENT (N = 106)
Alternate sites unsuccessful	1 (0.9)
Lower infectious risk	6 (5.7)
Lower thrombotic risk	0 (0)
Concern for cerebral venous drainage	1 (0.9)
Patient comfort	0 (0)
Training	0 (0)
Other	1 (0.9)

Abbreviations: CRNA, certified registered nurse anesthetist; CVC, central venous catheter; US, ultrasound.
*All answers were offered as multiple choice, with either single select or multi-select option.

thromboembolism with the subclavian as compared with alternate sites of CVC placement, appropriateness of subclavian CVC placement in coagulopathic patients, and institutional policy details regarding the placement of subclavian CVCs. The majority of participants correctly performed all a priori defined 20 steps of the procedure checklist in the standardized patient and in the task trainer, with an average score of 17.8 ± 2.9 (SD) out of 20 (Table 3). The average time to needle insertion in the subclavian vein, defined by the positive aspiration of blue stained saline, was 201 ± 181 seconds (range 25-827 seconds), and the average time to wire insertion was 231 ± 187 seconds (range 45-909 seconds). The average number of attempts defined as each time the needle was completely removed and reinserted, was 2.3 ± 1.6 (range 1-8). Complications included arterial puncture (n = 4), wire advanced through the vein (n = 1), and inability to successfully cannulate during the assessment period (n = 1). No pleural puncture was observed (Table 3).

Discussion

To our knowledge, we are the first to describe a comprehensive training program for ultrasound-guided subclavian CVC placement. Compared to traditional apprentice-model modes of education, simulation and competency-based approaches to procedural instruction for invasive bedside procedures have demonstrated improvements in testing scenarios, and procedural success in practice.[8,9] Therefore, for novel or rarely performed procedures, a simulation-based module with competency evaluation in CVC placement should be a standard component of training and continuing education.

For didactic training, we used a PowerPoint with embedded video that the participant viewed independently at their own pace, which allowed more time dedicated to hands-on learning during the simulation component of training.[2-4] For hands-on assessment, we chose a hybrid approach with both a standardized patient and task trainer for assessing different skills. The standardized patient provided high fidelity simulation of anatomy and practice in guiding the participant through expected steps of the procedure. The task trainer provided practice with needle guidance, wire advancement, and confirmation of wire placement with ultrasound. To our knowledge, no other training programs have reported this unique approach to aid learners in CVC placement.

To best evaluate competency among participants, checklists and global rating scales are most frequently used, and are well-validated measures of success for educational intervention in procedural skills. While global rating scales appear to have better validity than checklist assessments, they have worse inter-rater reliability and are less objective.[9] Since the goal of our training program was to familiarize participants with a wide range of clinical experience using a new technique, we believe our checklist provides the best assessment of competency for participants to proceed to supervised clinical practice. Our checklist was formatted similarly to another validated checklist used for measuring procedural success in ultrasound-guided internal jugular CVC placement.[10]

Limitations of our approach include lack of evaluation for posterior-wall puncture (as the task trainer could not be assessed physically after each participant's attempt) which is a common technical error of this procedure. Other measures of procedural competency include hand motion-tracking, eye gaze pattern-tracking, and robotic arm haptic feedback that correlate well with learner expertise, but still require study for threshold validation for learner success in practice.[11]

Another potential limitation includes participant dropout (36 of 106 participants who completed phase 1 did not go on to complete the in-person training, a potential source of attrition bias), and lack of follow-up for long-term knowledge and skill retention among participants. We also did not directly evaluate the success and proficiency of internal jugular CVC placement relative to subclavian, primarily because all participants were familiar with internal jugular placement.

Finally, the role of feedback in our protocol was neither assessed nor formalized. While we provided verbal feedback at the discretion of the preceptor, it is possible that "error exposure training" (errors incorporated into simulation with challenge and resultant feedback) may have improved knowledge/skill retention and adaptive transfer of skills as demonstrated in other studies of CVC education.[12]

Conclusion

Overall, our study participants demonstrated successful simulated line placement and improved comprehension of knowledge goals, which suggests that our simulation-based subclavian CVC placement training is an effective educational intervention that may be easily reproduced outside our department. In addition, our training intervention provides the basis for future

Table 2. Pre-training and post-training assessment. Values shown are N (%).

KNOWLEDGE ASSESSED	PRE-ASSESSMENT RESPONSES (N = 106)	POST-ASSESSMENT RESPONSES (N = 70)	*P* VALUE CHANGE[a]
Most preferred per policy			
Internal jugular[b]	94 (89)	63 (90)	.45
US-guided subclavian	4 (3.8)	3 (4.3)	
Femoral	0 (0)	0 (0)	
Landmark-guided subclavian	0 (0)	0 (0)	
No preferred site	7 (6.6)	3 (4.3)	
Not answered	1 (0.9)	1 (1.4)	
Least preferred per policy			
Internal jugular	0 (0)	0 (0)	.17
US-guided subclavian	3 (2.8)	1 (1.4)	
Femoral	26 (25)	9 (13)	
Landmark-guided subclavian[b]	65 (61)	52 (74)	
No preferred site	11 (10)	7 (10)	
Not answered	1 (0.9)	1 (1.4)	
Lowest CLABSI			
Internal jugular	18 (17)	3 (4.3)	<.01
Subclavian[b]	46 (43)	52 (74)	
Femoral	0 (0)	0 (0)	
IJ equivalent to subclavian	30 (28)	10 (14)	
All equivalent	10 (9.4)	4 (5.7)	
Not answered	2 (1.9)	1 (1.4)	
Lowest thromboembolic			
Internal jugular	19 (18)	5 (7.1)	<.01
Subclavian[b]	29 (27)	50 (71)	
Femoral	6 (5.7)	1 (1.4)	
IJ equivalent to subclavian	21 (20)	4 (5.7)	
All equivalent	30 (28)	8 (11)	
Not answered	1 (0.9)	2 (2.9)	
Not absolute contraindication			
Coagulopathy[b]	52 (49)	64 (91)	<.01
Fracture	44 (42)	5 (7.1)	
Thrombosis	5 (4.7)	0 (0)	
Infection	3 (2.8)	0 (0)	
Not answered	2 (1.9)	1 (1.4)	
Identify axillary vein on US			
A (artery)	11 (10)	0 (0)	>.99
B (vein)[b]	94 (89)	69 (99)	

(Continued)

Table 2. (Continued)

KNOWLEDGE ASSESSED	PRE-ASSESSMENT RESPONSES (N = 106)	POST-ASSESSMENT RESPONSES (N = 70)	*P* VALUE CHANGE[a]
C (pleura)	0 (0)	0 (0)	
Not answered	1 (0.9)	1 (1.4)	
N of procedures required to reduce complications by 50%			
100	19 (18)	4 (5.7)	<.01
50[b]	38 (36)	57 (81)	
20	32 (30)	6 (8.6)	
10	16 (15)	2 (2.6)	
Not answered	1 (0.9)	1 (1.4)	
True statements of axillary vein			
Landmark and US-guided have same insertion site	11 (10)	1 (1.4)	<.01
Landmark and US-guided have same needle trajectory	21 (20)	2 (2.9)	
Remove catheter and compress after arterial puncture	12 (11)	1 (1.4)	
No manometry necessary with US guidance	1 (0.9)	0 (0)	
Axillary becomes subclavian vein at the margin of first rib[b]	52 (49)	60 (86)	
Subclavian vein is posterior and inferior to artery	6 (5.7)	5 (7.1)	
Not answered	3 (2.8)	1 (1.4)	
Not a risk of procedure			
Pneumothorax	0 (0)	0 (0)	>.99
Brachial plexus injury	1 (0.9)	1 (1.4)	
Phrenic nerve injury	8 (7.5)	2 (2.9)	
Chylothorax	1 (0.1)	0 (0)	
Pericardial tamponade	5 (4.7)	7 (10)	
All of the above[b]	90 (85)	59 (84)	
Not answered	1 (0.9)	1 (1.4)	
Not used to confirm placement			
Ultrasound	1 (0.9)	0 (0)	.45
Manometry	1 (0.9)	0 (0)	
Pressure waveform analysis	0 (0)	0 (0)	
Blood gas	17 (16)	19 (27)	
Chest radiograph	3 (2.8)	1 (1.4)	
Color of blood	0 (0)	0 (0)	
Absence of pulsatile flow[b]	83 (78)	49 (70)	
Not answered	1 (0.9)	1 (1.4)	

Abbreviations: CLABSI, central line associated bloodstream infection; IJ, internal jugular; US, ultrasound.
[a]*P* values comparing discordant pairs for the correct responses in the pre- and post-test assessment questionnaires using McNemar test for pair binary data. Only participants completing both tests are included in this analysis (n = 70).
[b]This indicates the correct answer. Our institutional policy requires US-guidance for placement of internal jugular CVC.

Table 3. Providers' performance for hands on training, based on the catheter insertion checklist. Values shown are n (%), unless otherwise specified.

LINE PLACEMENT ASSESSMENT CHECKLIST	RESPONDENTS COMPLETING HANDS-ON TRAINING (N=70)
Standardized patient	
Positions patient with a towel under their shoulders	68 (97)
Positions patient in Trendelenburg position	67 (96)
Positions patient with ipsilateral arm along their side	69 (99)
Identified the area that should be prepped and draped	59 (84)
Stands in correct location relative to patient and ultrasound machine	69 (99)
Selects correct transducer	67 (96)
Positions probe with marker oriented cephalad	60 (86)
Correctly identified axillary vein to assess patency and rule out thrombi	66 (94)
Applies color flow Doppler to identify vein and artery	62 (89)
Identifies artery	60 (86)
Identifies clavicle	63 (90)
Identifies pleura	62 (89)
Identifies site of needle entry	59 (84)
Blue phantom	
Obtains 2-D short axis image of vein and artery concurrently	65 (93)
Applies color flow Doppler to identify vein and artery	33 (47)
Needle inserted at 45-degree angle (rather than shallow angle of landmark subclavian)	69 (99)
Attempts to keep needle tip in view as it is entering vein	65 (93)
Successful vein cannulation within 3 insertions	57 (81)
Wire advanced appropriate distance (12-17 cm)	68 (97)
Confirms wire position with ultrasound	63 (90)
Score, mean (SD)	17.8 (2.9)
Time to successful access (defined as return of venous blood), mean (SD)	201 (181)
Time to successful cannulation (defined as insertion of wire), mean (SD)	231 (187)
Number of attempts/passes, mean (SD)	2.3 (1.6)
Arterial puncture	4 (5.7)
Wire advanced through vein	1 (1.4)
Inability to successfully cannulate vessel during assessment period	1 (1.4)
Pleural puncture	0 (0)

Abbreviation: SD, standard deviation.

studies to directly compare the success and complication rates of ultrasound-guided internal jugular and subclavian CVCs. Future studies will evaluate clinical skills performing the procedure in clinical practice.

Our training program provides a comprehensive didactic and hands-on approach to training in placement of ultrasound-guided subclavian CVCs made more robust with the addition of standardized patients and checklist assessment of learner competency. Because this program was offered to providers with a wide range of experience, it is potentially generalizable to other institutions that wish to increase competence and comfort with this procedure.

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Contributors

JDD contributed to data acquisition, drafted and revised the manuscript, and approved the final version; MMT designed the study, analyzed the data, edited and revised the manuscript and approved the final version; EAD contributed to study design, data acquisition, revised the manuscript and approved the final version; PMS designed the study, edited and revised the manuscript and approved the final version.

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