Original Article

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Comparison of Simulation Models for Training a Diverse Audience to Perform Resuscitative Endovascular Balloon Occlusion of the Aorta

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Background: The use of resuscitative endovascular balloon occlusion of the aorta (REBOA) for hemorrhagic shock is increasing, but questions remain about who to train and how best to train them. We developed a REBOA training curriculum and performed a pilot course teaching the technique to surgeons and non-surgeons using four different simulation models.

Methods: A REBOA curriculum was created incorporating four simulation models: (1) virtual reality, (2) mannequin, (3) large animal live tissue, and (4) perfused cadaver. The course was taught to $n = 6$ military personnel, including two surgeons, two emergency medicine physicians, and two non-physicians, with no prior REBOA experience. Performance using each model was recorded, and pre and post-course tests and surveys were administered. Simulation models compared capabilities, learner preferences, and cost.

Results: Learners gained confidence and performed REBOA successfully in the perfused cadaver models. Higher-fidelity live tissue and cadaver models were preferred, and learners rated them as the most realistic. Virtual reality and mannequin simulation were rated the least realistic and most dispensable methods of learning. All simulation models required significant resource investment.

Conclusions: A simplified curriculum, focusing only on the skills necessary to perform REBOA, shows promise in providing medical personnel with the confidence and competence to perform the procedure. Higher-fidelity perfused cadaver and live tissue models are preferred by learners, and future work is required to improve the usefulness of mannequin and virtual reality simulation for training. Although REBOA simulation education is expensive, it has the potential to help revolutionize military and civilian prehospital hemorrhage control.

Keywords: *REBOA; Training; Simulation; Virtual Reality; Mannequin; Large Animal Model; Perfused Cadaver*

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INTRODUCTION

Percutaneous resuscitative endovascular balloon occlusion of the aorta (REBOA) is a minimally invasive technique capable of expeditiously stabilizing patients with hemorrhagic shock due to noncompressible hemorrhage originating from vessels and organs deep in the abdomen and pelvis. The basic procedure was described by

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Table 1 Course schedule.

Day 1	
2:00–2:30 pm	Registration, meet, and greet
2:30–2:45 pm	Pre-Test
2:45–3:20 pm	Didactic 1 – Course Overview • Problem of non-compressible hemorrhage • Diagnosis, signs and symptoms, mechanisms of injury • Historical management of non-compressible hemorrhage • Indications and contraindications for REBOA • Intro to REBOA
3:20–3:30 pm	Break
3:30–4:20 pm	Didactic 2 – Basics of REBOA • Equipment and technique • REBOA mannequin demonstration
4:20–4:30 pm	Break
4:30–4:50 pm	Didactic 3 – Management of the REBOA patient • Resuscitation • Monitoring • Balloon manipulations • Immediate complications • Late complications
4:50–5:00 pm	Break
5:00–6:30 pm	Hands-on technique practice • Virtual reality simulations (Mentice) • Mannequin simulators
Day 2	
7:30–8:00 am	Questions and answers
8:00–9:00 am	Hands-on technique practice • Virtual reality simulation (Mentice) • Mannequin simulation
9:00–11:00 am	Live tissue model simulation
11:00–11:30 am	Lunch
11:30 am–1:00 pm	Cadaver model simulation and testing
1:00–1:15 pm	Break
1:15–1:45 pm	Feedback
1:45–2:00 pm	Post-test, end of course survey

Hughes more than half a century ago [1], but only recently have improvements in technology merged with advances in training to allow the increasing use of REBOA to control hemorrhagic shock in trauma units throughout the world [2,3]. Because the equipment required to perform REBOA is extremely portable, the potential exists to use the technique as a temporizing measure in austere prehospital environments, and case reports describing such uses in both civilian and military populations are emerging [4,5].

Although the knowledge and skills to perform REBOA are relatively simple and are considered to be basic fundamentals for surgical and interventional specialists that frequently perform catheter-based procedures, these basic endovascular skills are often lacking in first-line trauma and general surgical providers that were not trained during the endovascular era. Civilian and military courses for acquiring the basic endovascular skills needed to perform REBOA are proliferating, but teaching and testing methods differ, and the majority of these courses primarily target surgeons [6,7]. Furthermore, course content detailing and performing more complex endovascular therapies, such as iliac artery embolization, may not be required if the ultimate training goal is to educate front-line health-care providers, who are closest to the point of injury, how to perform fluoroscopy-free REBOA. With teaching model costs often exceeding tens of thousands of dollars, comparisons between simulation tools are warranted to maximize resource utilization.

With these issues in mind, the goal of this pilot study was to develop a course capable of training a diverse group of learners to confidently and competently perform fluoroscopy-free REBOA. To help determine the best teaching and simulation strategies suitable for both surgeons and non-surgeons, we created a basic curriculum with associated evaluation tools and then administered the pilot course to a group of military medical personnel. Learner performance, simulation preferences, and costs were compared between virtual reality, mannequin, live tissue, and perfused cadaver simulation models to help guide optimal teaching methods and determine rational investment for future educational efforts.

METHODS

The study was approved by the Institutional Review Board and Institutional Animal Care and Use Committee at the University of Nebraska Medical Center (UNMC). Additional human subject and animal model research approval was also obtained through the Department of Defense to study n = 6 military personnel enrolled in a two-day pilot endovascular skills for trauma course incorporating multiple endovascular surgery simulation models, including a swine model of hemorrhagic shock (Table 1). This work built upon prior work involving the research groups in San Antonio, Ann Arbor (ESTARS), and Baltimore (Basic Endovascular Skills for Trauma, BEST). Three subject matter experts in trauma and vascular surgery participated in multiple REBOA training courses, performed a task analysis, and discussed the project with military and civilian thought leaders on REBOA. The three subject matter experts then created a curriculum composed of five elements: (1) didactic lectures (DL), (2) mannequin simulation (MS), (3) virtual reality simulation (VRS), (4) large animal live tissue simulation (LTS), and (5) perfused cadaver simulation (PCS). Survey and examination questions were based upon key points stressed during the didactic and simulation sessions. Prior to administering the pilot course to military personnel, an afternoon trial run session using the MS models and some of the didactic material was performed with the help of UNMC trauma faculty, medical students, and nurses.

Didactic

The didactic portion of the curriculum contained three slide-based lectures focusing on (1) diagnosis of hemorrhagic shock and indications for REBOA, (2) endovascular equipment and techniques for REBOA, and (3) post-REBOA resuscitation and complication management. Although this portion of the curriculum focused primarily on the cognitive aspects of REBOA training, the learners were able to get their first hands-on exposure with endovascular equipment and observe an expert performing REBOA on a mannequin simulator as part of the initial didactic sessions.

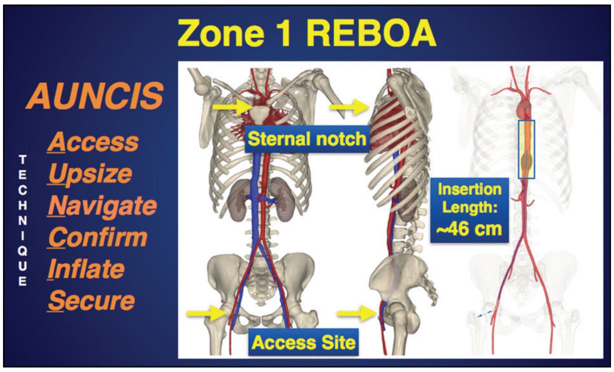

Figure 1 Procedural steps to REBOA and illustration of aortic occlusion Zone 1 balloon catheter placement.

Skills Simulation

For each of the four different modes of technical skills simulation, the REBOA procedure was deconstructed into a series of six successive steps and a checklist was created to record learner performance. For teaching purposes, the acronym *AUNCIS* (Figure 1) was used to help learners engrain the steps of performing REBOA into memory: (1) *Access* of the femoral artery; (2) *Upsizing* of the femoral artery sheath; (3) *Navigation* of the balloon catheter to the proper aortic occlusion zone; (4) *Confirmation* of proper balloon placement within the target aortic zone; (5) *Inflation* of the balloon; and (6) *Securing* of the balloon and sheath. Success or failure for each step, as well as time to completion, were recorded for each learner, during every trial, using each simulation model if applicable (VRS does not simulate femoral access). For the LTS and PCS simulations, failure to complete any of the steps was considered an unsuccessful attempt. Proper positioning of the balloon was determined by direct visualization in the MS and VRS models, palpation and blood pressure response in the LTS model, and fluoroscopy in the PCS. The volume of balloon inflation was not specifically assessed, although in the LTS model it was stressed to gently inflate only to the point of seeing a hemodynamic response on the arterial line tracing.

Mannequin Simulation (MS)

Two different mannequins were used for this pilot study. The Complete REBOA Task Trainer (CRTT) (Medalus, St. Louis, MO) is a partial torso mannequin trainer that allows simulation of the entire REBOA procedure from arterial access to balloon inflation. It contains pressurized arterial and venous systems that are represented by plastic tubes and an arterial access zone in an anatomically correct groin with soft tissue-like properties. The plastic artery and vein are visible using handheld ultrasonography and may be repeatedly accessed with needles, wires, sheaths, and catheters during training sessions. In addition, the artery and vein can be exposed surgically for teaching femoral artery cutdown techniques.

The REBOA Access Task Trainer (RATT) Pulsatile Simulator (Prytime Medical, San Antonio, TX) is a partial torso mannequin trainer similar to CRTT that also allows simulation of the entire REBOA procedure. In addition, the RATT mannequin model provides a pulsatile fluid flow that can simulate the physiology of hemorrhagic shock demonstrating visible improvements in arterial pressure waveforms via a tablet display upon successful balloon occlusion of the plastic tube that represents the aorta. Each learner completed three trials on each mannequin trainer.

Virtual Reality Simulation (VRS)

For VRS, the VIST G5 Endovascular Simulator (Mentice, Gothenburg, Sweden) was used to simulate the passage of wires and catheters using the Vascular Trauma Management software module. This VR simulator is capable of producing variable resistances to the passage of endovascular devices providing the user with some degree of haptic feedback during the advancement of the virtual occlusion balloon. Due to hardware limitations, this electronic simulator does not incorporate the actual wires and catheters used for REBOA and cannot simulate femoral artery access. Each learner completed three trials on the VR simulator.

Live Tissue Simulation (LTS – Swine Model)

On the second day of the course, a non-survival, acute non-compressible hemorrhagic shock model using anesthetized 40–45 kg domestic swine were employed to train providers for the live tissue simulation component. For each animal, the surgeon facilitator exposed the distal aorta and the left iliac artery through a retroperitoneal incision. A 10 cm 8 French sheath (Terumo, NJ) was placed in the left iliac artery for the purpose of creating massive, but controlled hemorrhage. Upon creation of a systolic blood pressure less than 80 mmHg, each learner accessed a femoral artery using handheld ultrasound guidance (V Scan, GE Healthcare, Chicago, IL) with a 5 French micropuncture access kit (Cook Medical, Bloomington, IN), upsized the access to a 7 French sheath (Terumo Medical, Somerset, NJ), and then navigated a balloon occlusion catheter (Prytime Medical, Boerne, TX) into the descending thoracic aorta (aortic occlusion Zone 1). The balloon was inflated to control blood loss and raise proximal aortic pressure. This model provided accurate, high fidelity haptic feedback to each learner during endovascular navigation and manipulation, using equipment identical to that actually used in humans. Animal hemodynamic parameters, including blood pressure and heart rate, were monitored and displayed for real-time physiologic feedback during active hemorrhage and aortic balloon occlusion. Each participant had one attempt at performing the entire procedure, with success versus failure and procedure times recorded. Following the timed procedure, each learner was also given the opportunity to perform surgical cutdown on the common femoral artery.

Perfused Cadaver Simulation (PCS)

We used lightly embalmed cadavers because light embalming improves the preservation of natural tissue properties while reducing biohazard issues [8]. Each cadaver was assessed the day prior to the course to assure lack of prohibitive femoral, iliac or aortic occlusive disease by passing a wire from the distal superficial femoral artery proximally for at least 60 cm. Suitable cadavers were then prepared with open surgical exposure of the right common carotid artery and an 18 French cannula (Terumo Medical) placed in a retrograde fashion into the aorta. The distal carotid artery was ligated and the cannulae were secured to the artery and then attached to a large animal pulsatile blood pump (Harvard Apparatus, Holliston, MA) with a reservoir containing warm colored water. One pump was able to simultaneously drive two simulated cadaver circulations. Upon starting the pump, the arterial vasculature was pressurized and entrance into the femoral artery with a needle produced the characteristic flash and pulsatile fluid flow from the needle hub, realistically simulating femoral artery access. Though teaching emphasized placement of access into the common femoral artery, we did not specifically assess whether or not the access might have been in the superficial femoral artery or distal external iliac artery. Learners performed REBOA in its entirety using this model. For the purpose of assessing the capability of the learner to perform REBOA, the perfused cadaver model was considered the gold standard for testing purposes due to its realistic anatomy and pulsatile flow characteristics. As with the live tissue model, each learner was again given the additional opportunity to perform surgical cutdown on the common femoral artery and perform REBOA through direct arterial access.

Evaluation

Pre- and post-tests assessing cognitive knowledge, and pre- and post-course surveys assessing learner demographics, experience levels, preferences, and beliefs were created and administered immediately before and after the training course. There were no passing or failing scores determined for the examination, as this was our initial pilot study. Means and standard deviations were calculated where appropriate, however the small sample size considerably limited statistical power for most comparisons.

Table 2 Learner characteristics.

Occupation	*Clinical Experience, Years*	*Central Venous Catheter Placements per Year*	*Performed REBOA Clinically?*
Acute Care Surgeon	11–20	>10	No
	In training	>10	No
Emergency Medicine	0–5	0	No
	11–20	>10	No
Non-Clinical (PhD)	0	0	No
	0	0	No

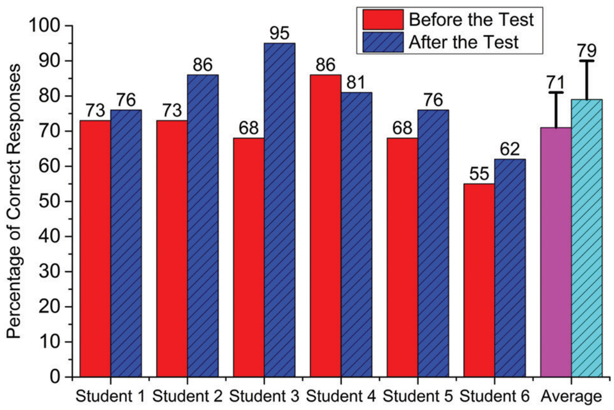

Figure 2 Pre- and post-test results.

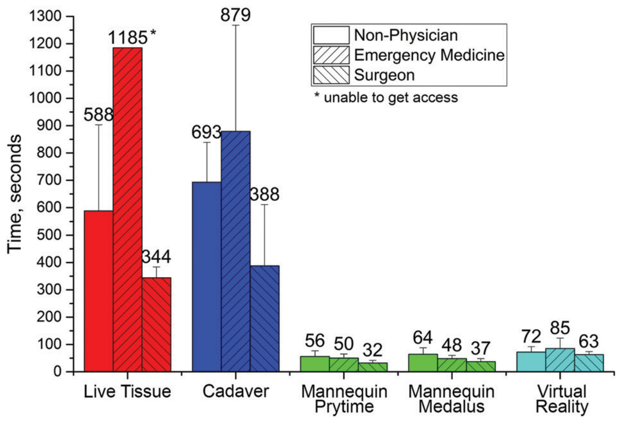

Figure 3 Times to complete the REBOA simulation for each model. Mannequin and virtual reality simulation did not include femoral access and upsizing of the sheath, resulting in greatly reduced times to completion.

RESULTS

We recruited six military personnel through an email announcement with the goal of having a mix of experienced clinician and non-clinician learners without prior training or experience performing REBOA. The characteristics of the trainees are listed in Table 2. All learners rated the didactic sessions highly and all but one learner demonstrated improved cognitive knowledge based on the pre- and post-test scores (Figure 2). All learners performed three trials on each of the VRS and MS models, while one trial was performed for each of the LTS and PCS models. Times to completion for the procedure were recorded for each trial (Figure 3).

Difficulties with the femoral access modules for each of the MS models severely limited the incorporation of this step into the simulation. As a result, for the MS and VRS trials, the learner began each trial with the upsized 7 French sheath already in place, with the times measuring the portion of the REBOA procedure that included navigation of the catheter, confirmation of balloon placement in Zone 1 of the aorta, inflation of the balloon, and verbalization of device securement. LTS and PCS model performance required significantly more time to completion for all learners due to the additional steps of percutaneous femoral access and sheath upsizing. One learner was unsuccessful at obtaining percutaneous femoral artery access in the LTS model due to hematoma and vasospasm of the artery following repeated attempts over the course of 15 minutes until the attempt was aborted. All learners were successful obtaining percutaneous access and navigating the balloon catheter to Zone 1 of the aorta in the PCS model. Learners gained confidence in their skills to deploy REBOA compared to their baseline (Table 3). Learners rated VRS as the least useful and least realistic of the simulation models (Figure 4). LTS and PCS were the preferred models and both MS and VRS were considered dispensable by the greatest number of learners (Figure 5).

Costs for all models were significant (Figure 6). Depending upon the presence of basic institutional simulation resources, like ultrasounds and reusable surgical instruments such as dissecting scissors, retractors, and arterial clamps, these costs can vary greatly. Costs may also be heavily influenced by the choice between purchase or rental of the necessary equipment. For VRS, initial outlays approaching or exceeding US$100,000 are often necessary to own the equipment and software, with several additional thousands of dollars in annual service contract fees for maintenance of optimal simulator function.

For our pilot course, we rented one simulator to use alongside the VIST G5 simulator owned by our institution. For purposes of cost comparison, we consider only

Table 3 Pre and post-course confidence in skills to deploy REBOA graded on a five-stage scale.

	Before the Course		*After the Course*	
Non-Physician	Not confident	Not confident	Slightly confident	Fairly confident
Emergency Medicine	Somewhat confident	Very confident	Fairly confident	Very confident
Surgeon	Not confident	Somewhat confident	Very confident	Very confident

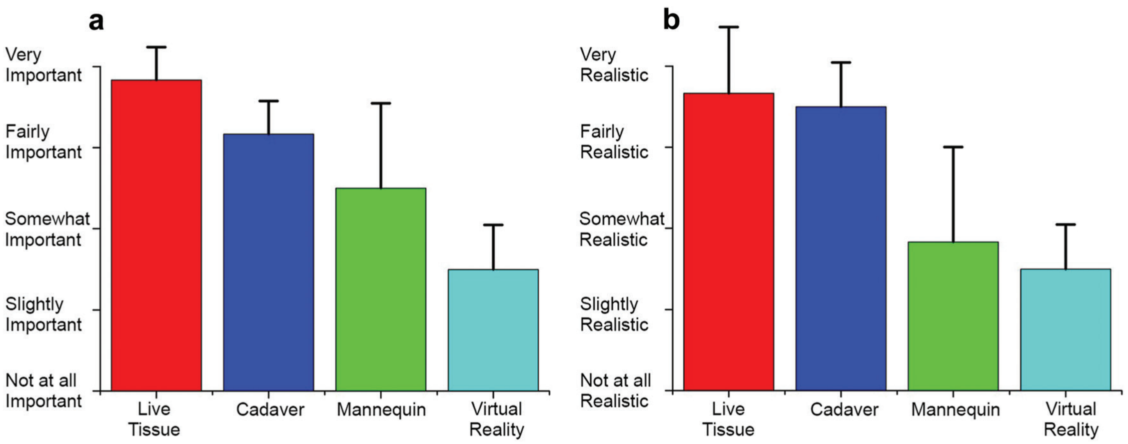

Figure 4 Learner ratings of simulation model utility (**a**) and realism (**b**).

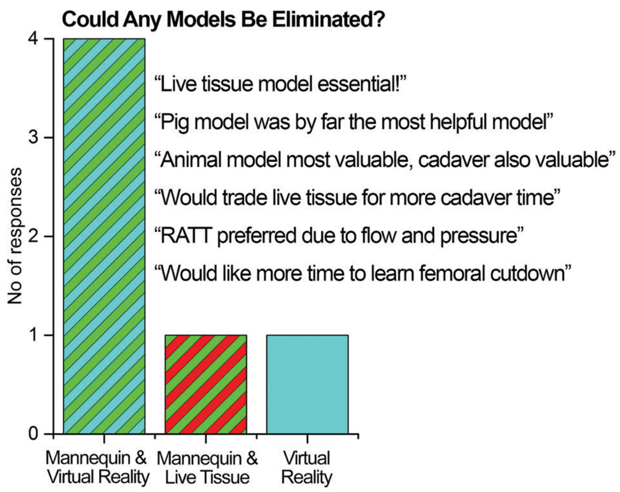

Figure 5 Learner comments and recommendations.

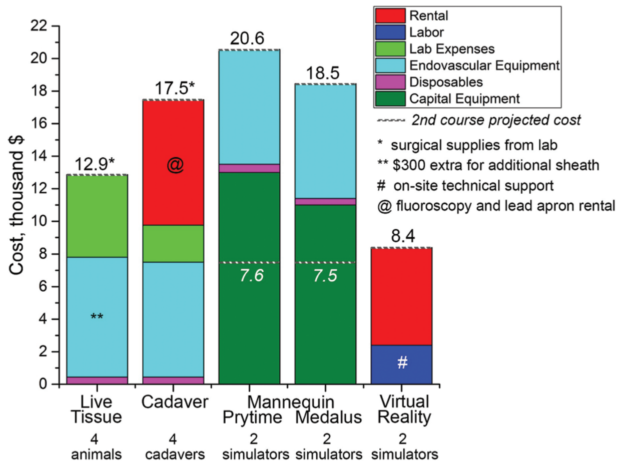

Figure 6 Cost comparison for the course with all models for six learners.

VRS rental, which also includes on-site technical support to help assure optimal function of the device and expert troubleshooting of any unforeseeable issues. MS models are the least expensive models to use over time once the upfront cost of purchasing the simulators is satisfied. The PCS model is significantly more expensive than the LTS model, primarily because of the high cost of fluoroscopy rental at our institution. Costs for the MS and LTS models over time would be primarily driven by endovascular equipment costs, most of which are related to purchase of the Prytime balloon occlusion catheters.

DISCUSSION

With the rapid adoption of REBOA as a viable means to rescue patients with exsanguinating non-compressible torso hemorrhage, data have begun to accumulate that support its utility for both civilian and military applications [4,9]. In addition to trauma, indications appear to be expanding to include other conditions that lead to circulatory collapse [10,11], spurring significant interest in the technique from non-surgical disciplines. Though REBOA theoretically is little more than an extended femoral arterial line [12], users must combine detailed knowledge regarding the indications, complications, and technical performance of the much higher stakes procedure. The ability to know how hard and fast one can push endovascular devices through iliac arteries, or how to gain percutaneous access into a pulseless femoral artery under adverse conditions, may also require more tailored training and experience.

In analyzing the steps to perform successful REBOA, our team developed the pneumonic AUNCIS to simplify the memorization of the procedure in its entirety for novice learners. Other memorization aids have also been proposed, including the pneumonic "MEFIZZ" distributed by the manufacturer of the REBOA specific catheter. The AUNCIS pneumonic comprehensively encompasses all the steps of the procedure required to get the balloon safely inserted and functioning, including femoral access and the upsizing of the access sheath necessary to introduce the catheter, whereas MEFIZZ deals primarily with specific catheter-related preparation such as emptying the balloon and flushing the catheter.

Deciding how to optimally train the most impactful health-care providers to perform REBOA is critical to its safe and effective implementation. Multiple civilian and military training courses have used different simulation and testing models for teaching and assessing the knowledge and skills required to perform REBOA [6,7]. These methods most often include the use of mannequins, virtual reality simulators, human cadavers [13], and live tissue, usually swine. Each of these models has distinct advantages and disadvantages (Table 4).

Our data demonstrate that learners of various backgrounds preferred higher-fidelity live tissue models above all others, with the perfused cadaver also preferred over the mannequin and virtual reality simulators. Animal live tissue models offer several unarguable advantages. Real-time and reactive physiology in live tissue produces a feel similar to that of an actual REBOA procedure. Moreover, the emotional component that creates a sense of urgency and mental stress to perform the procedure correctly is difficult to replicate [14]. In a military or civilian trauma scenario, it is arguable that this experience could provide learners with a significant edge. However, ethical and cost concerns over the use of live animals are potentially prohibiting [15]. Additionally, the anatomy, although similar in the swine, is still not identical to that of a human. This makes the live tissue model viable as a training option, but not without significant limitations.

The perfused cadaver model provides a training environment in which anatomic differences are less of a concern. The model is perfused, which is most useful for confirmation of arterial access and for providing some degree of physiological feedback, but it does not appear to produce the same emotional training component that the live tissue model does. This perfused cadaver model is similar in cost and resource utilization to the live tissue model, but issues with cadaver availability and vasculature variability, often including arterial occlusive disease in more aged donors, can be limiting. The risk of communicable disease transmission is also more of a concern with fresh or frozen cadaver models. The American College of Surgeons BEST course currently employs a cadaver model as the gold standard teaching and testing method [16].

Virtual reality simulators are the newest modalities being used in medical/surgical education. There is the potential for these models to provide very real physiological feedback and allow multiple repetitions without the need to replace expensive disposable components. In our study, the virtual reality simulator was incapable of simulating the most critical portion of the procedure – percutaneous access of the femoral artery. This may not be critical for learners that have had the experience of performing hundreds of arterial or venous access procedures, but for novice learners, this weakness severely limits the utility of VRS. This was reflected in our results, with learners rating virtual reality the lowest for scales of realism and utility. The absence of access simulation, low user ratings, and relatively high cost require further examination to improve the use of this exciting and promising technology in teaching REBOA. One very promising use for VRS is in the assessment of learner technical proficiency in a standardized manner. Sensors and algorithms are capable of translating user device handling into automatically generated reports that may correlate with user competence and skill. Although the virtual reality simulators have distinct advantages that should be further pursued and refined, this technology requires significant improvement before it could fully replace existing training modalities.

In an effort to potentially alleviate many of the concerns of live tissue and cadaver models, many training and educational programs have incorporated the use of mannequins into their curriculum. Although upfront costs are not necessarily drastically reduced compared to the live tissue and cadaver models, the ongoing use of mannequin simulation versus all of the other modes of simulation is significantly less. Major purported advantages of the mannequin models are the ability to simulate the entire procedure from start to finish and the capability to withstand multiple repetitions by multiple learners. Both mannequins used in our study were completely reusable with the exception of a replaceable groin femoral access module. As we experienced in our pilot study, issues remain with the femoral access modules, and the learners rated the realism significantly less than live tissue and cadaver models. As with VRS, significant room for improvement exists for mannequin simulators that may also perform both automated teaching and assessment tasks.

For patients in hemorrhagic shock that are alive when they arrive at hospitals equipped with REBOA catheters, first-line trauma and general surgeons must be able to gain access into the femoral artery, deliver the

Table 4 Simulation model comparative matrix.

Simulation Modality		*Strengths*	*Weaknesses*
Live Tissue		Simulates the entire procedure using real equipment High fidelity physiologic and haptic feedback Simulates femoral cutdown for access	Anatomical differences from human One to two users for each animal Expensive – animal care and use staffing Vessels are smaller, more difficult to access Ethical issues More regulatory issues
Cadaver		High anatomical fidelity Simulates the entire procedure using real equipment High fidelity physiologic and haptic feedback Simulates femoral cutdown for access	5–6 uses for each cadaver Expensive Tissues are stiffer More elderly donors with vascular occlusive disease
Mannequin	Prytime RATT	Simulates the entire procedure using real equipment Fluid pressure provides enhanced haptic feedback Can be used with fluoroscopy Simulated physiological feedback Portable – can be used for deliberate practice	Cannot catheterize smaller branch vessels Groin access material stiff, prone to leaks Seams in vasculature are frequent causes of obstruction No femoral bifurcation
	Medalus	Simulates the entire procedure using real equipment Less expensive Haptic feedback Can be used with fluoroscopy Simulates femoral cutdown for access Side branches present, though not anatomically correct Portable – can be used for deliberate practice	Groin access material needs improvement No physiological feedback Seams in vasculature are frequent causes of obstruction No femoral bifurcation
Virtual Reality		Can record data about learner technical skills Simulates physiological feedback Simulates fluoroscopy without radiation Simulates erroneous vessel catheterization Some haptic feedback upon catheter movement Portable – can be used for deliberate practice	Does not simulate access portion of the procedure Does not use identical equipment as real REBOA Expensive No haptic feedback to balloon inflation

balloon catheter to the proper zone in the abdominal or thoracic aorta, and inflate the balloon without rupturing the balloon or the aorta. If this technology is to be pushed closer to the point of injury, where it would likely have the greatest impact on mortality, other non-surgeon or non-physician providers will need to be trained to decide when and how to perform the procedure. Our pilot data suggest alignment with previous publications that demonstrate the feasibility of accelerating the training of trauma surgeons, non-surgeon clinicians, and even non-physicians to perform REBOA [17]. Though the costs of this training may differ somewhat between institutions, the resources required to execute each of the models are significant. Although our pilot study sample size is small, insights gleaned from our data should help optimize additional studies that will help improve REBOA training for a diversity of learners. Furthermore, although follow up clinical data documenting successful performance of the procedure following course participation should be the gold standard to judge the success or failure of a curriculum, these data are sparse [18]. Further work focusing on assessing competency, skill decay, and methods to incorporate constant advances in new technology should be done to assure the safe dissemination of REBOA to those in the best position to save lives that previously were inevitable mortalities.

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REFERENCES

[1] Hughes CW. Use of an intra-aortic balloon catheter tamponade for controlling intra-abdominal hemorrhage in man. Surgery. 1954;36:65–8.

[2] Brenner M, Teeter W, Hoehn M, et al. Use of resuscitative endovascular balloon occlusion of the aorta for proximal aortic control in patients with severe hemorrhage and arrest. JAMA Surg. 2018;153:130–5.

[3] Norii T, Crandall C, Terasaka Y. Survival of severe blunt trauma patients treated with resuscitative endovascular balloon occlusion of the aorta compared with propensity score-adjusted untreated patients: J Trauma Acute Care Surg. 2015;78:721–8.

[4] Manley JD, Mitchell BJ, DuBose JJ, Rasmussen TE. A modern case series of resuscitative endovascular balloon occlusion of the aorta (REBOA) in an out-of-hospital, combat casualty care setting. J Spec Oper Med. 2017; 17:1–8.

[5] Sadek S, Lockey DJ, Lendrum RA, Perkins Z, Price J, Davies GE. Resuscitative endovascular balloon occlusion of the aorta (REBOA) in the pre-hospital setting: An additional resuscitation option for uncontrolled catastrophic hemorrhage. Resuscitation. 2016;107:135-8.

[6] Brenner M, Hoehn M, Pasley J, Dubose J, Stein D, Scalea T. Basic endovascular skills for trauma course: Bridging the gap between endovascular techniques and the acute care surgeon. J Trauma Acute Care Surg. 2014;77:286–91.

[7] Villamaria CY, Eliason JL, Napolitano LM, Stansfield RB, Spencer JR, Rasmussen TE. Endovascular Skills for Trauma and Resuscitative Surgery (ESTARS) course: Curriculum development, content validation, and program assessment. J Trauma Acute Care Surg. 2014;76: 929–36.

[8] Wadman MC, Lomneth CS, Hoffman LH, Zeger WG, Lander L, Walker RA. Assessment of a new model for femoral ultrasound-guided central venous access procedural training: a pilot study. Acad Emerg Med. 2010;17: 88–92.

[9] DuBose JJ, Scalea TM, Brenner M, et al. The AAST prospective Aortic Occlusion for Resuscitation in Trauma and Acute Care Surgery (AORTA) registry: Data on contemporary utilization and outcomes of aortic occlusion and resuscitative balloon occlusion of the aorta (REBOA). J Trauma Acute Care Surg. 2016;81:409–19.

[10] Daley J, Morrison JJ, Sather J, Hile L. The role of resuscitative endovascular balloon occlusion of the aorta (REBOA) as an adjunct to ACLS in non-traumatic cardiac arrest. Am J Emerg Med. 2017;35:731–6.

[11] Stensaeth KH, Sovik E, Haig INY, Skomedal E, Jorgensen A. Fluoroscopy-free resuscitative endovascular balloon occlusion of the aorta (REBOA) for controlling life threatening postpartum hemorrhage. PloS One. 2017;12:e0174520.

[12] Stannard A, Eliason JL, Rasmussen TE. Resuscitative endovascular balloon occlusion of the aorta (REBOA) as an adjunct for hemorrhagic shock: J Trauma Inj Infect Crit Care. 2011;71:1869–72.

[13] Brenner M, Hoehn M, Stein DM, Rasmussen TE, Scalea TM. Central pressurized cadaver model (CPCM) for resuscitative endovascular balloon occlusion of the aorta (REBOA) training and device testing: J Trauma Acute Care Surg. 2015;78(1):197-200.

[14] Barnes SL, Bukoski A, Kerby JD, et al. Live tissue versus simulation training for emergency procedures: Is simulation ready to replace live tissue? Surgery. 2016;160: 997-1007.

[15] Board TE. Opinion – Ban Animal Use in Military Medical Training. *The New York Times*. 2016. https://www.nytimes.com/2016/06/26/opinion/ban-animal-use-in-military-medical-training.html. Accessed 7 February 2018.

[16] Brenner M, Bulger EM, Perina DG, et al. Joint statement from the American College of Surgeons Committee on Trauma (ACS COT) and the American College of Emergency Physicians (ACEP) regarding the clinical use of resuscitative endovascular balloon occlusion of the aorta (REBOA). Trauma Surg Acute Care Open. 2018;3: e000154.

[17] Teeter W, Romagnoli A, Glaser J, et al. Resuscitative endovascular balloon occlusion of the aorta: pushing care forward. J Spec Oper Med. 2017;17:17–21.

[18] Brenner M, Hoehn M, Teeter W, Stein D, Scalea T. Trading scalpels for sheaths: Catheter-based treatment of vascular injury can be effectively performed by acute care surgeons trained in endovascular techniques. J Trauma Acute Care Surg. 2016;80:783–6.