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ORIGINAL REPORTS

Feasibility and Evaluation of Surgical Simulation with Developed Crisis Scenarios: A Comparison of Performance by Vascular Surgery Training Paradigms

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OBJECTIVES: Surgical simulation is an integral component of training and has become increasingly vital in the evaluation and assessment of surgical trainees. Simulation proficiency determination has been traditionally based on accuracy and time to completion of various simulated tasks, but we were interested in assessing clinical judgment during a simulated crisis scenario. This study assessed the feasibility of creating a crisis simulator station for vascular surgery and evaluated the performance of vascular surgery integrated residents (0+5) and vascular surgery fellows (5+2) during a technical testing with an integrated crisis scenario.

METHODS: A Modified Delphi method was used to create vascular surgery crisis simulation stations containing a clinical scenario in conjunction with either an open or endovascular simulator. Senior level vascular surgery trainees from both integrated residencies (0+5) and traditional vascular surgery fellowships (5+2) were then evaluated on two simulation stations: 1) Elective carotid endarterectomy (CEA) where the crisis is a postoperative stroke and 2) Endovascular aneurysm repair (EVAR) for a ruptured abdominal aortic aneurysm (rAAA). Each simulation had a crisis scenario incorporated into the procedure. Assessment was completed using a performance assessment tool containing a Likert scale. Total score was calculated as a percentage. Scores were also sub-divided in the following four categories: Situation Recognition and Decision-making, Procedural Flow, Technical Skills, and Interpretation and Use of Imaging Skills. Student's t-test was used for analysis.

RESULTS: 40 senior-level trainees were evaluated (27 fellows and 13 integrated residents) completing 80 simulations. The CEA crisis simulation yielded similar results between both groups (0+5 vs. 5+2, $p = 1.00$). The 0+5 residents in vascular surgery were graded to be more proficient in the EVAR for rAAA crisis simulation and demonstrated significant differences in Total Score ($p = 0.04$), Procedural Flow ($p=0.03$), and Interpretation and Use of Imaging Skills ($p = 0.02$).

CONCLUSIONS: The creation of crisis-based simulation for trainees in vascular surgery is feasible and actionable. Integrated 0+5 residents performed similarly to 5+2 fellows on an open carotid endarterectomy (CEA) crisis simulation, but 0+5 residents scored significantly higher compared to traditional 5+2 fellows in an endovascular rAAA crisis simulation. Crisis simulation may offer better educational experiences and improved value compared to routine simulation. Further studies using different procedural models and clinical scenarios are needed to assess the validity of crisis simulation in vascular surgery and to better understand the performance disparities found between these training paradigms. (J Surg Ed 000:1−7. © 2021 Published by Elsevier Inc. on behalf of Association of Program Directors in Surgery.)

KEY WORDS: simulation, vascular surgery, medical education, quality of surgical care, crisis management

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INTRODUCTION

Surgical simulation has become an increasingly valuable tool for both teaching and evaluating trainees. The current era of resident work-hour restrictions has shortened the total time that residents train. In addition, new integrated residency programs with shorter training duration have been introduced in fields such as vascular surgery, cardiothoracic surgery, and plastic surgery. As such, there is a need for alternative methods for surgical trainees to gain experience and skill. In an effort to address this problem, the Surgical Skills Curriculum Task Force was created in 2005 by the American College of Surgeons (ACS) and Association of Program Directors in Surgery (APDS). Since that time, surgical simulation has become an integral part of the curriculum in many training programs.[1]

One goal of simulation-based training is to provide trainees with opportunities for skill-acquisition in a safe environment with the expectation that skills attained will transfer to a patient-based operative setting. Surgical simulation has also provided a new way to evaluate trainees. Many training programs use trainee performance on surgical simulation to track individual progress and compare trainees with their peers. Some programs have proficiency-based benchmarks in simulation for their residents before they are allowed to perform certain skills on patients in an operative setting, and most programs have some form of simulation-based remediation for residents that do not meet standards of performance in the operating room.[1]

Surgical simulation traditionally is based on skill-acquisition and standard procedural steps of a surgical procedure are followed. Less common are surgical simulations involving a crisis that occurs during the simulation, where trainees are forced to think quickly and adapt accordingly while performing technical skills. Studies that do involve such crisis simulation have shown better discriminatory ability compared to standard simulation.[2-4] Creation and incorporation of crisis scenario was integrated into surgical simulation and was evaluated between vascular surgery trainees in regard to their relative level of expertise.

Although evaluating trainees based on simulation performance is common,[5-10] there is a paucity of research comparing performance between different groups of trainees for vascular surgery. The specialty of vascular surgery provides a unique opportunity to study two groups of trainees who undergo distinct training pathways, both of which can result in board certification in vascular surgery. The traditional 5+2 paradigm requires completion of a 5-year general surgery residency followed by a 2-year vascular surgery fellowship. The newer, integrated 0+5 vascular surgery residency involves completion of a 5-year program that incorporates general surgery training during the early years, with some programs offering or requiring completion of 1 or 2 research years. Trainees who complete the 5+2 pathway are eligible for board certification in both general surgery and vascular surgery. Those who complete the 0+5 pathway are only eligible for board certification in vascular surgery. As such, both paradigms are capable of producing board-certified vascular surgeons, and surgical simulation provides a unique way to compare the two training paradigms. In this study, crisis scenarios were created and integrated into surgical simulations completed by senior-level vascular surgery trainees from two training paradigms, and performance was assessed.

METHODS

At the Midwestern Vascular Surgical Society (MVSS) annual meeting, open and endovascular simulation stations had been used to evaluate vascular surgery trainees for several years prior to our study. We incorporated crisis scenarios in combination with simulation "hands-on" centers to enhance the learning experience for the vascular trainees. Vascular surgeons that comprise the Midwestern Vascular Surgical Society (MVSS) education simulation course committee, other vascular surgeons who were members of the MVSS, or previous members of the simulation committee were convened. All six surgeons were affiliated with academic institutions which have vascular surgery training programs and were all trained via the traditional 5+2 training paradigm and all had greater than five years of experience in practice. A modified Delphi technique was utilized to gain consensus with the goal of creating typical crisis scenarios encountered by vascular surgeons. The Modified Delphi protocol is a recognized strategy for consensus building amongst experts and based on the current literature a panel size of 5 to 11 members was found most beneficial.[11] This technique has been used widely in various specialties including biomedical disciplines and surgery.[12,13] A Modified-Delphi process was used to identify specific condition−outcome pairs where the panel felt there was a link between quality of care and a completion of the crisis scenario. The feasibility of calculating these indicators was determined by applying them to a routinely collected data set. Members of the panel were asked to choose, rank, and evaluate their most important factors and steps deemed necessary to complete the procedure and crisis scenario. A performance assess tool was subsequently created combining the Modified-Delphi process results into a tool containing a Likert scale with three anchoring metrics (scores of 1, 3, and 5).

These crisis simulations were focused on situational scenarios which are commonly encountered on the oral boards. This study was not evaluating open versus endovascular for aortic procedures but was rather focused on creating accurate crisis scenarios which could be employed to trainees in preparation for oral boards. Based on the simulators available as well as the limitations of the current simulators for open surgery, we felt that the two crisis scenarios chosen would offer the most educational experience for trainees and their future oral board preparation.

The first simulation developed was a carotid endarterectomy (CEA) that involved a crisis in which the patient suffered an on-table postoperative stroke secondary to retained plaque distal to the patch, causing occlusion of the carotid artery. The trainee was expected to evaluate the patient, identify the stroke, identify the occlusion using imaging, and make the decision to re-operate. A thrombectomy in the correct sequential steps was to be performed and the retained plaque identified. Finally, the carotid patch needed to be repaired.

The second simulation was an endovascular aneurysm repair (EVAR) of a ruptured abdominal aortic aneurysm (rAAA). The trainee was expected to size and deploy an endovascular aortic stent graft on the simulator during a rAAA. The scenario required placement of an aortic occlusion balloon in the correct position. During the simulation, the patient became hypotensive and the trainee was required to identify the cause, which was deflation of the occlusion balloon. At the end of the case there was a type 1 endoleak that required re-ballooning of the proximal seal zone.

Protocols and data collection sheets were developed for the two simulations: 1) Management of open carotid endarterectomy (CEA) with a postoperative stroke and 2) management of a ruptured abdominal aortic aneurysm (rAAA) via endovascular aneurysm repair (EVAR). A total of 19 procedural steps for the CEA simulation and 27 procedural steps for the EVAR simulation were created by the panel. In order to evaluate trainee performance at each step, a performance assessment tool was created using the modified Delphi method. This tool contained a Likert scale with three anchoring metrics (scores of 1, 3, and 5) that described expected performance for that score (Appendix A). Simulations stations were set-up at the MVSS annual meeting in the years of 2018 and 2019 and completed by senior-level vascular trainees as a requirement for those who were registered for the Mock Oral examination.

The simulations were completed by a total of 40 vascular surgery trainees over the two years that data was collected. The trainees were all senior-level within their respective training paradigm, meaning that they were in their final year of training. There were 13 residents who were in their 5th and final year of the integrated 0+5 vascular surgery training paradigm at their program. There were 27 fellows who had completed general surgery residency and were in their 2nd and final year of vascular surgery fellowship training. The trainees came from various academic institutions throughout the Midwest that are affiliated with the MVSS.

Simulations were observed and scored by practicing, board-certified vascular surgeons who attended the conference and are active members of the MVSS. All proctors in attendance at the conference were trained via the traditional 5+2 training paradigm and have a wide range of years spent in practice. All were affiliated with academic institutions that have vascular surgery training programs. One day prior to the simulation, all proctors were trained on the specific simulation cases to be performed, including expected answers and outcomes. The performance assessment tool was reviewed in detail regarding to each step in the expected response for the examinees, following the protocols developed by the panel.

The scenarios were completed by the trainees with individual scores assigned to each step ranging from one (lowest) to five (highest). During data collection, missing values due to proctor error were imputed with the mode for that participant's results. A total score was summed and divided by the total possible to produce a total score percentage. Scores were also grouped into four sub-categories that included: 1) Situation Recognition and Decision-making Skills, 2) Procedural Flow, 3) Technical Skills, and 4) Interpretation of Imaging. Scores for the two groups of trainees, 0+5 integrated residents and 5+2 fellows, were compared. Scores for individual steps in the simulations were also compared between groups. Statistical analysis was performed using Student's t-test.

RESULTS

Forty trainees underwent assessment (13 residents and 27 fellows) in CEA simulation, and thirty-eight trainees (13 residents and 25 fellows) in EVAR simulation. In the CEA crisis simulation, group-wise comparisons revealed no significant difference in performance between residents and fellows in total score or sub-category analysis, with an average total score percentage of 83% for both groups (Table 1). In the EVAR crisis simulation, residents scored higher than fellows in total score (86.27% vs. 77.64%, $p = 0.04$) as well as in categories of Procedural

TABLE 1. Simulation Scores for Each Crisis Simulation Station

Total Score (%)	EVAR Crisis Simulation			CEA Crisis Simulation		
	Fellows 77.64	Residents 86.27	p-value 0.04	Fellows 82.73	Residents 82.67	p -value 1.00
Situation Recognition and Decision-making Skills (%)	85.56	92.05	0.19	85.19	85.38	0.97
Procedural Flow (%)	73.66	83.76	0.03	79.26	80.77	0.77
Technical Skills (%)	71.23	79.23	0.15	84.17	82.50	0.72
Interpretation of Imaging (%)	82.10	91.28	0.02	84.20	85.13	0.87

TABLE 2. Evaluation of Individual Simulator Steps for EVAR Crisis Station

Procedural Flow			
Simulation step	**Fellows**	**Residents**	**p-value**
Removal/deflation of the aortic occlusion balloon with placement of the balloon up the ipsilateral side through the graft	3.04	4.0	0.03
Removal of the occlusion balloon and completion of the ipsilateral side with an extension if needed	3.70	4.77	<0.0001
Use of assistant	3.48	4.23	0.04
Interpretation of Imaging			
Simulation step	Fellows	Residents	p-value
Description of appropriate graft selection including sizes	4.07	4.69	0.03
Completion angiogram	4.22	4.77	0.02
Situation Recognition and Decision-making Skills			
Simulation step	Fellows	Residents	p-value
Crisis management: BP drops during the case. Needs to recognize that hypotension is secondary to occlusion balloon deflation and that patient is bleeding again.	3.67	4.46	0.02

Flow (83.76% vs. 73.66%, p = 0.03), and Interpretation and Use of Imaging (91.28% vs. 82.10%, p = 0.02).

When comparing individual procedural steps for the EVAR crisis simulation (Table 2), residents were found to significantly out-perform fellows in the following steps: “Removal/deflation of the aortic occlusion balloon with placement of the balloon up the ipsilateral side through the graft” (4.0 vs. 3.04, p = 0.03), “Removal of the occlusion balloon and completion of the ipsilateral side with an extension if needed” (4.77 vs. 3.70, p < 0.0001), “Use of assistant” (4.23 vs. 3.48, p = 0.04), “Description of appropriate graft selection including sizes” (4.69 vs. 4.07, p = 0.03), “Completion angiogram” (4.77 vs. 4.22, p = 0.02), and “Hypotension secondary to balloon deflation” (3.67 vs. 4.46, p= 0.02) . Of note, no differences were observed when evaluating the procedural steps in the CEA crisis simulation.

DISCUSSION

This study demonstrates the feasibility of incorporating crisis management into surgical simulation for vascular surgery. Crisis simulation was successfully completed and provided results that discriminated between two groups of vascular surgery trainees. Integrated 0+5 residents performed equally as well as 5+2 fellows on an open carotid endarterectomy (CEA) crisis simulation and performed better than fellows on an endovascular aortic repair (EVAR) for ruptured abdominal aortic aneurysm (rAAA) crisis simulation.

Research on expert performance describes a period of deliberate practice with a duration of 10,000 hours or approximately 10 years.[14] Given the current climate of surgical education, trainees have relatively reduced the deliberate practice opportunity, which may delay expert skill acquisition.[15] As such, surgical simulation has been targeted as a way to address this problem. In 2005, the American College of Surgeons (ACS) and Association of Program Directors in Surgery (APDS) created the Surgical Skills Curriculum Task Force with the goal of designing a national curriculum that would improve the training of surgical residents with a new emphasis on simulation use. In 2006, the ACS introduced the ACS-Accredited Education Institutes (ACS-AEIs) program, which formed a Consortium of institutes that could help surgical trainees meet core competencies required by their programs. As of 2017, 81 simulation centers had joined the Consortium, and 94% of general surgery programs used ACS-AEIs as part of training for residents.[1] There has also been particular emphasis on the use of open simulation in recent years as open cases continue to be replaced by less-invasive procedures and resident training in open cases becomes scarcer.[15,16] Several studies have shown that simulation practice improves individual performance and operative skill in a simulation setting.[6,7,17] Improved simulation performance is especially marked when surgical skills required for the simulation are taught in a standardized method, as opposed to the way residents commonly learn in the operating room via various techniques dependent on attending surgeon preference.[18] The association between simulation training and improved performance in a real operative setting has been more difficult to elucidate given a lack of objective, measurable markers of improvement.[5] However, systematic review on this topic has demonstrated improved performance, using various metrics, for surgical trainees who practiced via simulation compared with those who did not.[19]

Performance on surgical simulation has been measured in various ways. One common assessment is the objective structured assessment of technical skill (OSATS) global rating scale which gives a score ranging from 8 to 40, with 24 representing a competent performance.[20] As in the present study, many performance evaluations incorporate the use of a Likert scale developed by consensus using the modified Delphi method. Trainees are observed by a practicing surgeon and rated with a score from 1 to 5 at each crucial step of the simulation or in various categories of performance. This type of evaluation generally also includes a global assessment score from 1 to 5 that rates the overall performance and quality of the final product.[17,21,22] A consensus amongst experts is an accepted strategy to guide patient management in areas of clinical practice where there is a relative lack of high-quality evidence and has been used in other surgical fields for practice improvement.[12] It can be used to decide the best steps and methods for treating procedural and surgical problems. The modified Delphi method allows for processes to be broken into individual steps with varying importance for each step. The current literature suggests that a panel size of 5 to 11 members was most beneficial across all consensus methods.[11]

This project is unique in its design, specifically regarding the utilization of surgical simulation with incorporated crisis scenarios to compare groups of trainees from different training paradigms. The specialty of vascular surgery, which currently has two different training paradigms, provides an excellent opportunity to use surgical simulation as a discriminator of performance between groups. Since the integrated 0+5 residency was introduced in vascular surgery in 2009, there has been debate in the field as to whether integrated residency programs are capable of producing the same quality of vascular surgeon as the traditional fellowship training paradigm.[23-26] This study contributes to the ongoing discussion. Integrated 0+5 residents performed equally as well as 5+2 fellows on a carotid endarterectomy (CEA) crisis simulation and performed better than fellows on endovascular aortic repair (EVAR) for ruptured abdominal aortic aneurysm (rAAA) crisis simulation. The categories evaluated in which residents out-performed fellows included the overall total score, the procedural flow, and the interpretation of imaging. Reasons why residents performed better than fellows on an endovascular crisis simulation are uncertain but may include earlier exposure to vascular surgery during training, increased endovascular simulation experience, increased vascular surgery case numbers, and overall differences in the educational paradigms. Previous simulation experience among the trainees in this study is unknown. The study was not specifically designed to compare open versus endovascular skills, but rather to compare performance on two independent crisis scenarios to prepare the trainees for oral boards. Further studies are needed to evaluate these aspects. In analyzing the individual steps in which residents out-performed fellows, the endovascular therapy skillset is highlighted. For example "description of appropriate graft selection including sizes" and "removal of the occlusion balloon and completion of the ipsilateral side with an extension if needed" are steps that require a high level of knowledge and familiarity with endovascular therapy.

Crisis simulation is common in the training of surgical teams and often involves a patient that becomes hemodynamically unstable for various reasons during an operation.[27-29] Management generally involves a team effort and following steps of a standard protocol. However, the incorporation of a crisis in surgical simulation with an etiology and solution specific to the case at hand is less common. Studies that do involve such crisis simulation have shown improved performance and differentiation over standard simulation, and have demonstrated the importance of operative experience, stress levels, and coping strategies in the operative setting.[2,4] A previous study using simulated carotid endarterectomy compared technical and non-technical performance of different level trainees (junior and senior) with attending surgeons. The simulation was first carried out without crisis, and then carried out with incorporation of crisis such as stroke or myocardial infarction. Whereas most senior level trainees displayed both technical and non-technical competence in the simulation without crisis, introduction of crisis resulted in deterioration of overall scores and lack of competence in the majority of senior level trainees.[4] Successful completion of a crisis simulation, as such, requires extensive knowledge of the details of the case. It also requires sound judgment and quick decision-making on the part of the operator to demonstrate the ability to overcome stressors. Adequate skills and experience are often only found in highly competent senior-level trainees and attending surgeons, emphasizing the utility of crisis implementation in surgical simulation, especially when comparing groups.

Our study is limited by resident and fellow participant sample size; thus, results may differ by inclusion of vascular surgery trainees from other programs in a larger national multi-institutional study. Previous simulation experience among the trainees in this study is unknown which may add bias to the conclusions, but the novel incorporation of crisis scenarios and simulation is unlikely to have been encountered by the candidates prior to completing the simulators. The creation of an open rAAA repair simulator to compare with the endovascular rAAA repair simulation may in the future provide better distinction between the groups regarding open and endovascular skills, but was not the focus of this study, rather the feasibility of combining a crisis scenario with hands-on simulation. Furthermore, the feasibility of this approach is limited to this analysis and will need to be further developed to evaluate whether a simulated setting can effectively transfer to patients in the operating room.

CONCLUSIONS

The creation of a crisis scenario is feasible for vascular surgery trainees and can be implemented in conjunction with hands-on open and endovascular simulators. Crisis simulation may provide additional discriminatory detail when comparing performance of trainees. In this study, 0+5 integrated vascular surgery residents performed as well as 5+2 vascular surgery fellows on a CEA crisis simulation, and significantly out-performed 5+2 fellows on an endovascular rAAA crisis simulation. Further studies are needed to evaluate multiple crisis scenarios within vascular surgery as well as elucidate factors for differences in performance among traditional vascular fellows compared to vascular residents. Simulator-based crisis stations may have the potential to be an important component in the future training of vascular surgeons as well as assessing different training paradigms within vascular surgery.

AUTHOR CONTRIBUTIONS

TRV and LSK conceived and designed the study; LSK, JB, CJG, MAM, FJC, and TRV were the expert panel; JPT collected the data; TRV and PS analyzed the data statistically and interpreted the results; JPT, LSK, JB, CJG, MAM, FJC, and TRV drafted and revised the manuscript.

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