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Development and Videographic Evaluation of a Vascular Access Simulation-Based Curriculum for Surgical and Medical Trainees

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Background: There is a paucity of data evaluating femoral arterial access training, despite significant morbidity/mortality associated with incorrect femoral arterial access. The aim of this study was to develop and evaluate a novel 2-component simulation-based curriculum to address a lack of standardized access training and identify the most frequent errors in access.

Methods: The femoral arterial access curriculum was developed through a multi-disciplinary collaboration and utilized in-person simulation sessions in conjunction with online and in-person didactic training. Access errors and curriculum efficacy were assessed using mixed-methodology evaluation of video recordings of trainee arterial access pre- and postcurriculum. All recordings were reviewed and scored by 2 blinded, independent investigators.

Results: Twenty-six participants completed the curriculum with pre- and postcurriculum recordings. Sixteen participants (62%) were in their first year of residency training. Fifteen participants (58%) belonged to general surgery residency, 9 (35%) to emergency medicine, 1 to vascular surgery, and 1 to interventional radiology residency programs. The global rating for the overall ability to obtain femoral arterial access under ultrasound guidance (0 = fail, 4 = excellent) improved following the curriculum (0.87 ± 0.15, 2.79 ± 1.26, $P < 0.0001$). Fourteen participants (54%) were unable to independently complete the procedure before training, compared to only 2 participants (8%) following the curriculum. Procedural completion time decreased from 7.14 ± 4.26 to 3.81 ± 2.53 minutes ($P < 0.001$). Most frequent errors, determined through qualitative analysis, included difficulty using the ultrasound and unsafe maneuvers.

Conclusions: Before the curriculum, there were significant frequent errors in junior resident femoral arterial access with major patient safety concerns. A novel simulation-based femoral arterial access curriculum resulted in improved procedural skills across all metrics.

Keywords: medical education, simulation-based training, surgical education, vascular access

INTRODUCTION

Arterial line access is the gold standard for accurate, real-time hemodynamic monitoring and allows for rapid repeated arterial blood gas measurements.[1] Arterial lines are frequently utilized in critically ill patients, emergency settings, and for monitoring during surgical cases, with over 8 million arterial lines placed in the United States annually.[2] While arterial access may be placed in radial, brachial, axillary, and dorsalis pedis arteries, femoral arterial access is commonly obtained in emergency scenarios or when radial access options have been exhausted by prior lines or thrombosis.[2–4]

Errors during any step of femoral arterial access may result in complications including groin hematomas, pseudoaneurysm formation, retroperitoneal hemorrhage, arteriovenous fistula, arterial dissection, vessel thrombosis, infection, and femoral nerve injury.[5,6] Such complications may require urgent surgery or result in significant patient morbidity and mortality. Complication rates are higher in the critically ill population secondary to factors such as hypotension, peripheral edema, obesity, prior access attempts, and coagulopathy.[4,5] While the overall failure rate of arterial catheterization is less than 10%, this rate approaches 50% for patients who are in shock.[6] Repeat arterial access attempts cost valuable time, cause patient discomfort, and are associated with an increased risk of complications.[7]

Poor operator technique exponentially increases the risk of vascular complications,[8] making vascular access training a crucial component in minimizing procedural complications. While traditional surgical training has followed a see one, do one, teach one model, online or virtual procedural training has been increasing in popularity. A study by Pitcher et al[9] however, found that out of over 2000 YouTube videos for "femoral artery access", less than 10% of videos demonstrated clear femoral artery access technique. Hands-on simulation training mannequins are currently in use for training on venous catheterization, Foley urinary catheter insertion, and chest tube insertion. Although these models are also available for femoral arterial

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access training, an integrated curriculum combining in-person simulation training and online didactic training has been lacking. This project aimed to develop a standardized femoral arterial access simulation curriculum and to rigorously evaluate this simulation curriculum within a junior multi-disciplinary trainee cohort. The secondary aim of this study was to identify the most frequent errors in junior trainee femoral vascular access.

METHODS

Curriculum Design

Two separate components of a simulation-based training curriculum were developed: an online didactic course and an in-person simulation curriculum. The online course was developed to be used asynchronously by trainees before training on the simulation model. The course included an overview of anatomical landmarks, indications and contraindications, proper use and identification of artery and vein under ultrasound, procedural steps, and potential complications in a PowerPoint presentation (Supplemental Figure 1, http://links.lww.com/AOSO/A377). The curriculum was developed through a multi-disciplinary collaboration between vascular surgery, interventional cardiology, emergency medicine, and trauma surgery. In-person simulation training sessions were conducted using the SimuLab FemoraLineMan System, a trainer for arterial and venous femoral line access compatible with ultrasound-guided access (Supplemental Figure 2, http://links.lww.com/AOSO/A378). Bony landmarks and vessel characteristics including pulsatility differentiate artery and vein by ultrasound. A micropuncture introducer set by Cook and the following materials were provided for access: prep sponge, drape with fenestration, 1% lidocaine solution, a 22 Ga injection needle, a 5 mL Leur-Slip syringe, micropuncture needle, micropuncture catheter, micropuncture wire, T tubing piece, 3-0 braided silk with straight needle, gauze 4 × 4, tegaderm, and needle driver. All training sessions were conducted from March 2022 to August 2022. This study was conducted with approval from the participating institution's review board.

Cohort

The target cohort for this study included trainees from departments in which vascular access is frequently required in critically ill patients. Trainees at a tertiary care center were recruited from the following specialties: vascular surgery, general surgery, and emergency medicine. General surgery at our institution includes interventional radiology residents for their first year. Invitations to participate in the curriculum were sent by email to all junior residents in these programs. All residents were offered femoral simulation training, with consent obtained for those opting to participate in online and videographic assessments. Participants in the study received a $5 gift card following completion of the study.

Curriculum Assessment

The efficacy of the simulation-based training curriculum was evaluated in 2 formats. First, a 17-item web-based survey designed to specifically assess trainee knowledge and comfort level with femoral arterial access was distributed to participants pre- and postdistribution of online didactic materials and in-person simulation session. The survey was adapted from previously published surveys used to assess catheterization lab simulation[3,10,11] (Supplemental Table 1, http://links.lww.com/AOSO/A378). Surveys were pretested among residents from participating residency programs for readability, clarity, and interface usability.

Vascular access proficiency was further assessed via videographic analysis of the trainee facility obtaining femoral arterial access on the simulation models. Each participant was recorded and timed obtaining femoral arterial access on simulation mannequins both pre- and postcurriculum participation. All videos were reviewed by 2 blinded independent examiners (A.P. and S.L.) who scored participants on critical procedural steps. The examiner checklist in Supplemental Table 2, http://links.lww.com/AOSO/A378 for observed pre- and postcurriculum assessment was developed from a previously published procedural checklist tool for simulation-based learning.[12] Participants were rated on a scale of 0 to 4: 0 being fail, 1 to 3 being intermediate based on varying degrees of skill and performance, and 4 being success/excellent. Additionally, examiners recorded a rating of the participants' overall global performance. They also recorded responses for a 5-item list pertaining to essential procedural steps and a 9-item list pertaining to major themes within access performance. The 5-item list included the ability to identify external landmarks, to identify the vessels at an appropriate level, cannulate the vessel under ultrasound, advance the wire, and demonstrate proper Selinger technique. The 9-item list consisted of reviewer scores regarding trainee time and motion obtaining access, facility using ultrasound, wire and catheter handling, maintenance of wire stability, flow of operation, procedural knowledge, ability to complete the procedure, knowledge of materials, and procedural safety. Scores were reviewed to ensure consistency with reviewers. Score differences of greater than 1 point were reviewed and consensus between reviewers was obtained. Additionally, a qualitative assessment of the trainee facility and errors in obtaining access were recorded by both reviewers in a free-response section.

Statistical Analysis

De-identified responses were analyzed for all pre- and postcurriculum online surveys and videographic analysis scores were averaged between reviewers. Student t test and χ^2 test were used to assess changes in mean confidence and procedural knowledge scores, as well as changes in the proportion of residents demonstrating pre- and postcurriculum vascular access proficiency. All statistical analyses were performed using Stata/SE statistical software, version 15 (StataCorp LLC, College Station, TX). Significance was defined at an alpha level of 0.05. Qualitative data regarding reviewer videographic assessment of participant facility and errors obtaining access were analyzed using NVivo12 software (QRS International 2020; Burlington, MA). Thematic data analysis was conducted by A.P. All reviewer descriptive responses were read in their entirety to familiarize the researcher with the entire data set. Some codes were defined *a priori* such as "Difficulty using ultrasound to access the vessel", while other codes emerged inductively such as "Unsafe maneuvers". Over the process of data analysis, A.P. and A.D. ensured adherence to principles of rigorous thematic analysis and the integrity of developed themes.

RESULTS

Trial Design and Demographic Characteristics

In total, 26 participants completed the curriculum with pre- and postcurriculum video recordings. The majority (62%) of participants were in their first year of residency training, while 38% were in their second year of residency training (Table 1). Fifty-eight percent of participants were trainees in general surgery, 35% in emergency medicine, 4% in vascular surgery, and 4% in interventional radiology residency programs (Table 1).

All 26 participants completed the precurriculum survey and 22 participants completed the postcurriculum survey. In terms of prior experience, 10 participants (37%) had no prior virtual

TABLE 1.

Demographic characteristics of participants (n = 26) who participated in the curriculum

Participant Characteristics	Pre-Curriculum Assessment Mean ± SD or N (%) N = 26	Post-Curriculum Assessment Mean ± SD or N (%) N = 22	*P*
Age (years)	29.19 ± 2.53	29.64 ± 2.74	0.5520
Gender			1.000
Women	14 (52)	11 (50)	
Men	12 (44)	10 (45)	
Nonbinary	1 (4)	1 (5)	
Postgraduate year of training	1.41 ± 0.50	1.45 ± 0.51	0.961
Prior virtual or didactic training		—	—
No prior training	10 (37)		
<30 minutes	11 (41)		
30 minutes–1 hour	3 (11)		
>1 hour	3 (11)		
Prior in-person simulation training		—	—
No prior training	9 (33)		
<30 minutes	10 (37)		
30 minutes–1 hour	5 (19)		
>1 hour	3 (11)		
Prior number of radial arterial lines placed	6.30 ± 10.70	5.41 ± 1.92	0.758
Prior number of femoral arterial lines placed	1.15 ± 2.41	1.09 ± 2.54	0.930

Not all participants completed the postcurriculum assessment. Data expressed as mean ± SD or N (%). Pre- and postcurriculum ratings were compared using Student's *t* test or χ^2.

or didactic training and 9 (33%) had no in-person simulation training (Supplemental Table 3, http://links.lww.com/AOSO/A378). Only 3 participants had greater than 3 hours of virtual or in-person training before this study (Table 1). On average, participants had placed 1.15 ± 2.41 femoral lines (range 0–10) before the curriculum. Postcurriculum assessment demonstrated increased participant knowledge regarding the location of relevant anatomy, optimal access location, arterial access indications, and ultrasound usage ($P < 0.05$) as detailed in Supplemental Table 3, http://links.lww.com/AOSO/A378. The average comfort level obtaining femoral arterial access improved from a score of 1.37 ± 0.63 to 1.86 ± 0.71 ($P = 0.0132$) postcurriculum. Whereas 70% of participants indicated their overall comfort level as "poor" before the training, only 7 (32%) rated their level as "poor" following the training.

Regarding the overall ability to cannulate the artery using ultrasound guidance, 54% of participants were unable to independently complete the procedure before the curriculum. This was reduced to 8% of participants unable to independently complete the procedure and failed to gain competence following the curriculum. The global examiner rating for the overall ability to obtain femoral arterial access under ultrasound guidance improved following the curriculum from a mean score of 0.87 ± 0.15 to 2.79 ± 1.26 ($P < 0.0001$) (Supplemental Table 4, http://links.lww.com/AOSO/A378). Facility using ultrasound (1.77 ± 1.11 *vs* 3.17 ± 0.96, $P < 0.0001$), ability to advance the wire (1.29 ± 1.00 *vs* 3.08 ± 1.10, $P < 0.0001$), Seldinger technique (1.11 ± 1.20 *vs* 2.67 ± 1.13, $P < 0.0001$), wire and catheter handling (1.02 ± 1.08 *vs* 2.81 ± 1.09, $P < 0.0001$), maintenance of wire stability (1.34 ± 1.05 *vs* 2.83 ± 1.02, $P < 0.0001$), and flow of operation (1.46 ± 0.96 *vs* 3.38 ± 0.91, $P < 0.0001$) all significantly improved following the curriculum (Supplemental Table 4, http://links.lww.com/AOSO/A378). Procedural completion time decreased significantly from 7.14 ± 4.26 to 3.81 ± 2.53 minutes ($P = 0.0045$).

Qualitative analysis revealed 5 major themes along with subcategories of minor themes. The first major theme was "Difficulty using ultrasound", in which residents were unable to identify or visualize the artery and vein under ultrasound, mistook the vein for the artery, or did not appropriately adjust gain or depth resulting in the inability to identify the vessels properly (Table 2). The second major theme was "Challenges using the introducer needle", which included letting go of the needle, losing needle access, advancing the needle at an inappropriate angle, back-walling or side-walling the vessel, or multiple punctures of the skin and vessel. "Poor wire technique" included advancing the wrong end of the wire into the vessel, losing wire access, or failure to advance the wire far enough into the vessel, consequently losing access. "Inappropriate catheter handling" included poor Seldinger technique, advancement of the catheter over a significantly kinked wire, or failure to remove the dilator. The last major theme "Unsafe maneuvers" included actions that could cause harm to the patient. This theme included the usage of a cheater that was included in the Micropuncture kit to dilate the vessel, breaking of the wire within the needle, losing the wire

TABLE 2.

Common errors identified in obtaining femoral arterial access

	Major Themes	Sub-Themes
1	Difficulty using ultrasound to access the vessel	1) Inability to identify artery using ultrasound 2) Mistaking vein for artery 3) No visualization of artery and vein 4) No adjustment of ultrasound gain or depth
2	Challenges using the introducer needle	1) Letting go of the needle 2) Losing needle arterial access 3) Advancing the needle at an inappropriate angle 4) Back-walling or side-walling the vessel 5) Multiple punctures of the skin or vessel
3	Poor wire technique	1) Advancing wrong end of the wire into the vessel 2) Losing wire access 3) Wire not advanced far enough into needle/vessel
4	Inappropriate catheter handling	1) Poor Seldinger technique 2) Advancement of catheter over significantly kinked wire 3) Failure to remove dilator
5	Unsafe maneuvers	1) Usage of cheater to dilate the vessel 2) Breaking of wire within the needle and/or vessel 3) Losing wire within the patient 4) Attempting to advance catheter into subcutaneous tissue

Themes of videographic assessment descriptive responses were analyzed using NVivo12 software (QRS International 2020; Burlington, MA).

within the mannequin, and/or attempting to advance the catheter into the subcutaneous tissue after intraluminal wire access had already been lost. The purpose of the cheater is to assist with wire insertion into the catheter. Twelve residents attempted to use a cheater to dilate the vessel, creating a hole much larger than the 4F micropuncture catheter within the vessel wall.

DISCUSSION

The goal of this study was to develop a comprehensive competency-based, graded curriculum for the integration of vascular access theory and simulation. We utilized currently available vascular access simulators paired with an associated educational curriculum. Curriculum efficacy was evaluated through multimodal videographic, qualitative, and survey-based assessments. Quantitative and qualitative evaluation of the comprehensive training demonstrated significant improvement in junior resident procedural understanding and performance.

A significant procedural knowledge deficit for femoral arterial access was evident in the precurriculum evaluation, in which over half of the participants were unable to independently complete the procedure. This coincides with the fact that 2-thirds of the participants had less than 30 minutes of prior training in placing femoral lines and had only placed an average of 1.15 femoral lines before our curriculum. The global rating for the overall ability to obtain femoral arterial access under ultrasound guidance was less than 1, indicating a failing procedural completion score. In addition, overall procedural safety was a major issue precurriculum with an average rating of 1.1, again demonstrating a failing score. Qualitative analysis identified unsafe maneuvers as a major theme. One resident lost the wire within the patient, one resident broke the wire within the needle/vessel, and numerous residents attempted to advance a catheter into subcutaneous tissue after unknowingly losing arterial access. All these maneuvers would likely have resulted in adverse patient outcomes in a real patient setting including possible need for operative retrieval of the wire and/or repair of the vessel.[8] Nearly half of the participants attempted to use a cheater to dilate the vessel, which would have resulted in pulsatile bleeding in a real patient, requiring significant pressure and potentially operative repair. All these findings indicate significant trainee procedural ability and knowledge deficit, with potential deleterious patient impact.

Many of the issues identified in the precurriculum evaluation were easily corrected with proper training. Following the curriculum, the global rating for the overall ability to obtain femoral arterial access improved significantly from a mean score of 0.87 ± 0.15 to 2.7 ± 1.26 ($P < 0.0001$). Similarly, there was a significant improvement in the overall safety score from 1.1 ± 1.00 (poor) precurriculum to 2.96 ± 1.15 (good/very good) postcurriculum ($P < 0.0001$), demonstrating a significant reduction in unsafe motions performed during the procedure. Facility using ultrasound, ability to advance the wire, Seldinger technique, wire and catheter handling, maintenance of wire stability, and flow of operation all improved following the curriculum. Moreover, the procedural completion time was nearly halved. This improvement in procedural ability and speed can be critical in patients presenting in extremis in the intensive care unit and emergency department contexts.

There is immense data to support the incorporation of simulation education into a variety of surgical procedures given the ability to practice without incurring patient harm, which is a risk of the traditional see one, do one, teach one approach.[13,14] Training in low-acuity situations with guided instruction certainly allows for a better learning environment.[12] In fact, a review on the future of cardiovascular education and training by Brown et al[15] describes a call for simulation-based training to include catheterization skills such as vascular access and catheter manipulation. However, creating a simulation that is similar to a real-life scenario can be challenging given the limitations of models and equipment available.[16,17] In addition, the presence of instructors and continuous teaching makes it difficult to discern the impact of simulation-based training in performing correct and accurate procedures.[18] Our curriculum has not only identified an appropriate model with a pulsatile artery to reflect a real-life situation, but we have also created an examiner checklist to accurately discern the impact of our curriculum on students being filmed and timed in a simulated scenario. Our curriculum, in conjunction with videographic evaluation of performance utilizing our novel examiner checklist, can be applied to help train a wide variety of specialties in obtaining vascular access and accurately identifying improvement in performance. Future studies could focus on the consistency of skills demonstration, where 3 rounds of successful skills completion are required to demonstrate competence as required in the fundamentals of laparoscopic surgery skills examination.[19]

LIMITATIONS

There are several limitations to this study. First, the curriculum was performed with mannequins rather than live patients. Although the mannequins are an excellent training platform, they incompletely simulate live patients with regard to patient tissue elasticity. Additionally, although participation invitations were sent to all junior trainees in general surgery and emergency medicine programs (n = 153), only 26 fully completed the training curriculum given conflicting clinical duties. This may have introduced selection bias in our sample, in which residents who were less comfortable obtaining access self-selected to participate in the curriculum. Nonetheless, significant safety and procedural concerns were identified among these 26 residents operating in departments in which facility obtaining femoral arterial access is an essential skill. Another limitation of this study is that postcurriculum assessments were performed in the days immediately following training, and therefore, retention of knowledge over a prolonged period was not assessed. This study was limited to trainee femoral arterial access in a simulation scenario and did not subsequently observe trainee ability to obtain femoral arterial access in real-time with live patients given institutional review board limitations. While we do believe the improvements in access-related skills were attributable to our curriculum, it is possible that increased familiarity with the simulator also impacted participant improvement. It is also possible residents had variable levels of familiarity with the Micropuncture set provided for access and this was not captured in this study.

CONCLUSIONS

This study demonstrated significant, frequent errors in junior resident femoral arterial access with major patient safety concerns. A simulation-based curriculum resulted in improved safety scores and procedural skills across all metrics measured as well as significant improvement in trainee comfort level with obtaining femoral arterial access. This study clearly demonstrated the need for further junior resident training regarding femoral arterial access and the ability of an integrated simulation curriculum to improve trainee femoral arterial access facility. Further work should be aimed at standardizing this curriculum across junior resident training programs to ensure expedient and safe femoral arterial access.

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