Evaluation of Simulation-Based Training Model on Vascular Anastomotic Skills for Surgical Residents

Vaia Y. Sigounas, MD;
Peter W. Callas, PhD;
Cate Nicholas, EdD;
Julie E. Adams, MD;
Daniel J. Bertges, MD;
Andrew C. Stanley, MD;
Georg Steinthorsson, MD;
Michael A. Ricci, MD

Introduction: Reduced work hours and concerns over patient safety have encouraged surgical educators to find methods to advance resident skills more efficiently. Simulation provides the opportunity to improve technical surgical skills outside the operating room. We hypothesized that practice on surgical task simulators would improve residents' technical performance of vascular anastomotic technique.
Methods: Senior general surgery residents at an academic medical center completed pretests and posttests on 3 vascular surgery simulators: femoral-popliteal bypass, carotid endarterectomy, and abdominal aortic aneurysm repair. The initial training sessions began with a 15-minute instructional video on how to perform the procedures, followed by supervised sessions in anastomotic technique with attending vascular surgeons. Initial individual sessions were videotaped as a pretest, and the final attempt was videotaped as the posttest. Each test was evaluated by a single experienced attending vascular surgeon blinded to the examinees. Anastomoses were graded using a performance rating and a modified objective structured assessment of technical skill rating. Results were analyzed using mixed model P values.
Results: The residents showed statistically significant improvement between the pretest and the posttest in both their performance rating (1.9 vs. 2.4, $P = 0.02$) and the objective structured assessment of technical skill (2.6 vs. 3.1, $P = 0.01$), as well as in most subsets of each assessment scale.
Conclusions: We conclude that practice using simulated anastomotic models leads to measurable improvement in vascular anastomotic technique in senior general surgery residents.
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Key Words: Vascular surgery, Deliberate practice.

Traditional surgical training has involved apprenticeship training with graduated transfer of responsibility as the trainee gains experience. However, reduced work hours and, consequently, lower case volume as well as heightened concerns for patient safety have required surgical educators to advance resident skills more efficiently outside the operating room.[1] Simulation provides an appealing method to improve surgical skills as part of residency training, allowing residents to practice, in a safe learning environment at any hour of the day, unimpeded by the availability of staff or preparation of an animal model.[2,3] Moreover, evaluative tools such as the objective structured assessment of technical skills (OSATS) and performance ratings allow for systematic evaluation of surgical skills, providing a more structured evaluation for residents.[4,5]

In this study, vascular surgery simulators for aortic aneurysm repair, carotid endarterectomy (CEA), and femoral-popliteal bypass (FPB) were used as part of a simulation-based vascular surgery curriculum developed at the University of Vermont for upper-level surgery residents. Our hypothesis was that the practice of anastomotic techniques using these simulators would objectively improve surgical resident technical skills.

MATERIALS AND METHODS

This study was approved by the University of Vermont Committee on Human Research. The training course was introduced as a pilot study that included 7 general surgery residents at the postgraduate year 3 (PGY3) to PGY5 (3 at PGY3, 1 at PGY4, and 3 at PGY5). The residents completed the pretest and the posttest on 1, 2, or 3 anastomotic simulators, based on their availability. Typically, 1 session per month was scheduled on the weekly teaching day, so occasionally, a resident had work-hour restrictions or vacation and was not available for every session. Attendance was voluntary. Residents use virtual reality simulations and high-fidelity mannequin simulators on other rotations. The anastomotic training is a locally developed initiative during the residents' rotation onto the vascular surgery service.

From the Division of Vascular Surgery (V.Y.S., J.E.A., D.J.B., A.C.S., G.S.), Department of Surgery, Medical Biostatistics (P.W.C.), and Clinical Simulation Laboratory (C.N.), University of Vermont, Burlington, Vermont and Central Maine Heart and Vascular Institute, Lewiston, Maine (M.A.R.).

Reprints: Michael A. Ricci, MD, Central Maine Heart and Vascular Institute, 300 Main Street, Lewiston, ME 04240, (e-mail: riccimi@cmhc.org).
The following products were donated to the University of Vermont Clinical Simulation Laboratory for education and training: 6-mm PTFE (WL Gore, Flagstaff, AZ), bovine pericardial patches (Vascu-Guard; Synovis, St Paul, MN), and Prolene sutures (Ethicon, Somerville, NJ).

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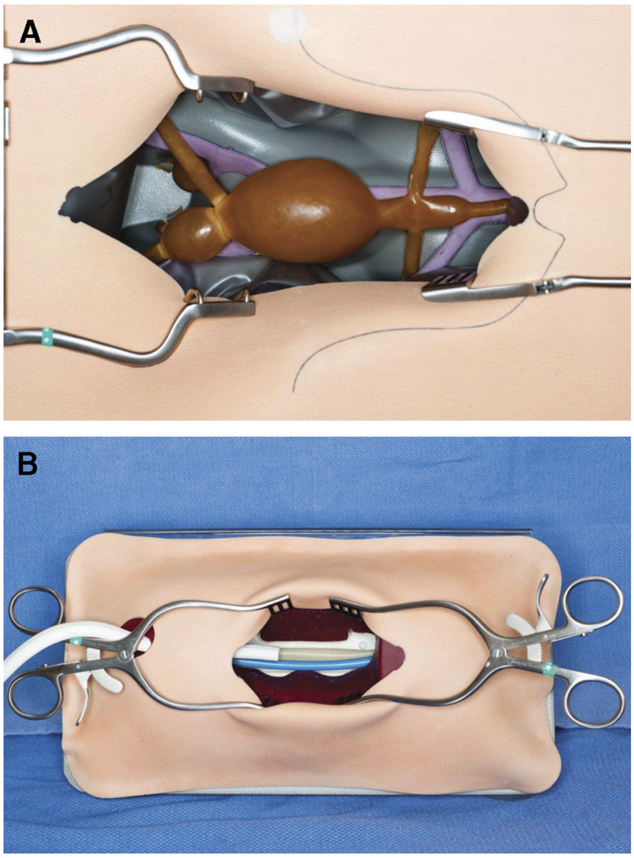

FIGURE 1. A, Aortic simulator. B, Femoral-popliteal simulator.

A total of 33 sessions were recorded. A single vascular surgery attending surgeon (M.A.R.) evaluated all of the pretest and posttest videos in a blinded fashion. Four additional vascular surgery attending surgeons served as instructors during the initial training sessions.

Vascular procedure simulators (Limbs and Things, Bristol, UK) included FPB, CEA, and abdominal aortic aneurysm (AAA) (Fig. 1). The following operative steps are carried out on each simulator: management of pre-incised skin and soft tissue, placement of retractors for proper exposure, using the correct surgical instruments, identification of the internal structures around the vessel, maintaining access and conducting delicate maneuvers within a confined space, and anastomosis of arterial grafts and patches. The simulators have anatomically accurate vessels with relevant soft tissue landmarks, a realistic tissue response, plaque for removal in the carotid model, and "internal organs" in the AAA trainer. Surgical instruments, grafts (6-mm Polytetrafluoroethylene [PTFE]; WL Gore, Flagstaff, AZ), patches (bovine pericardial patch, Vascu-Guard; Synovis, St Paul, MN), and suture (3-0, 5-0, and 6-0 Prolene; Ethicon, Somerville, NJ) were identical to those used in our operating rooms.

Residents attended 2-hour sessions monthly over the course of 5 months. The training session began with the residents watching a 15-minute instructional video of a vascular surgery attending surgeon completing the anastomoses in standard fashion. In the first training session, the residents were asked to complete a standardized anastomotic technique for their specific simulator. One of 4 attending vascular surgeons who circulated during each 2-hour session taught the residents anastomotic technique. During the training sessions, the teaching surgeon inspected each resident's anastomosis and offered feedback during and after completion of the anastomosis. Between formal teaching sessions, residents had 24-hour access to the Clinical Simulation Laboratory to practice independently on the simulators, but none of the residents did extra practice time between sessions. The first attempt by each resident to complete each of 3 trainers was videotaped for blinded evaluation as a "pretest." In the next month, the residents attempted a different simulator. The rotation continued until the residents had an opportunity to complete all 3 simulators.

After initial training and practice sessions, each resident completed an anastomosis with each of the 3 simulators and was videotaped for blinded "posttest" evaluation by the same evaluator who graded the pretests. The reviewer had no knowledge of the skill level. The audio was muted, and the video showed only the gloved hand of the participants. (We recognize that multiple raters may represent a preferred method. However, we felt that a single rater would introduce consistency to the evaluations, and because the other vascular surgery attending surgeons participated in training, we could not have truly blinded them as raters.) The residents were aware that the anastomoses would be formally reviewed and evaluated. The evaluation of each anastomosis was on a 3-point scale modified slightly from Fann et al[3]: 1 = poor, 2 = average, and 3 = good. Attending surgeons were instructed on the use of the 3-point scale. The components of the evaluation included a performance evaluation of 1 to 5 points as follows: graft/patch orientation, appropriate bite, appropriate spacing, use of a needle holder, use of forceps, needle angles, needle transfer, suture management, and knot tying. A modification of the OSATS[4,5] was also used, with a rating of 1 to 5: respect for tissue, time and motion, instrument handling, flow of operation, and knowledge of specific procedures. The time to complete each evaluation anastomosis on each model was also recorded.

The primary end point was the change in evaluation score from the beginning of the initial training session to the final evaluation session. In our analysis, we combined the results of all 3 simulators because anastomotic technique is reinforced and improved by repeated practice using the same skills on different vessels and surgeries. We analyzed our results using mixed models, which account for the correlated data, where the same resident worked on multiple simulators.[6] To assess the sensitivity of the findings to the assumption of normality, we repeated the analyses using Wilcoxon signed rank tests and obtained consistent results. All analyses used a 2-sided type I error rate of 0.05.

RESULTS

Seven residents were invited to participate in this study for 5 months. Complete participation would have resulted in a total of 42 sessions. However, work-hour restrictions or vacation time resulted in absences, so that a total of 33 sessions (pretest and posttest evaluations) were completed. None of the residents practiced on the simulators between sessions.

TABLE 1. Results of Performance Rating and OSATS

	Mean (SD)			
	Before	After	Difference	P
Performance rating (scale, 1 = poor to 5 = excellent)				
Graft/patch orientation	2.7 (0.9)	2.8 (0.9)	0.1 (0.9)	0.75
Bite appropriate	3.0 (0.6)	3.5 (0.7)	0.5 (0.8)	0.05
Spacing appropriate	3.1 (0.5)	3.5 (0.7)	0.4 (0.8)	0.09
Use of a needle holder	2.9 (0.6)	3.6 (1.0)	0.7 (0.9)	0.01
Use of forceps	2.8 (0.7)	3.4 (0.7)	0.6 (0.9)	0.02
Needle angles	2.5 (0.7)	3.6 (0.9)	1.1 (1.0)	0.001
Needle transfer	2.8 (0.7)	3.5 (0.7)	0.6 (0.7)	0.003
Suture management	2.8 (0.4)	3.2 (0.6)	0.3 (0.6)	0.10
Knot tying	2.8 (0.7)	3.2 (0.7)	0.4 (0.9)	0.13
Mean of performance rating	2.8 (0.5)	3.4 (0.6)	0.5 (0.5)	0.003
OSATS (1–5 rating)				
Respect for tissue	2.7 (0.6)	3.2 (0.6)	0.5 (0.8)	0.05
Time and motion	2.6 (0.5)	3.4 (0.9)	0.8 (0.6)	<0.001
Instrument handling	3.0 (0.6)	3.6 (0.8)	0.6 (0.9)	0.03
Flow of operation	2.6 (0.8)	2.6 (0.8)	0.0 (0.7)	1.00
Knowledge of specific procedure	2.3 (0.8)	2.8 (0.9)	0.5 (1.2)	0.18
Mean of OSATS	2.6 (0.5)	3.1 (0.6)	0.4 (0.6)	0.01
Overall rating (1 = poor, 2 = average, or 3 = good)	1.9 (0.6)	2.4 (0.7)	0.5 (0.7)	0.02
Time (min)	33 (6)	36 (10)	3 (8)	0.24

The residents showed statistically significant improvement between the pretest and the posttest in both their performance rating (1.9 vs. 2.4, $P = 0.02$) and the OSATS (2.6 vs. 3.1, $P = 0.01$; Table 1). They also improved in the following subsets of the performance rating: graft patch orientation (2.7 vs. 2.8, $P = 0.04$), use of a needle holder (2.9 vs. 3.6, $P = 0.01$), use of forceps (2.8 vs. 3.4, $P = 0.02$), needle angle (2.5 vs. 3.6, $P = 0.001$), needle transfer (2.8 vs. 3.5, $P = 0.003$). Although they also improved in obtaining an appropriate bite (3.0 vs. 3.5, $P = 0.05$), creating appropriate spacing (3.1 vs. 3.5, $P = 0.09$), suture management (2.8 vs. 3.2, $P = 0.1$), and knot tying (2.8 vs. 3.2, $P = 0.13$), these results were not statistically significant. For the OSATS, subsets that showed statistically significant improvement include time and motion (2.6 vs. 3.4, $P < 0.001$), instrument handling (3.0 vs. 3.6, $P = 0.03$), and knowledge of specific procedure (2.3 vs. 2.8, $P = 0.02$). Respect for tissues showed nonstatistically significant improvement (2.7 vs. 3.2, $P = 0.05$), and there was no improvement in the flow of operation (2.6 vs. 2.6, $P = 1$). Although it was not statistically significant, it is worth noting that the time spent on each of the anastomosis lengthened between the pretest and the posttest, as did the total time of all 3 simulators (33 vs. 36 minutes, $P = 0.24$).

DISCUSSION

More than 100 years ago, Halsted introduced a graduated responsibility model of surgical education to his trainees at The Johns Hopkins University.[7,8] That model was based on the principle that teaching could be based entirely on constant, large-volume exposure to surgical cases. To that end, surgery residents worked upward of 110 hours a week, were not permitted to marry, and literally lived in the hospital for the duration of their training. Since 1890, the field of surgery has dramatically changed, with the advent of laparoscopy, cardiopulmonary bypass, critical care, bariatric surgery, endovascular surgery, and transplantation. In addition to advances in medical knowledge, social changes, including a demand for increased professional transparency and accountability, have led to work-hour restrictions and increased oversight of trainees. Surgical training, however, has remained largely unchanged, with the requirement for large volumes of cases to assure competency.

Simulation, the act of mimicking a real person, object, event, or process, provides the ideal learning environment to allow the learner to become proficient by deliberate repetitive practice in a protected environment, offering a modern day variation on the Halsted training principles. Deliberate practice is defined as "focused, repetitive practice that leads to rigorous, precise educational measurements that yield informative feedback from educational sources."[9] Thus, simulation-based deliberate practice allows novices to learn basic skills on inanimate simulators in a safe environment before progressing to assisting on patients, reducing the risk for learners and patients. Simulation can be designed for all levels of individual learners, giving them the opportunity to practice specific skills at their own pace. Simulation also offers training flexibility because a large ancillary staff is not needed, as is the case for animal "wet labs." Because of these strengths, simulation is becoming the new cornerstone of health professions education, patient safety, and error reduction.[10–12] Recognizing the power of simulation methods and techniques, the American College of Surgeons has developed an accreditation program for surgical simulation programs, anticipating the increasing need for simulation in residency training.[13] In addition, simulators have found acceptance in the American College of Surgeons Advanced Trauma Life Support course, the mainstay of basic trauma education.[14,15]

With the advent of this new educational technology, residency programs have begun developing curriculums around the use of simulators. For instance, as part of their resident assessment, the Department of Surgery at the University of Toronto developed a 2-hour, 8-station evaluation of resident technical skills called the OSATS.[4] Cardiovascular surgeons have begun to use technical simulators to train residents and fellows. Fann et al[16] have developed and tested a simulation-based curriculum for first-year cardiothoracic residents. They used both a porcine heart wet lab simulator and a lower-fidelity synthetic anastomotic simulator. Thirty-three residents participated in a 4-hour session supervised by 6 to 7 attending surgeons for 8 to 9 residents. Anastomotic skills were assessed in person and by blinded observers reviewing video on a standardized 3-point rating scale. Anastomotic performance improved since simulation training. At 6 months, residents noted that the session was helpful, but only about half continued to practice. Unfortunately, the use of a porcine model precludes widespread use because of difficulties and costs associated with maintaining live animals.

Bath et al[2] used a commercially available femoral-popliteal anastomotic simulator and a standardized approach to instruction. Residents were divided into a study group that learned how to perform an FPB by deliberate practice using a standardized learning approach and a control group that learned using traditional teaching methods. There was no attempt at obtaining a pretest and a posttest, but these investigators found that both groups attained technical scores higher than 75% and global skills scores higher than 65%, suggesting that simulation improves surgical skills. It also seems that, when a single expert instructor teaches the technical aspects of femoral anastomosis in a standard fashion each time, residents learn better than when they are taught by several expert instructors in a traditional way with variable technique. In a prospective randomized trial out of Oregon, 24 surgical interns were randomly assigned to either 4 weekly training sessions or 4 monthly sessions, practicing how to perform an anastomosis on a vascular simulator. At the end of the study, their motor skill acquisition was similar, suggesting that, as long as practice is distributed, motor skill acquisition is similar regardless of whether the training time involves weekly or monthly training.[17]

More recently, Robinson et al[18] showed that junior residents benefit greatly from simulation. In their study, 37 residents at PGY1 to PGY3 were randomized to either a 3 or 6-week course of hour-long teaching sessions on a vascular anastomosis simulator. They were evaluated using a standardized vascular skills assessment at 1 week after course completion and 16 weeks after course completion. The PGY 1 to PGY3 resident scores after completion were higher than their baseline scores for both groups. Moreover, they were as high as baseline scores of PGY4 to PGY5 residents, suggesting that PGY1 to PGY3 residents can attain the proficiency of PGY4 to PGY5 residents after three 1-hour training sessions.

In our study, midlevel (PGY3 and PGY4) and senior (PGY5) residents all showed improvement with practice. We acknowledge that other variables may have led to improvement, such as rotation onto the vascular service and increasing actual operative experience. However, at most, only a few residents would have actually rotated onto the vascular service, which would not account for the overall improvements. Mean performance rating scores improved between the pretest and posttest scores. Mean scores on the OSATS scores also improved between the pretest and posttest scores. We used a modified OSATS by excluding the "knowledge of instruments" because there was no written assessment of instrument knowledge and "use of assistants" because some senior residents used assistants and some did not, depending on personal preference and type of simulator used. In our analysis, we used both a mixed model approach and a Wilcoxon signed rank test. The mixed model approach accounted for the fact that the same resident may have had a pretest and a posttest on multiple simulators and that improved skill on 1 anastomosis transferred to the others. However, the outcome was not normally distributed on all simulators, and so, we also used a Wilcoxon signed rank test for nonnormal data, although there were correlated data. It seems that, although the residents trained on 3 different vascular simulators, learning how to complete 1 type of anastomosis improved overall skill in performing any subsequent anastomosis.

There was no difference in the time to completion in this study. Although perhaps it is not the most important variable, it was an objective indicator. Because the time required for the 3 different techniques varied (patch vs. small vessel anastomosis vs. proximal aortic repair), we suspect the number of sessions and anastomoses in each group was too small to detect a significant difference.

Costs of development for such a training program are obviously a concern. A set of 4 trainers (CEA, AAA, FPB, and femoral-tibial bypass) cost $2600 in 2010. Replacement femoral-popliteal blood vessels are approximately $30 for 6 vessels, the AAA replacement is $35, and 3 replacement carotid vessels were $95. Consumable supplies were donated for educational use by the same vendors who stock our clinical operating rooms. Approximately 2 hours of simulation technician times was required to set up the day before each session. In this pilot project, a vascular surgery attending surgeon spent 2 hours in each of 3 initial sessions.

Our hypothesis that practice of anastomotic techniques using the surgical simulation trainers would improve technical skill was validated, as judged by objective assessments. Overall surgical skills did improve, and most subsets of each evaluation scale also showed statistically significant improvement. Practice using simulation models led to measurable improvement in vascular anastomotic technique in general surgery residents. The final "bench-to-bedside" translation of this project would be if the residents' performance in the operating room improved as well, but this is beyond the scope of our project. It is possible that resident skill improved but only on the simulated platform. However, the improvement we found in our senior surgery residents allows us to use these simulators as part of our core curriculum for residents while they rotate onto the vascular surgery service in years 3 and 5. We suspect that junior residents will see even greater improvement after practicing on the simulators and look forward to having them participate in this curriculum as well. This pilot project is a positive first step in the design of a simulation-based vascular surgery curriculum for surgical residents and may potentially become valuable preparation for the operating room.

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