Endovascular Simulation Leads to Efficiency and Competence in Thoracic Endovascular Aortic Repair Procedures

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OBJECTIVE: Endovascular interventions such as thoracic endovascular aortic repair (TEVAR) have largely replaced invasive open procedures, and have been demonstrated to be effective in treating patients. Our study used endovascular simulation to assess the effect of TEVAR rehearsal on surgical trainees at different levels in training.

DESIGN: Participants were oriented on an endovascular simulator and subsequently a simulated TEVAR was performed during 4 separate sessions over a 1-month period. Metrics included total procedure/fluoroscopy time and volume of contrast used. Likert scale qualitative analysis evaluated participant's skills involving major procedural steps. Analysis of data across cohorts included 1-way analysis of variance, Kruskal-Wallis, and paired *t*-tests.

SETTING: All data were collected at University Hospitals—Case Medical Center, Cleveland, OH.

PARTICIPANTS: In all, 12 trainees in 3 cohorts (student, surgery resident postgraduate year [PGY] 1-3, surgery resident/fellow PGY 4-7, $n = 4$ each) were recruited.

RESULTS: All trainees reduced total procedure time (mean $= 537 \pm 148$ vs 269 ± 66 s, first session vs fourth, $P < 0.05$, CI: 195-341) and fluoroscopy time (mean $= 201 \pm 74$ vs 110 ± 37 s, $P < 0.05$, CI: 51-132) with TEVAR case progression. The student cohort decreased procedure time from 551 ± 84 s to 313 ± 65 s ($P < 0.05$, CI: 189-287) whereas PGYs 1 to 3 decreased procedure time from 591 ± 149 s to 264 ± 29 s ($P < 0.05$, CI: 113-541). Use of contrast decreased over time, but the difference was not significant. Participants acquired proficiency after a few runs in most steps of the procedure. The average qualitative score for all groups combined improved significantly ($P < 0.03$). PGY 4 to 7 trainees had higher technical scores but this was not statistically significant. The initial gap in junior vs senior trainee performance narrowed after a few practice sessions in all aspects evaluated.

CONCLUSIONS: TEVAR rehearsal on an endovascular simulator can reduce overall procedure and fluoroscopy time, independent of trainee skill level or experience, as well as improve subjective measures of technical success. Further studies are needed to compare simulator performance to outcomes in live cases. (J Surg 72:1158-1164. © 2015 Association of Program Directors in Surgery. Published by Elsevier Inc. All rights reserved.)

KEY WORDS: simulation, endovascular surgery, aneurysm, training, assessment

COMPETENCIES: Medical Knowledge, Practice-Based Learning and Improvement

INTRODUCTION

The advancement of endovascular surgery over the last 20 years has dramatically expanded the scope of therapy available to treat patients. In the span of a decade between 1996 and 2006 the number of endovascular procedures in peripheral vascular beds tripled from 138 to 445/100,000 Medicare patients although the rate of lower extremity bypasses decreased by 50%.[1] Endovascular interventions have replaced more invasive open procedures[2,3] and have been demonstrated to be effective in treating patients with aneurysmal and occlusive disease.[4-7] In addition, for patients with thoracic aortic disease, thoracic endovascular aortic repair (TEVAR) has become an attractive minimally invasive option.[8] A Cochrane review comparing thoracic stent graft vs open surgery for thoracic aneurysm showed reduction of early adverse outcomes (e.g., paraplegia), mortality, and hospital stay in the first group.[9]

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This rapid endovascular development has required a significant transition in skill set as both surgeons and trainees have had to adopt entirely new modes of practice. In the setting of resident work hour restrictions and streamlined training regimens, considerable pressure has been placed on the training programs to adequately prepare residents and fellows for independent practice. This challenge is compounded by the need for adequate case volume experience. For example, complex procedures such as carotid artery stenting have been shown to yield the best patient outcomes when performed by experienced surgeons as compared with less experienced practitioners.[10]

Senior Integrated Vascular ("0-5") residents recently reported decreased confidence in performing low-volume cases, with less common endovascular procedures such as carotid stenting and TEVAR procedures representing the lowest training volume overall. However, those trainees with access to simulation reported a significant increase in confidence level over those with no access at all.[11] This suggests that the use of high-fidelity simulation has a role to play in ensuring that residents are adequately exposed to less common clinical cases.

The aim of this study is to quantify trainee improvement through participation in a series of TEVAR-specific simulations.

METHODS

Study Design

Trainees volunteered to participate in the study and, after informed consent, were assigned to 3 different cohorts according to their level of training (student, junior surgery resident postgraduate year [PGY] 1-3, senior surgery resident, or fellow PGY 4-7, $n = 4$ each). Each participant attended a standardized orientation that included an introductory PowerPoint (Microsoft, Redmond, WA) presentation and a practice TEVAR case on the simulator. This was designed to standardize instruction about the basics of catheters and guidewires in vascular surgery as well as the steps on how to perform a straightforward TEVAR case. The practice case was not assessed and allowed for the participants' queries to be addressed. Following orientation, each participant performed a TEVAR simulation case, on 4 separate occasions with a minimum of 5 days between sessions. Primary end points included total procedure and fluoroscopy time, total contrast use, and subjective qualitative performance assessment. A Likert scale qualitative analysis was used to evaluate participant proficiency during each simulation. The scoring tool was adapted specifically for TEVAR procedures from one developed for lower extremity simulation by Chaer et al.[12] (Table 1). Observing and scoring all performances were conducted by 2 study investigators. A qualified thoracic vascular surgeon with thoracic aortic experience instructed this team on specifically what to look for during evaluation. Immediately after each case, these 2 investigators completed scoring independently and then discussed results for each category. Consensus was reached based on the average of the 2 scores. Interobserver agreement was found to be moderate using Cohen's kappa analysis ($\kappa = 0.576$). The scores were not shared with the participants until they had completed all 4 sessions.

Simulation Device

All simulations were conducted on the Angio Mentor Dual Slim (Simbionix, Cleveland, OH) endovascular simulator. It is a dual-access system with 2 representative lower limbs, each measuring $104 \times 10 \times 13$ cm. The individual limb contains 3 haptic sensors responsible for generating sensory and tactile information to the participant. The system also contains a 17 in monitor for displaying live radiographic imaging, a replica foot pedal for controlling fluoroscopy, and a laptop used to control selection of wires and catheters. To the simulator, 2 computed tomographic scans of prior thoracic aneurysm cases were uploaded. Raw digital imaging and communication in medicine data were segmented manually for 3-dimensional reconstruction of the thoracic aneurysm. A case was used for the practice session and the other was serially used for performance assessment (Fig. 1).

Statistical Methods

Continuous variables between first and last cases for each cohort were analyzed with paired t-tests. Intergroup comparisons were done using 1-way analysis of variance. Combined overall Likert scores between first to last case were compared using a Kruskal-Wallis test with a Dunn's test for multiple comparisons. Individual cohort scores were assessed by comparing first and last cases using a Wilcoxon signed-rank test. Threshold for statistical significance was defined as $P < 0.05$.

RESULTS

Study Participants

A total of 12 participants were recruited to 3 vascular surgical experience-based cohorts, each containing 4 individuals. The student group consisted of Masters of Physiology candidates from our institution with no previous exposure to endovascular procedures but with some didactic knowledge of thoracic aortic disease. The junior trainee group was composed of a vascular surgery integrated resident (PGY-2) and 3 third-year general surgery residents with 2 clinical years of experience. The mean number of months of dedicated vascular training each person had was 3.8 ± 2.4. The senior trainee group was the most experienced and consisted of a vascular surgery fellow (PGY-7), a minimally invasive surgery fellow (PGY-6), and 2 general

TABLE 1. Performance Scoring Tool. Likert Scale Criteria Used to Evaluate Participants' Performance

Likert Scale Criteria					
1. Advancement of wire into the aorta	1 Awkward movements, pushes against resistance, forms a J, selects inappropriate wire	2	3 Good economy of motion, some awkward movements	4	5 Excellent economy of motion, wire moves freely and without resistance
2. Placement of angiographic catheter into ascending aorta	1 Selects wrong catheter and places in wrong position	2	3 Selects incorrect catheter or places in wrong position (not both)	4	5 Correctly places catheter to ascending aorta, fluid movements, and handling of the wire
3. Angiogram performance	1 Angiogram performed at AP view	2	3 Able to partially identify anatomy/lesion, inadequate angiogram	4	5 Correctly identifies lesion, complete angiogram (LAO 45-55)
4. Wire access	1 Completely lost wire access	2	3 High degree of shifting of wire with wire access still being maintained	4	5 Wire access maintained throughout the case
5. Able to select appropriate endograft	1 Incorrect graft sizing and no measurement of lesion	2	3 Correct graft sizing without measuring lesion	4	5 Correct graft sizing and measurement of lesion
6. Percentage of lesion covered	1 Complete Type 1 Endoleak	2	3 Partial Type 1 Endoleak	4	5 100% coverage with no Endoleak
7. Completion angiogram	1 Does not perform a completion angiogram	2	3 Inadequate angiogram	4	5 Correctly performed angiogram

LAO, left anterior oblique.

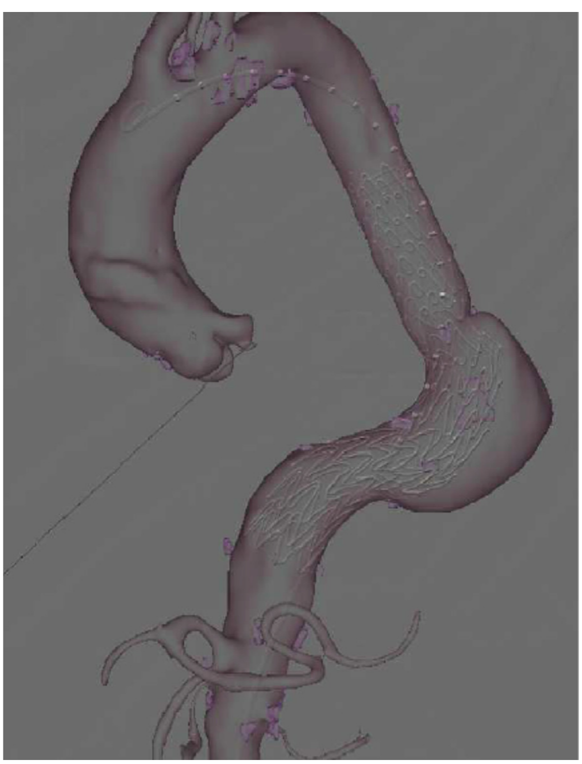

FIGURE 1. Case image. A 3D reconstruction of thoracic aneurysm case used in the study with endograft deployed. 3D, 3 dimensional.

surgery residents (PGY-4 and PGY-5). The mean number of months of dedicated vascular surgery training for this cohort was 10.0 ± 8.1, including at least 2 months experience as a senior resident/fellow on a vascular service. A PGY 4 to 7 cohort participant did not complete the fourth case and thus this cohort was analyzed with an n of 3 for the final time point.

Objective Performance

Analyses of objective data points from individual cohorts and all participants combined are summarized in Table 2. Examining the combined means from all groups shows that both total procedure time and fluoroscopy time were significantly reduced by 50% between the first and fourth sessions. Total procedure time was lowered by an average of 268 seconds between the first and fourth sessions from 537 to 269 seconds, ($P < 0.01$; Fig. 2). Mean fluoroscopy time decreased from 201 seconds at the first session to 110 seconds at the fourth session ($P < 0.01$, Fig. 3). Analysis within cohorts demonstrates that students and PGYs 1 to 3 both had a significant decrease in procedure time by 238 seconds (551 vs 313 s, first session vs fourth, $P < 0.01$) and 327 seconds (591 vs 264 s, first session vs fourth, $P < 0.02$), respectively. PGYs 4 to 7 also showed improvement regarding total procedure times, but these data were not statistically significant. Fluoroscopy times decreased within each individual group as well, but did not reach significance with case progression.

TABLE 2. Results Summary. Data Listed by Cohort for All Session Numbers, Including Total Procedure Time, Total Fluoroscopy Time, As Well As Total Contrast Used. All p Values Reflect an of 0.05

Summary Results Table

	Session 1	Session 2	Session 3	Session 4	First vs Fourth Comparison
Mean total procedure time (s)					
Students	551.00	480.50	413.00	312.75	**$P = 0.0006$**
PGY 1 to 3	591.25	367.75	331.25	264.25	**$P = 0.017$**
PGY 4 to 7	465.50	326.75	340.00	217.25	$P = 0.11$
Combined mean	535.92	391.67	361.42	264.75	**$P = 0.00001$**
Mean total fluoroscopy time (s)					
Students	233.00	199.25	154.25	128.50	$P = 0.06$
PGY 1 to 3	184.75	138.00	120.75	111.75	$P = 0.12$
PGY 4 to 7	199.00	157.50	133.00	80.75	$P = 0.08$
Combined mean	205.58	164.92	136.00	107.00	**$P = 0.0005$**
Mean total contrast volume (mL)					
Students	45.00	45.00	45.00	45.00	$P = 1$
PGY 1 to 3	55.00	45.00	40.00	40.00	$P = 0.06$
PGY 4 to 7	55.00	40.00	50.00	40.00	$P = 0.06$
Combined mean	51.67	43.33	45.00	41.67	$P = 0.10$

Contrast use did not vary significantly as participants progressed through cases. Students maintained a mean of 45 mL $\pm$ 0 throughout all 4 sessions. PGYs 1 to 3 and PGYs 4 to 7 decreased their use of contrast by an average of 15 mL and 13 mL, respectively, but this difference was not statistically significant (Table 2).

Subjective Performance

Likert scale scores showed significant improvements in mean overall score for all groups combined as they progressed from first and fourth sessions ($P < 0.03$) (Fig. 4). Individual cohort scores also improved but did not reach a threshold of statistical significance (Fig. 5). Variance in scores decreased with time. Students improved the most (mean = 28.75 $\pm$ 0.50 vs 34.50 $\pm$ 0.58, first vs fourth session, non-significant (ns) from the first to the last session whereas PGY 4 to 7 demonstrated high performance scores at all time points (mean = 33.3 $\pm$ 2.89 vs 34.67 $\pm$ 0.58, first vs fourth session, ns).

DISCUSSION

Surgical training has traditionally relied on an apprenticeship model. The sharp increase in case variety and complexity in tandem with a shortened resident training period has necessitated exploration of nontraditional training modalities including the use of technologies such as simulation to ensure a level of uniform baseline competency in surgical

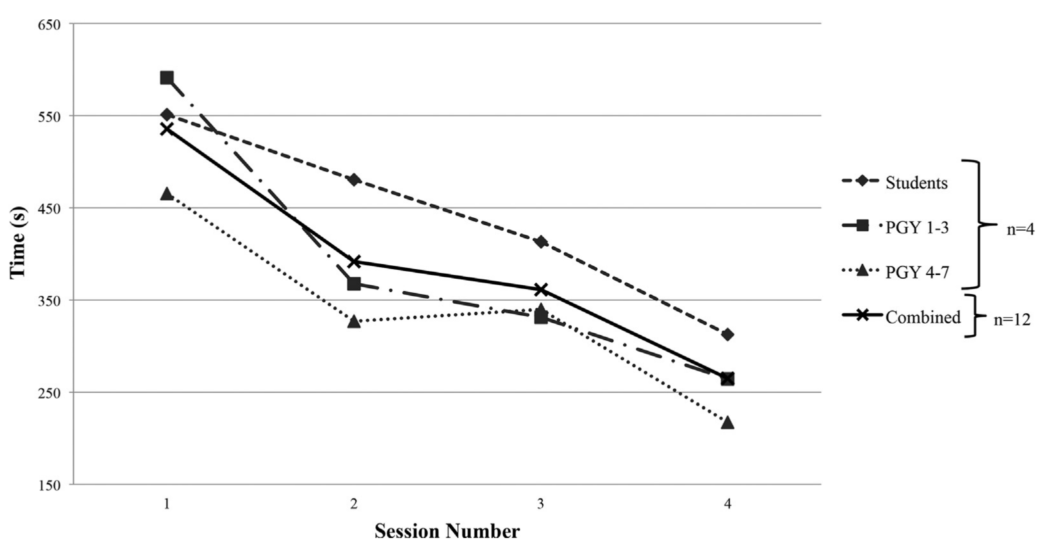

FIGURE 2. Total procedure time. Mean cohort procedure times by sessions. Session 4 PGY 4 to 7, $n = 3$.

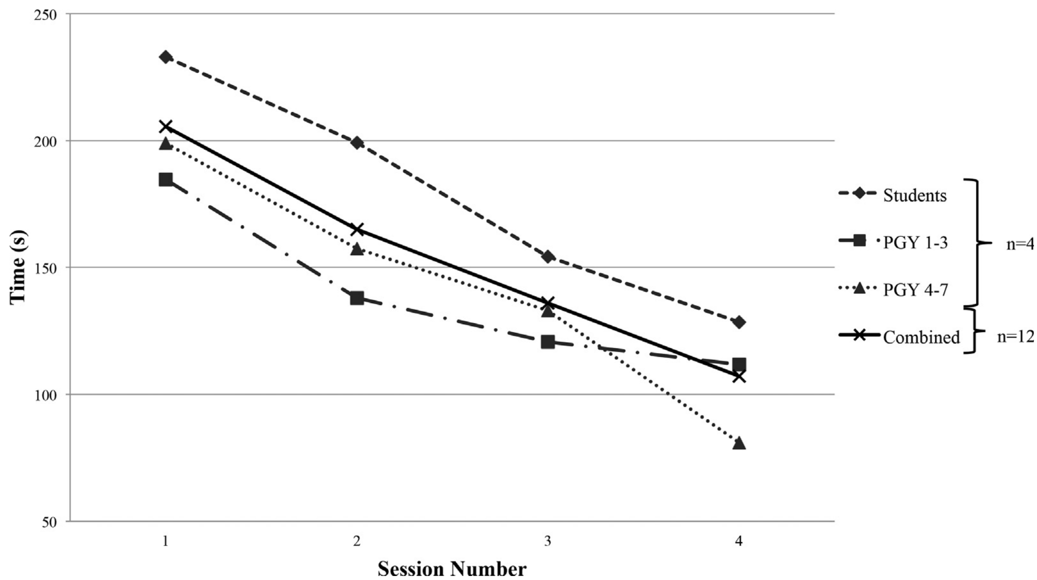

FIGURE 3. Total fluoroscopy time. Mean cohort fluoroscopy times by sessions. Session 4 PGY 4 to 7, $n = 3$.

procedures. Laparoscopic surgery simulators were described in 1993 and their importance for the future surgeon was compared to the importance of flight simulators for pilots.[13] These early forays demonstrated improved outcomes[14] and henceforth the role of virtual reality simulators has expanded into other subspecialties. Currently, multiple endovascular surgical simulators are commercially available and marketed in the United States. Each device offers unique characteristics and different technologies.[15] A variety of training modules are available for the different surgical techniques in the endovascular field, including angioplasty, endovascular aortic repair, TEVAR, and stenting of renal, coronary, iliac, and femoral vessels. Patient-specific information and imaging data can also be incorporated into simulations, allowing for the opportunity to practice challenging cases before surgical intervention.[16]

Previous efforts in endovascular simulation have demonstrated that those trained on an infrainguinal intervention model show improvement in subjective performance over cohorts who do not receive this instruction.[12] Use of

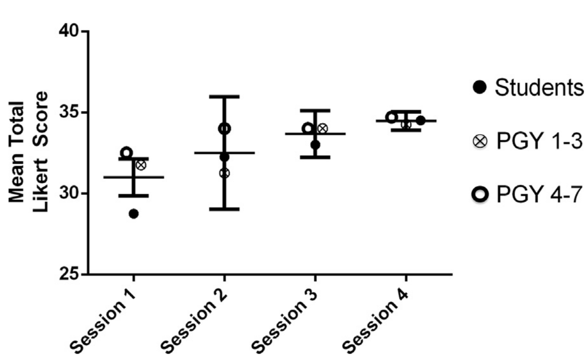

FIGURE 4. Overall mean performance score. Comparison of Likert mean performance scores among groups across all time points.

simulation as an adjunctive training platform to teach carotid artery stenting to residents has also been demonstrated to improve both objective and subjective performance measures.[17-19] This effect has consistently been observed to be most prominent in novice practitioners as more experienced trainees and staff demonstrate a higher starting proficiency before simulation, making subsequent gains incremental.

This study is the first to demonstrate performance improvement in a novel TEVAR-specific simulation model. Similar effects were observed as in previous simulation studies in that the less experienced student and PGY 1 to 3 cohorts showed the greatest reduction in procedure and fluoroscopy times. The performance gap between students and senior trainees narrowed in moving from the first to the last case, indicated by improving Likert scale scores. The score variance was reduced across all groups as well. This reflects a marked improvement in student and junior trainee performance, eventually reaching parity with the consistent quality performance observed from the PGY 4 to 7 cohort. This lends further credence to the benefit of simulation in groups with less experience to assist in reaching competence before applying these skills in live endovascular cases. These gains may be maximized when simulation is targeted specifically toward procedures in which adequate trainee exposure is problematic such as TEVAR or carotid stenting.

This study is limited by its small sample size of 12 trainees in total. Despite these numbers, there was a significant improvement in simulated performance for both objective and subjective end points. Additionally, the thoracic case used may not have been technically challenging enough to adequately discern the more subtle differences in skills that separate a senior vascular fellow from a novice student. Observation of participant performance on

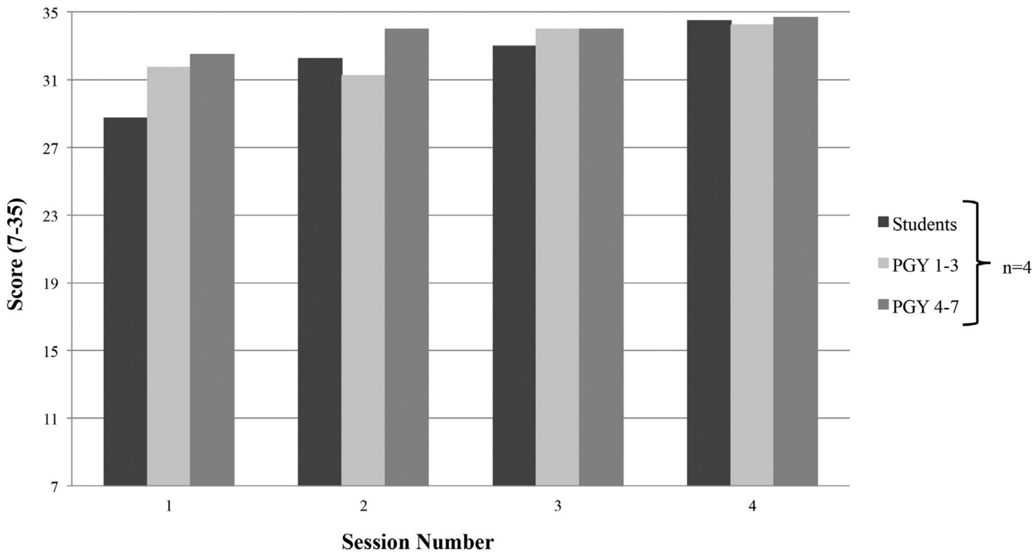

FIGURE 5. Cohort mean performance score. Comparison of Likert mean individual cohort performance score across all time points. Session 4 PGY 4 to 7, $n = 3$.

a more demanding case, such as aortic dissection, may not result in equalization of subjective scoring as we demonstrated in this study. Further, with this study design, it is impossible to differentiate learning by rote as opposed to true cognitive skill acquisition. Each participant performed the same case 4 times without further demonstration of skill assimilation in a novel simulated case or in a live case in the operating room.

The results of our study strongly support junior trainees practicing on endovascular surgical simulators for skill acquisition. Although every group in our study showed improvement, the most experienced group remained the fastest and most skilled and demonstrated the smallest improvements in performance. This suggests that practice on simulation outside the operating room is beneficial, but should be tailored to fit the skill level of the participant. Straightforward practice of representative case types is sufficient for junior vascular surgery residents seeking development of operative flow and fundamental skills. Senior trainees may gain more benefit from simulation through true patient-specific case rehearsal before entering the operating room.

Future studies may examine whether endovascular simulation improves surgeon/trainee performance measures in live endovascular cases. It stands to reason that “practice makes perfect,” but whether simulator-based preparation reduces operative time or leads to better patient outcomes is yet to be determined. Additionally, there are little data available about the durability of the performance gains after practice on simulation. The number of training sessions and the proper time interval necessary to improve performance and then preserve those improvements are not clear. The translation of performance gains to real operative scenarios and the durability of such gains have important implications for training programs, in deciding how best to invest resources toward fellow/resident preparation.

CONCLUSIONS

This study shows that a TEVAR-specific simulated case can improve both objective and subjective measures of endovascular technical success in trainees. This effect is more pronounced in less experienced participants, as has been seen in prior studies. Simulation is an efficient and effective methodology to build competence and confidence in residents and fellows who may have inadequate exposure in low-volume endovascular cases. We believe that endovascular simulators should be considered effective tools in residency training. Further studies are needed to compare simulator performance to outcomes in live cases.

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