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Preparing interns for clinical practice through an institution-wide simulation-based mastery learning program for teaching central venous catheter placement

Jennifer Yee, DO[a,*], Scott Holliday, MD[b], Carleen R. Spitzer, MD[c], Michael Essandoh, MD[d], David P. Way, MEd[e], Ashish R. Panchal, MD, PhD[f]

Abstract

Central venous catheter (CVC) placement is a challenging procedure with known iatrogenic risks. However, there are no residency program requirements to demonstrate baseline CVC procedural competency. Competency-based procedural education has been shown to decrease CVC-associated morbidity, but there has been limited literature about institution-wide efforts to ensure initial trainee competency for CVC placement. This study describes the implementation of a competency-based CVC curriculum for first-year interns across an institution before supervised clinical care. An institution-wide, simulation-based mastery training curriculum was designed to assess initial competency in CVC placement in first-year residents during 2021 and 2022. A checklist was internally developed with a multidisciplinary team. Using the Mastery–Angoff technique, minimum passing standards were derived to define competency levels considered appropriate for intern participation in supervised clinical care. Interns were trained through the competency-based program with faculty assessing intern performance using the CVC checklist to verify procedural competency. Over 2 academic cycles, 229 interns from 20 specialties/subspecialties participated. Overall, 83% of interns met performance standards on their first posttest attempt, 14% on the second attempt, and 3% on the third attempt. Interns from both cycles demonstrated significant improvement from baseline to posttest scores ($P < .001$). Overall, 10.5% of interns performed dangerous actions during assessment (malpositioning, retained guidewire, or carotid dilation). All interns ultimately achieved the passing standard to demonstrate initial competency in the simulation assessment. All participating interns demonstrated simulation-based competency allowing them to place CVCs under supervised clinical care. Dangerous actions, however, were not uncommon. Simulation-based teaching and learning frameworks were a feasible method to promote patient safety through an institutional-wide verification of preliminary procedural competency.

Abbreviations: ACGME = Accreditation Council for Graduate Medical Education, CVC = central venous catheter, EM = emergency medicine, IM = internal medicine, MPS = minimum passing score, SBML = simulation-based mastery learning.

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1. Introduction

Graduate medical education requires a delicate balance between providing residents with procedural experience while promoting patient safety. To reduce the 13% to 24% rate of adverse events attributable to procedural complications across the United States,[1–3] medical educators must ensure that residents, particularly those in procedural specialties, are well prepared to perform procedures before engaging in patient care.

Central venous catheter (CVC) placement is a procedure with known iatrogenic complications.[4–9] Patients across hospital settings may require CVC placement due to changes in clinical status, potentially when the most experienced proceduralists are unavailable. At these times, residents are

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[a] Department of Emergency Medicine, The Ohio State University Wexner Medical Center, Columbus, OH, [b] Department of Pediatric Medicine, The Ohio State University Wexner Medical Center, Columbus, OH, [c] Department of Internal Medicine, The Ohio State University Wexner Medical Center, Columbus, OH, [d] Department of Anesthesiology, The Ohio State University Wexner Medical Center, Columbus, OH, [e] Department of Emergency Medicine, The Ohio State University Wexner Medical Center, Columbus, OH, [f] Department of Emergency Medicine, The Ohio State University Wexner Medical Center, Columbus, OH.

** Correspondence: Jennifer Yee, Department of Emergency Medicine, The Ohio State University College of Medicine, 760 Prior Hall, 376 W 10th Avenue, Columbus, OH 43210, USA (e-mail: jennifer.yee@osumc.edu).*

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typically tasked with emergent CVC placement, which may include those who do not routinely place CVCs as part of their training. Procedural competencies may vary based on a resident's rotation schedule and training level. Therefore, medical educators have an obligation to patients to verify that all residents have demonstrated procedural competency before engaging in performing procedural activities with live patients.

Simulation-based mastery learning (SBML) is a training paradigm used to verify procedural competence.[10] In SBML, learners first undergo a baseline skills assessment. Then they perform deliberate practice with real-time feedback from an expert until they are prepared to demonstrate competence. When ready, the learner is offered the opportunity to perform the procedure in simulation and be assessed against a predetermined performance standard. This cycle is repeated until the passing standard is achieved, with an overall goal of all learners achieving competency with minimal performance variation.[10]

When applied to interns (first-year residents) who may perform CVC placement as part of their training, a sponsoring institution-wide SBML curriculum ensures that all residents are held to the same standard regardless of their associated residency program. Previous studies have yet to demonstrate the feasibility or results of an institution-wide SBML CVC program implemented during the intern onboarding process and before their first contact with patients. The primary purpose of this study was to describe the impact of an institution-wide, SBML program for verifying the CVC placement competence of interns before participation in clinical care. A secondary purpose was to define the "competent novice" resident as one who is well prepared to perform the CVC placement procedure under direct supervision without incurring dangerous behaviors that may increase morbidity. The authors also outlined logistical challenges with program implementation and future potential solutions.

2. Methods

2.1. Setting and participants

The authors performed a prospective observational cohort study to investigate the implementation of an institution-wide simulation-based mastery training program and used STrengthening the Reporting of OBservational studies in Epidemiology Reporting Guidelines to assemble this paper. The program was delivered during intern orientation in 2021 and 2022 at The Ohio State University Wexner Medical Center; a large, university-based quaternary care teaching hospital. Eligible participants were interns who were likely to perform CVC placement at some point during their intern year. These interns were all scheduled for night float or critical care months during which they may be confronted with the need to place CVCs without an experienced senior resident or fellow available. The authors felt strongly that the inclusion of these residents in this SBML program would provide interns with baseline competency and working knowledge for CVC placement. Interns without competence in placing CVCs theoretically place patients at higher risk of suffering iatrogenic injuries. This study was approved by the Institutional Review Board of The Ohio State University: Study ID: #2021E0278.

2.2. Intervention

Using Griswold–Theodorson synthesis of the Dreyfus–Benner SBML model of skill acquisition, the program sought to progress all learners from the "advanced beginner" stage (where they viewed procedures as a series of steps) to the "competent novice" stage (where they established a working knowledge base and could address most procedural tasks with their judgment).[11] The program consisted of 3 stages: standard setting to build an assessment checklist and determine a minimum passing score (MPS), mastery-based training including pretest assessments and deliberate practice, and posttesting until participants achieve the predetermined MPS. Once participants attained the MPS, they were deemed safe to perform the procedure under direct supervision in the clinical setting, where continued clinical encounters afforded opportunities to progress into "proficient" levels of procedural performance.[11]

Before the intervention, faculty stakeholders from anesthesiology, emergency medicine (EM), internal medicine (IM), interventional radiology, and surgery developed a de novo CVC checklist (see Checklist Instrument, Supplemental Digital Content 1, http://links.lww.com/MD/M727) based on our own institutional safety protocols with consideration of published guidelines for best practice.[12,13] Faculty established the MPS using the Mastery–Angoff method.[14] Each checklist item was scored dichotomously (correct or incorrect) and all items were given equal weight for scoring.

Faculty from anesthesiology, EM, IM, and surgery also served as facilitators for the one-on-one assessment of incoming interns during their orientation. Facilitators were asked to prepare for the assessment in 3 ways: to familiarize themselves with the items on the performance checklist, review a video that specifically outlined performance expectations for interns, and to practice performing CVC placement using the checklist. Specific instructions were given to prohibit facilitators from prompting learners during pretesting or posttesting assessments unless explicitly outlined on the checklist. In 2022, facilitators were compensated approximately $120 per hour with funding provided by the Ohio State University Wexner Medical Center Risk Management Committee to incentivize participation.

The SBML CVC program consisted of a pretest/deliberate practice session and additional posttest sessions (spaced approximately a week apart). Before their initial pretest, the authors asked interns to view an internally developed video demonstrating proper CVC placement technique. The video content corresponded to the items on the CVC checklist and was designed to reinforce institution-specific safety protocols, such as verbalizing when the guidewire is inserted and removed. Other safety measures demonstrated in the video included prescanning the target area with ultrasound and confirming the venous placement of the guidewire with 2 different ultrasound views before dilation and catheter placement. This video was also edited to emphasize iatrogenic injury prevention strategies. Ideally, learners who viewed the video had an advance notice of how they would be taught and assessed regarding CVC placement.

On the pretest day, a facilitator briefly introduced the program and session. Interns were then dispersed to 6 separate stations for their one-on-one pretest. Each station was equipped with an ultrasoundable internal jugular vein CVC task trainer, a CVC kit, and an ultrasound machine. Personal protective equipment, sterile ultrasound probe covers, and extra CVC kit supplies were also available. Interns were allotted 30 minutes to complete CVC placement as facilitators graded their pretest performance in real time. After the allotted time, all interns reconvened to observe a faculty member demonstrate proper CVC placement and answer questions. Participants returned to their assigned stations for one-on-one deliberate practice with their pretest facilitator for the remainder of the 2-hour session. All interns were encouraged to spend time practicing CVC placement even if they had achieved the MPS during their pretest assessment.

Participants who did not attain the MPS during their pretest attempt returned approximately 1 week later for their posttest. If the intern did not achieve the MPS on their posttest attempt, they were shown which items they missed and were allowed to practice their skills with facilitator feedback before posttesting a second time. Interns who did not achieve the MPS on the second posttest attempt were scheduled to return to the simulation center for additional deliberate practice and a repeat posttest at a future date. Once an intern demonstrated competency by scoring at or above the MPS, they were designated as safe to perform CVC placement under direct supervision in the clinical setting.

In addition to observing the CVC performance of interns with the checklist items during assessments, facilitators were also asked to identify any "dangerous actions" performed by interns, including guidewire retention, dilation of a carotid artery, or a CVC placed in a cephalad direction. When these actions occurred during pretesting or posttesting, the facilitator immediately stopped the assessment and debriefed the intern to highlight the action's gravity. If the dangerous action occurred during posttesting, interns were required to perform deliberate practice for the remainder of their scheduled hour but were not permitted to repeat a same-day posttest. Instead, they were provided time to reflect and review additional resources and were scheduled for a follow-up posttest day.

2.3. Outcomes measured

The primary outcome was the difference between pretest and posttest checklist scores. The authors collected data on the number of residents who achieved the MPS on the pretest versus posttests and the length of time it took residents to accomplish the MPS. Last, data were collected on the number of predetermined "dangerous actions" that were observed by facilitators.

2.4. Statistical analysis

Cumulative percentages with frequencies were used to describe competency achievement per assessment attempt. The percent correct for baseline (pretest) and final scores were demonstrated with box and whisker plots, which described the median, interquartile ranges, and upper and lower extremes. Outliers were designated via single points below or above the plot. Differences between baseline and final scores were evaluated using the Wilcoxon matched-pairs signed-rank tests (for ordinal data). All analyses were completed using STATA SE, version 17 (StataCorp LP, College Station, TX).

3. Results

In 2021 and 2022, 96 and 133 residents, respectively, participated in a SBML CVC placement procedural program. Twenty different specialties/subspecialties were represented by participants. The number of residents and their affiliated training programs are shown in Table 1.

The majority of interns (189/229, or 82.53%) across both years were able to attain the MPS, indicating competency, within 1 posttest attempt (Table 2). Forty residents (17.47%) required a second posttest, and 7 of these 40 (3.06%) required a third posttest (Table 2). Overall, 97% of all residents demonstrated competency within 2 attempts. The maximum amount of instructional and assessment time required by an intern was approximately 9 hours. There was a significant improvement from pretesting to posttesting for both cohorts ($P < .001$) (Fig. 1) and across specialties (Fig. 2).

Facilitators observed and documented dangerous actions performed by interns. In 2021, 14 dangerous actions by 12 residents (12.5%) were observed. These included: 10 retained guidewires, 1 CVC advanced in a retrograde fashion toward the head, 1 carotid artery dilation, 1 needle left in the neck unattended, and 1 dilator retained in the neck. Similarly, in 2022, 12 dangerous actions were noted for 12 interns (9.0%), including 5 retained guidewires, 3 CVCs advanced toward the head, 2 carotid artery dilations, 1 needle left in the neck unattended, and 1 concern for iatrogenic air embolism. Dangerous actions were evenly distributed between the pretest and the first posttest. Only 1 occurred on a second posttest.

This institution-wide SBML program required a considerable investment of faculty time. In 2021, 59 faculty delivered approximately 6 full days of pretesting and deliberate practice and 3 full days of posttesting for a total of 300 hours of instructional and assessment time or an average of 5.5 hours per faculty member. In 2022, 63 faculty devoted approximately 6.5 full days for pretesting and deliberate practice, and 3.5 full days for posttesting for a total of 375 hours of instructional and assessment time, or an average of 5.9 hours per faculty member.

4. Discussion

The institution-wide SBML program was able to train 229 interns up to established performance standards for CVC placement within a 3-week orientation period prior to intern performance of this procedure on live patients. Once residents demonstrated competency in the simulation laboratory, they were permitted to perform the procedure under supervision in the clinical setting. While most residents demonstrated competency by their first posttest attempt, a small subset required repeat attempts. These findings are the first step in demonstrating the value of applying SBML methods to prepare residents to perform procedures before supervised clinical practice. The next step is to verify whether this intervention contributes to improved patient outcomes.

Performance errors considered dangerous were observed in 10.5% of interns during our program. While retained guidewires and carotid dilations were errors that might be expected of novices during their first attempt, the number of performance errors during posttests was higher than expected. Generally, we expect to observe more dangerous actions in simulation as compared

Table 1

Competency-based simulation program for teaching and assessing interns on central venous catheter placement participants by residency program.

	Number of learners in 2021	Number of learners in 2022
Anesthesiology		
Clinical anesthesia-1st year	17	16
Reserved positions (R-spot)	0	2
Emergency medicine		
Emergency medicine	17	18
Emergency medicine/internal medicine	2	2
Family medicine		
Family medicine	0	9
Internal medicine		
Internal medicine categorical	17	26
Internal medicine/pediatrics	7	10
Neurology (preliminary IM)	3	8
Ophthalmology (preliminary IM)	3	6
Primary care track	2	4
Physical medicine and rehabilitation (preliminary IM)	1	3
Physician Scientist Training Program	3	3
Surgery		
Surgery categorical	10	12
Plastic surgery	3	4
Vascular surgery	0	1
Urology	1	3
Neurosurgery	0	3
Cardiothoracic surgery	0	1
Total	96	133

IM = internal medicine.

to the clinical setting, which typically ranges from 1.9% to 2.2%.[15,16] This is because in simulation learners are permitted to fail as part of learning, in contrast to the clinical setting where a supervising physician would intervene to prevent iatrogenic injury. By identifying and remediating dangerous actions in the psychologically safe environment of simulation, residents build competence without the risk of actual patient harm. The number of dangerous actions observed during our program highlights the importance of establishing procedural competence in simulation, before participation in actual patient care.

CVC placement is an expectation of graduate medical training across multiple specialties, such as IM, anesthesiology, general surgery, and EM. The Review Committee for EM through the Accreditation Council for Graduate Medical Education (ACGME)[17] considers CVC placement a requisite procedural skill for residency training. However, neither the ACGME, the American Board of Internal Medicine,[18] nor the American Board of Emergency Medicine® have outlined how to obtain or document resident procedural competency. In fact, unlike some specialty boards, the American Board of Internal Medicine has not established a minimum number of procedures needed to be designated as competent. Out of the 4 residency programs mentioned above, only EM has delineated the minimum number of procedures required for residency graduation through their Residency Review Committee.[17] Still, requisite procedural numbers assessed through procedure logs are not based on empirical evidence nor through direct assessments of procedural competency. Currently, no ACGME residency program requires documented procedural competency for successful residency completion.

Previous procedural experience, years of clinical practice, in-training exam scores, or subsequent board certification scores alone do not translate into evidence of procedural proficiency.[19–21] The SBML program presented in this paper trained incoming first-year residents to a "ready to practice" standard. However, supervising physicians may have variable knowledge and procedural skillsets, including ultrasound proficiency. As residents progress from "competent novice" to "proficient" and "expert" through practice in performing procedures in the clinical setting, limitations of supervising physicians must be considered alongside patient-specific factors such as unexpected aberrant anatomy.

Studies have shown reduced needle passes, arterial punctures, catheter adjustments, and central line-associated

Table 2

Cumulative frequencies and percentages of intern participants who attained competence by assessment attempts baseline pretest through posttest 3.

	Pretest	Posttest #1	Posttest #2	Posttest #3
2021	15/96 (16%)	82/96 (85%)	92/96 (96%)	96/96 (100%)
2022	9/133 (7%)	107/133 (80%)	130/133 (98%)	133/133 (100%)
Combined	24/229 (10%)	189/229 (83%)	222/229 (97%)	229/229 (100%)

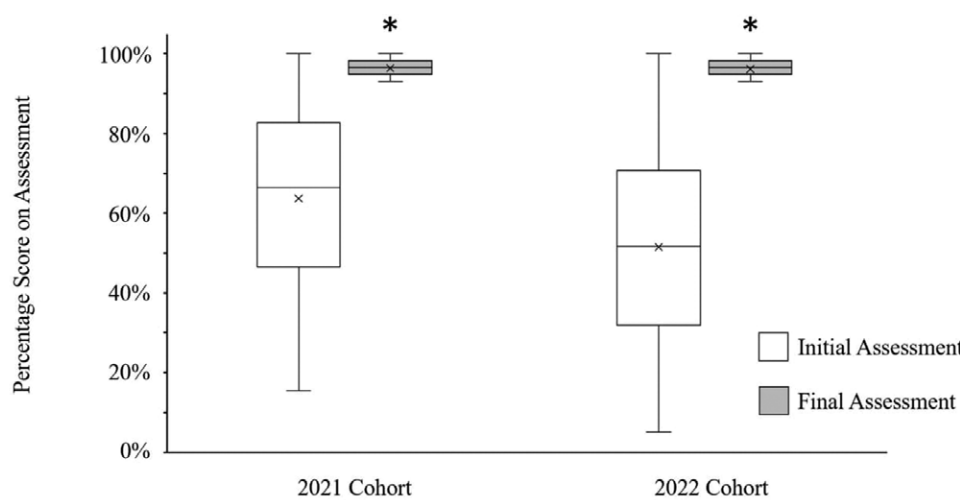

Figure 1. Boxplots of pretest (baseline) and final posttest performance assessment scores for interns in the institution-wide competency-based program for teaching central venous catheter placement. *$P < .001$.

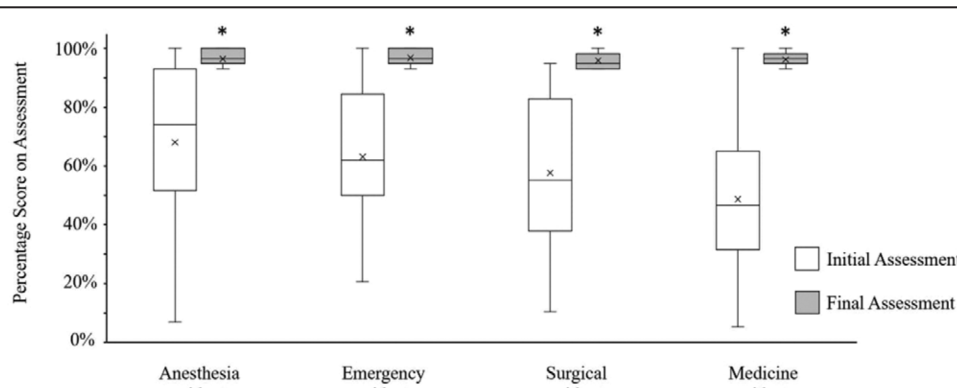

Figure 2. Boxplots of pretest (baseline) and final posttest performance assessment scores for interns in the institution-wide competency-based program for teaching central venous catheter placement by residency program. *$P < .001$.

bloodstream infections with SBML training in EM and IM residents.[22,23] Multiple studies have also described previous CVC training curricula,[24–27] orientation-based CVC curricula,[28–30] CVC curricula with SBML principles,[31,32] and an SBML orientation which included paracentesis and lumbar puncture for IM residents and medical students.[33,34] These previous efforts have focused on just-in-time education[22,23,31] or assessment of residents who traditionally performed more procedures during their training.[22–25,27–31,33] The literature is generally void of investigations of system-wide SBML programs for establishing resident competence across an entire hospital system. While starting with wide variability in baseline performance of residents from numerous specialties, getting them all to a level of demonstrated competence was particularly important for those isolated critical care or night float rotations in which these interns may be the only provider available to perform an emergent CVC placement.

This SBML program required considerable physical, time, and financial resources. Multiple CVC kits, task trainers, and ultrasound machines were needed for 6 simultaneous stations to be run over 10 full days. The institution's graduate medical education procedural workgroup spent substantial time coordinating resident and facilitator sign-ups. The most challenging resource was securing facilitator time, particularly in departments without dedicated educational buy-down. This was complicated by multiple illness call-offs and unpredicted clinical duty constraints. Other institutions may not have the educational infrastructure to support such a program. The feasibility of training residents during orientation must be weighed against focused, just-in-time training before rotations where they are most likely to place CVCs.

5. Limitations

This pilot study was performed at one site over 2 cycles, however, the required investment of resources may make this program impractical for other institutions. The number of faculty facilitators required to run this program made scheduling difficult. Additionally, with so many facilitators involved, inter-rater reliability during performance assessments was challenged. Despite the dissemination of rater training materials, the number of different raters along with their variable amounts of preparation and experience with checklist-based assessments likely led to inconsistency in teaching and rating intern performance. The checklist assessment developed by our faculty was designed to reinforce our own institutional practices. Other institutions may have different safety protocols and institution-specific practices. Finally, although a checklist was developed via the Mastery–Angoff method over multiple iterations, evidence of the predictive validity of this instrument has not yet been established.

6. Future directions

Further development of this program will involve adding CVC competency assessments over time to assess potential decay of procedural skills, needs for retraining, and gathering evidence of predictive validity of the checklist. The program may be expanded to evaluate other clinicians, including fellows and advanced practice providers. If the cadre of faculty facilitators for running this program can be reduced, formal rater training may be performed to ensure inter-rater reliability. The impact on direct patient care may be evaluated by measuring incidences of complications, iatrogenic infections, the need for additional interventions, and overall patient outcomes.

7. Conclusions

A hospital-system-wide SBML program allowed incoming first-year residents to demonstrate competency in CVC placement using an established institutional standard. Interns from multiple specialties varied widely in their baseline performances, however performance variability was reduced to a negligible amount by the end of the program. Potentially dangerous actions were identified and remediated before the interns were involved in clinical patient care.

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Author contributions

Conceptualization: Jennifer Yee, Scott Holliday, Carleen R. Spitzer, Michael Essandoh, David P. Way, Ashish R. Panchal.
Data curation: Jennifer Yee, Carleen R. Spitzer, Michael Essandoh.
Formal analysis: Jennifer Yee, Carleen R. Spitzer, Michael Essandoh, David P. Way, Ashish R. Panchal.
Investigation: Jennifer Yee, Carleen R. Spitzer, Michael Essandoh.
Methodology: Jennifer Yee, Carleen R. Spitzer, Michael Essandoh, David P. Way, Ashish R. Panchal.
Project administration: Jennifer Yee, Scott Holliday, Michael Essandoh.
Supervision: Jennifer Yee.
Writing—original draft: Jennifer Yee, Scott Holliday, Carleen R. Spitzer, Michael Essandoh, David P. Way, Ashish R. Panchal.
Writing—review & editing: Jennifer Yee, Scott Holliday, Carleen R. Spitzer, Michael Essandoh, David P. Way, Ashish R. Panchal.
Resources: Scott Holliday, Carleen R. Spitzer, Michael Essandoh.

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