Editors' Choice

Simulation training streamlines the real-life performance in endovascular repair of ruptured abdominal aortic aneurysms

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ABSTRACT

Objective: Difficulties in distributing endovascular experience among all operating room (OR) personnel prevented full-scale use of endovascular aneurysm repair (EVAR) in emergencies. To streamline the procedure of EVAR for ruptured aneurysm (rEVAR) and to provide this method even to unstable patients, we initiated regular simulation training sessions.

Methods: This is an observational study of 29 simulation sessions performed between January 2015 and December 2017. We analyzed the development of time from OR door to aortic balloon occlusion during simulations and OR door to needle times in real-life rEVARs as well as the outcome of the 185 ruptured abdominal aortic aneurysm (rAAA) patients who arrived at the university hospital between January 2013 and December 2017. A questionnaire was sent for simulation attendants before and after the simulation session.

Results: In the first simulations, the door to occlusion time was 20 to 35 minutes. After adding a hemodynamic collapse to the simulation protocol, the time decreased to 10 to 13 minutes in the 10 recent simulations, including a 5-minute cardiopulmonary resuscitation ($P = .01$). The electronic questionnaire performed for attendees before and after the simulation session showed significant improvement in both confidence and knowledge of the OR staff regarding rEVAR procedure. In the real-life rEVARs, 75 of the 185 patients with rAAAs underwent EVAR. Among rEVAR patients, the median OR door to needle time was 65 minutes before and 16 minutes after the onset of simulations ($P = .000$). The overall 30-day mortality among all rAAA patients was 44.8% and 30.6% accordingly ($P = .046$). When patients who were turned down from the emergency surgery were excluded, the 30-day operative mortality was 39.2% and 25.1% during the periods, respectively ($P = .051$). The 30-day mortality was 16.2% after rEVAR and 40.6% after open surgery ($P = .001$).

Conclusions: Simulation training for rEVAR significantly improves the treatment process in real-life patients and may enhance the outcome of rAAA patients. (J Vasc Surg 2019;69:1758-65.)

Keywords: Ruptured abdominal aortic aneurysm; Endovascular aneurysm repair; Simulation; Mortality

Open surgery used to be the only treatment option for patients with a ruptured abdominal aortic aneurysm (rAAA). Treatment protocols in most high-volume centers were streamlined, and effective emergency department computed tomography (CT) diagnostics, patient transfer to the operating room (OR), immediate general anesthesia, laparotomy, and aortic clamping were achieved. At present, most elective abdominal aortic aneurysm (AAA) patients are treated with endovascular aneurysm repair (EVAR) and a growing number of rAAA patients with EVAR of the ruptured aneurysm (rEVAR).[1,2] Although randomized trials have failed to prove lower mortality after endovascular treatment of rAAA, an increasing number of experts acknowledge the benefits of endovascular repair for anatomically suitable patients.[3-6] Plenty of knowledge, skill, and training of a wide range of professionals is required for rEVAR; these include vascular surgeons, anesthesiologists, scrub nurses, anesthesia nurses, and radiographers. Each occupational group should be familiar with the endovascular process and trained to prepare these critically ill patients for EVAR in a hybrid OR as quickly as they perform open surgical cases.

When rEVARs were initiated in our institution in 2009, the preoperative process for an endovascular procedure was much more complicated and slower to perform than that of open surgery for several reasons. First of all, although a dedicated hybrid OR has existed since 2001 in our hospital, only a limited proportion of the OR personnel were familiar with endovascular equipment. A specialized group frequented the elective hybrid procedures, and the expertise was concentrated. The majority of the staff was less familiar with wires, catheters, and

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balloons. Consequently, the great challenge in the development of emergency endovascular aortic activity was to train 120 scrub nurses, 100 anesthesia nurses, 23 vascular surgeons, 40 anesthesiologists, and 40 radiographers.

Simulation-based learning has proved to be an effective and safe means to learn and to practice skills needed in the acute care setting.[7-10] It has been used and studied in different contexts including crisis resource management and team training but also in procedural skills training, especially in endovascular surgery.[11-14] To improve the preparation process of an rEVAR patient and to shorten the "OR door to occlusion balloon" time, we started multidisciplinary simulation sessions in a real hybrid OR environment in 2015. The aims of this report are to describe the simulation intervention targeting rapid initial management of rAAA patients from door to placement of the occlusion balloon (endoclamping); to analyze our experience and progress in the simulation sessions as well as the influence of these on the self-confidence of the OR staff in the care of rEVAR patients; and to evaluate the possible changes in the treatment of real rAAA patients after this topic was acknowledged, training material was distributed to all personnel, and first simulations were performed.

ARTICLE HIGHLIGHTS

- **Type of Research:** Prospective and retrospective cohort study
- **Key Findings:** During 29 simulation sessions of endovascular repair of ruptured abdominal aortic aneurysm, time from entry to operating room to aortic balloon occlusion decreased from 25 to 30 minutes to 10 to 13 minutes after adding a hemodynamic collapse and 5-minute cardiopulmonary resuscitation ($P = .01$). As a result of simulation training, both time from entry to gaining percutaneous access and 30-day mortality decreased significantly in patients with endovascular repair of ruptured abdominal aortic aneurysm.
- **Take Home Message:** Simulation training of endovascular treatment of ruptured abdominal aortic aneurysms will shorten time from entry to gaining percutaneous access, and it will also decrease 30-day mortality.

METHODS

Simulation sessions. Multidisciplinary simulation sessions have been arranged once a month since August 2015. The simulations take place on Monday mornings before elective surgery in the hybrid suite where all the real-life rEVAR procedures are performed as well. One simulation session requires about 1 hour of OR time. In addition to monthly simulations, special simulation days have been organized when OR capacity has been decreased because of a national congress of the physicians. The room is equipped with a Siemens Artis zeego interventional angiography system (Siemens Healthcare, Hoffman Estates, Ill). Altogether, 9 or 10 persons participate in each session: 2 scrub nurses, 2 anesthesia nurses, 1 radiology nurse, 1 or 2 anesthesiologists, and 2 vascular surgeons. All participants change between sessions, except constant coaches leading the briefing sessions, monitoring and filming, and giving feedback during debriefing.

A week before the actual session, all participants receive electronic material on the simulation. Furthermore, they fill out an electronic questionnaire with six items on a 7-point Likert scale, where 1 represented "not at all" and 7 "I totally agree." All participants repeat the questionnaire after the simulation. The simulation session includes three parts. All sessions start with a briefing, in which participants are informed of the course of the simulation and receive their duty cards. There are six different types of duty cards (Table I), one for each player in the team. During briefing, the duties are reviewed with each participant. The actual simulation starts when the vascular surgeon receives a telephone call informing about the arrival of an rAAA patient in the CT room at the emergency department. At this stage, the patient is in the CT room with the nurses and anesthesiologist of the emergency department, where a hemodynamic collapse takes place. The emergency department staff takes care of the first steps of hypotensive hemostasis and transportation to the OR. The simulation ends when the occlusion balloon is in place. The "patient" arrives to the OR 5 to 10 minutes after the call. The simulations carefully mimic the real-life procedure: all equipment needed to insert the occlusion balloon is collected from the cart situated outside the hybrid OR (Fig 1). The simulation protocol includes a hemodynamic collapse requiring cardiopulmonary resuscitation (CPR). Finally, during debriefing, a video recording of the simulation session is shown, and the participants are free to relate their views on the rehearsal. The coaches also encourage the group to suggest improvements related to the simulations and the treatment process of real-life rEVARs. The participants are ensured that the discussions in the debriefing remain confidential. After each debriefing, the coaches meet briefly, evaluate the session, and reflect on possible future improvements. As a result of these reflective discussions, the briefing process has been constantly modified after the first five or six simulation sessions. The electronic questionnaire that was filled in before the simulation is repeated after the simulation session.

A patient simulator (Resusci Anne Simulator; Laerdal Medical, Wappingers Falls, NY) is used. The simulator is anatomically realistic with functionalities for airway management, live defibrillation and synchronized electrocardiography, blood pressure and heart rate monitoring, voice, lung and heart sounds, and CPR feedback.

Table I. Duty cards

	Before patient's arrival	After patient's arrival
Anesthesia nurse	Order emergency blood transfusion (rEVAR order)	Set oxygen mask, ECG, NIBP, Spo_2, and defibrillator electrodes
	Put on X-ray gown	Place patient's arms safely to the tracks, secure the left arm tightly by patient's side
	Prepare the medication and ventilator needed for general anesthesia induction	Take blood samples (blood gas analysis, ACT, blood group)
		Connect the IV line to the patient
		Administer IV antibiotics
		Administer heparin if ordered by the surgeon
Scrub nurse	Put X-ray gown on	Cover the patient's genitals with a sterile cloth
	Wash hands, put operation gown on	Cover the patient with sterile cloths, leaving the groin visible (allows possible cut)
	Cover the ultrasound machine with a sterile shield (bulb and keyboard), secure the bulb on the keyboard with a towel clip	Prioritize covering the patient over preparing the instruments
	Begin arranging the instruments on the table	
	Rinse the instruments needed for angiography with sterile NaCl 0.9%	
	Fill a 50-mL syringe with 20 mL NaCl and 20 mL contrast medium	
Circulating nurse	Inform the radiology nurse of the rEVAR patient expected to the OR	Make sure that the patient is comfortably placed on the table and secured with a safety belt
	Put on X-ray gown	Diathermy plate not needed
	Ask the radiology nurse to assist with opening the sterile instrument packages	Place urinary catheter after the barrage balloon is filled and the patient is hemodynamically stable
Radiology nurse	Put X-ray gown on	
	Feed the patient's name in the zeego files	
	If needed, feed the patient in as John or Jane Doe	
	Help the circulating nurse to open the sterile instrument packages	
	Check regularly whether the scrub nurse needs help in any way	
Anesthesiologist	Put X-ray gown on	Perform the WHO checklist
	Make sure that rEVAR blood transfusion order has been made	Insert large peripheral cannulas for rapid transfusions (consider CVC only for patients having poor vascular status)
		Insert arterial cannula to the patient's right arm
		Check that defibrillator electrodes have been placed
		Sedate the patient: the aim is conscious, co-operative, and painless patient having systolic arterial pressure 70-90 mm Hg
		Optimize hemodynamics with volume replacement and norepinephrine infusion
		Communicate regularly with the patient and keep the surgeon informed
		Be prepared to induce general anesthesia in case of hemodynamic collapse
Surgeon	Put X-ray gown on	Inject local anesthetic to the patient's left groin
	Negotiate the patient's suitability for rEVAR with the anesthesiologist	Insert the instruments
	Perform measurements for the stent prosthesis using the CT scans	Fill the barrage balloon

Table I. Continued.

	Before patient's arrival	After patient's arrival
	Choose the potential prosthesis and control the availability	Communicate regularly with the anesthesia team about the patient's condition
	Wash hands and put the operation gown on	
	Assist the scrub nurse in preparing the instruments	

ACT, Activated clotting time; *CT,* computed tomography; *CVC,* central vein catheter; *ECG,* electrocardiography; *IV,* intravenous; *NIBP,* noninvasive blood pressure; *OR,* operating room; *rEVAR,* endovascular repair of ruptured abdominal aortic aneurysm; *Spo_2,* oxygen saturation as measured by pulse oximetry; *WHO,* World Health Organization.

Fig 1. Simulation session situated in the hybrid suite.

In each simulation session, the time between the arrival of the patient to the OR and the placement of the occlusion balloon is recorded (door to occlusion time).

Performance in real life. In addition to evaluating the team's performance during the simulation, we analyzed the changes in the treatment of real-life rAAA patients. All true CT-verified rAAA patients treated endovascularly between January 2013 and December 2017 in Helsinki University Hospital were reviewed retrospectively from hospital and patient records. The time between the arrival of the patient to the OR and the start of the procedure (the patient is ready for puncture) was recorded. Furthermore, we evaluated the treatment of all rAAA patients in our hospital during the 4-year period: turndown rate, proportions of open surgery and EVAR, hemodynamic stability (as assessed by the surgeon performing the rEVAR procedure), and 30-day mortality.

The Ethical Committee of Helsinki University Hospital has approved the study (No. 399/13/03/02/2015). During the simulation sessions, no real patients were treated, so no informed consent was applicable. In the analysis of the real-life patients treated for rAAA during 2013 to 2017, no informed consent was asked from the patients because of the retrospective nature of the evaluation.

RESULTS

Simulations. Since August 2015, there were 29 simulation sessions arranged by December 2017. In the first nine simulations, the door to occlusion time was 20 to 35 minutes. After pointing out to the personnel that the patient needed urgent treatment by adding a hemodynamic collapse to the simulation protocol, the time decreased to 10 to 13 minutes in the 20 recent simulations, including a 5-minute CPR ($P = .01$).

In the electronic questionnaire with a 7-point Likert scale on confidence and knowledge of the OR staff regarding treatment of rEVAR patients before and after the simulations, there was improvement in all except one of the questions. The best improvement was seen in the question "I feel confident of my skills during rEVAR," for which the median answer changed from "uncertain" before to "confident" after the simulations. In only one question did the answer remain at the same level; to the question "I have already enough experience of rEVAR cases in real life," the median answer both before and after was 2. The results of the questionnaire are reported in Table II.

Real-life rEVARs. During the 4-year period from 2013 to 2017, there were 185 rAAA patients who arrived to the emergency department of our hospital or were diagnosed in the hospital. Fifteen (8.1%) patients were turned down for the emergency surgery. Of these 185 patients, 87 presented during January 2013 to August 2015, before the initiation of simulation training, and 98 patients presented thereafter. Turndown rates before and after simulation initiation were 9.2% (n = 8) and 7.1% (n = 7; NS). Of the patients who underwent an emergency operation, 22.8% (18/79) underwent rEVAR during the first period and 61.5% (56/91) during the second period ($P = .000$). Among rEVAR patients, the median time from arrival of the patient to the OR to the start of the procedure was 65 minutes before simulations and 16 minutes after the onset of simulations ($P = .000$; Fig 2).

The overall 30-day mortality among rAAA patients was 44.8% (39/87) during the first period and 30.6% (30/98) during the second period ($P = .046$). When patients

Table II. The electronic questionnaire before and after the simulation training (183 answers)

	Before		After		
	Median	IQR	Median	IQR	*P*
I feel confident of my skills	3	2-5	6	5-6	.000
I master my role	4	2-6	6	5-6	.000
I know my duties during an rEVAR procedure	4	3-6	6	5-7	.000
I manage well the preparation of an rEVAR procedure	4	2-5	6	5-7	.000
I am aware of the other professionals' roles	4	3-5	5	4-6	.101
I already have enough experience of rEVAR procedures	2	1-3	3	2-4	.103

IQR, Interquartile range; *rEVAR*, endovascular repair of ruptured abdominal aortic aneurysm.

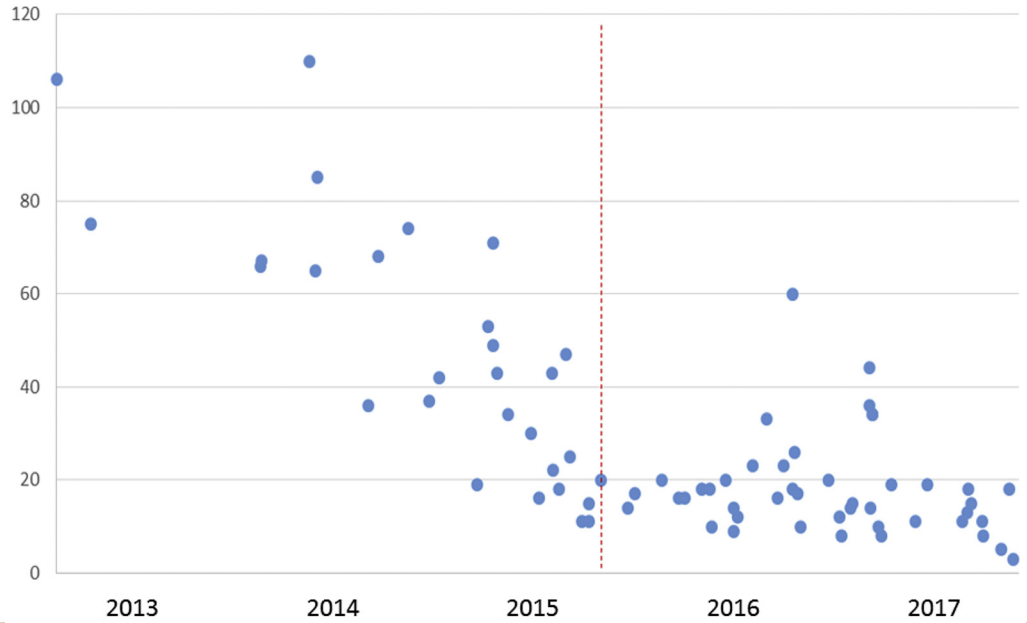

Fig 2. The time between arrival of the patient to the operating room (OR) and the start of the procedure in relation to the onset of simulation training (*interrupted red line*) in real-life patients who underwent endovascular repair of ruptured abdominal aortic aneurysm (rEVAR).

who were turned down for the emergency surgery were excluded, the 30-day operative mortality was 39.2% and 25.2% during the periods, respectively ($P = .051$). The 30-day mortality was 16.2% after rEVAR and 40.6% after open surgery ($P = .001$).

DISCUSSION

Although EVAR had developed to be the first-line treatment of AAA and experienced teams familiar with the procedure existed in our hospital, it was impossible to summon the whole team for all emergency cases. The preparation times with less experienced personnel were far from optimal. To improve the performance, knowledge, and confidence of the OR personnel to achieve faster preparation of the patient and balloon occlusion of the aorta, we introduced regular simulation sessions. This is one of the first papers to show that simulation may have immediate positive consequences and an impact on real patient care. Simulation training has led not only to improvements in the simulation sessions, like faster aortic occlusion, but also to a significantly improved self-confidence of the OR personnel as analyzed with a repeated questionnaire. During the same period, we have seen that the treatment of real-life patients has improved, measured as a decrease in the time from OR door to groin puncture and maybe as better survival of the patients. A greater proportion of patients have been treated with EVAR since simulations were started. This is at least partly due to increased confidence and trust in the procedure among all participants involved in the care of patients. The increase of the EVAR proportion has in turn led to decreased overall mortality of the rAAA patients in our hospital.

Simulation training in emergency situations has been extensively studied and shown to improve the performance of multiprofessional teams in acute care settings.[8,9,15,16] Trauma resuscitation is similar in many

ways, such as compromised hemodynamics and a need for prompt performance, but trauma training must take into consideration a wider variety of situations. In these situations, every team member acts according to his or her predefined role and every participant knows what to expect from the other members of these ad hoc teams.[8,9,16,17] Taking care of a bleeding patient is exceptionally challenging because the obvious leader of the team, the surgeon, is preoccupied with controlling the bleeding. The need for explicit training of nontechnical skills (communication, leadership, vigilance) is evident. In our experience, only one in four patients treated with EVAR in the first period was graded "hemodynamically unstable," and this proportion increased to 52% during the year 2017; in open surgery patients, the proportion was 44% during the first study period and 32% in 2017. The EVAR simulations have made this progression possible as the protocol has been streamlined and become extremely rapid, the shortest time from the door of the OR to the puncture being 3 minutes during 2017. A well-trained system may offer treatment to old and morbid patients who may not have received treatment earlier. Although a big proportion of rAAA patients are hemodynamically stable and do not require emergency occlusion balloon, the main focus of our simulation training is to manage rapid performance in unstable patients. In the end, every rAAA patient is at risk of sudden bleeding and hemodynamic collapse.

Simulation training for EVAR has also been previously studied. In 2013, Desender et al[18] described patient-specific rehearsal before EVAR, and the results were published recently.[19,20] They practiced elective EVAR with a three-dimensional model of the patient's relevant anatomy created on the basis of CT. A virtual reality simulator was used. They found a significantly better performance during the actual procedure in the group that had had training beforehand compared with the nontrained group.[19,20] Saratzis et al[21] recently reported shorter simulator EVAR performance times for trainees after more than four training sessions. The previously mentioned research groups trained in the procedure itself. However, our surgeons are familiar with EVAR. The same surgeons are responsible for the elective EVARs, and the EVAR training itself takes place elsewhere. For this reason, we have decided to focus on activities of the whole team and especially on the delay before hemodynamic control by endoclamping could be reached. In the end, this is the period with hypotension, diminished perfusion, and a growing retroperitoneal hematoma potentially increasing the risk of abdominal compartment syndrome, the strongest predictor of poor outcome after rEVAR.[22-24] We do believe that simulation training and faster hemodynamic control may lead to decreased incidence of abdominal compartment syndrome and mortality.

When the simulation sessions were started, it could take 32 minutes to get the patient ready for the occlusion balloon. Although we tried to emphasize in the briefing session before the simulation that the patient should be prepared for groin puncture as soon as possible, it did not happen as fast as we wanted. When analyzing the videos, we noticed that there seemed to be no rush in the actions taken as the "patient" was more or less stable. To prompt the team into action, we lowered the blood pressure of the simulation patient and initiated ventricular fibrillation demanding CPR in every session. Second, we started to point out in the briefing session that any action made should support occlusion balloon insertion. After these changes, the time from door to balloon decreased significantly and stabilized in the simulations to 11 to 13 minutes, including a 5-minute CPR period. The continuous evaluation of the simulation protocol is beneficial as such reflection leads to continuous learning of the coaches of the simulation and thereafter improved performance.[17] After all, isolated full-scale simulation sessions are useless; they should strive to achieve predetermined goals using repetitive, focused practice.[8-10,13]

The self-confidence and attitude of the personnel toward rEVAR were assessed with an electronic questionnaire before and after the simulations. The results showed improvement in all categories. Interestingly, self-confidence was reported to be significantly better after the simulations despite the fact that real-life experience was considered insufficient. Because of this lack of experience, some individuals were reluctant to take part in procedures performed in the hybrid suite. Today, an opposite atmosphere prevails, and many are eager to work in the hybrid environment. This may at least partly be due to the fact that a larger proportion of the personnel have had an opportunity to train without risking the life of a real patient.

This study has some important limitations. First, the causality between simulation training and real-life improvements cannot be proved. Simultaneous with the onset of simulations, as shown in Fig 2, an increasing number of rEVAR procedures were performed. This contributed to the skills of the personnel. It is impossible to know whether this improvement has been due to the simulation, improved general skills, or the fact that we paid attention to this issue. As with any clinical study, the mere awareness of an ongoing study may have prompted real-life performance (Hawthorne effect). Second, because of a need to train a large number of individuals, most employees could join the simulation only once. Our future training will focus on repetition. Third, these are the early results of our simulation and therefore a clear learning curve for the instructors has an impact on the result. Furthermore, the number of simulations is limited not only by lack of extra time and resources but also because the simulations were

performed in a real hybrid suite. We think, however, that there is a lot to gain when the training is brought to the environment where actual treatment takes place. To limit the OR hours lost, we chose to perform the simulations at 8 to 9 AM on Mondays, when the elective case could be prepared somewhat simultaneously and minimal time loss was achieved.

CONCLUSIONS

To streamline the rEVAR procedure and to provide this method to unstable patients, we started regular simulation training sessions. The door to needle times in rAAA patients have shortened to a quarter of the time required before the simulations. Not all rAAA patients are suitable for EVAR. Probably the best-case scenario for a patient would be to arrive to a hospital where both skills are available and offered on an experienced level. As all patients are treated in the same OR, those who require open surgery may also benefit from the simulations—the occlusion balloon may be a good alternative to blind clamping in the beginning of the open procedure. Simulation training for rEVAR significantly improves the treatment process in real-life patients and may enhance the outcome of rAAA patients.

AUTHOR CONTRIBUTIONS

Conception and design: PA, LV, LNM, MV
Analysis and interpretation: PA, LV, MV
Data collection: PA, LV, MV
Writing the article: PA, LV, MV
Critical revision of the article: LV, LNM, MV
Final approval of the article: PA, LV, LNM, MV
Statistical analysis: MV
Obtained funding: MV
Overall responsibility: MV

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INVITED COMMENTARY

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The effectiveness of team training in reducing morbidity and mortality in the emergency care of patients with myocardial infarction and stroke has been well established. Indeed, minimizing "door to needle/balloon time" by ongoing team education and use of critical pathways and periodic outcomes analysis is de rigueur in most acute care facilities.

Vascular surgeons have had long experience in the dismal outcomes associated with the open management of ruptured abdominal aortic aneurysm (rAAA). The seminal introduction by Dr Veith and colleagues of using endovascular aneurysm repair (EVAR) in the treatment of rAAA has clearly been shown to dramatically reduce the early morbidity and mortality compared with open surgical repair. This has led several major vascular centers to publish critical pathways to improve outcomes in the use of EVAR in the treatment of rAAA.

In this unique study, Aho and colleagues have attempted to demonstrate the value of team training in improving outcomes in the use of EVAR in the management of rAAA. Team training was conducted monthly using simulation sessions beginning in August 2015 and ending in 2017. They reported significantly better early outcomes with EVAR for rAAA in real-life situations after training than in the preceding 2 years and advocate its adoption at centers involved in rAAA treatment.

The authors acknowledge some of the significant limitations of their study, including the self-reporting of knowledge assessment and improvement before and after attending training and that most employees could participate only once because of the need to train a large number of individuals. It is also not clear that those who attended training were the ones responsible for the improved outcomes seen after training.

Most reports dealing with simulation training to improve outcomes in EVAR have focused on the implanter and technology or technical aspects of performing EVAR, ignoring the equally important nontechnical aspects involved in the multidisciplinary teamwork (communication, cooperation, coordination, leadership) necessary for obtaining excellent outcomes. The authors are to be commended for attempting this one-of-a-kind study focused on improving the nontechnical aspects by simulation training and reporting their early results.

However, while we wait for the carefully vetted, multicentered, prospectively randomized, adequately powered studies for confirmation of the value of team training in the emergency management of rAAA with EVAR, it only makes sense to support and to participate in periodic performance improvement measures that should improve outcomes in the treatment of these gravely ill patients.

The opinions or views expressed in this commentary are those of the author and do not necessarily reflect the opinions or recommendations of the Journal of Vascular or the Society for Vascular Surgery.