Evaluation of a Novel Team-Based VR Curriculum for Advanced Resuscitative Care

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ABSTRACT

Maximizing operational medical personnel readiness for Large Scale Combat Operations will require extensive training for austere surgical and resuscitative care (ASRC) teams, who must maintain clinical and tactical expertise across an ever-changing spectrum of techniques, tactics, and protocols. Traditional simulators used for ASRC training, such as manikins, often struggle to stay up to date with cutting edge medicine and provide sufficient repeatability due to the time and expense of developing, deploying, and modifying training simulations. As technology advances, virtual reality (VR) simulation has emerged as another possible option for trauma team training. This modality has the potential to reduce cost of training, allow for teams to train in geographically separated areas, and enable training between teams that may accept the patients in the continuum of care. Early studies suggest that VR simulation is an effective means of training, but there is no current evidence comparing its practical use for team-based ASRC training. This paper reports on a training and evaluation study of a recently developed VR curriculum for advanced resuscitative care. First, the simulation curriculum will be described, detailing the learning objectives, techniques, tactics, and protocol coverage, and usability design considerations identified through a capability gap analysis with ASRC practitioners. The paper then outlines study hypotheses of evaluating immersion, usability, and efficacy as they pertain to ASRC training for both clinical and team-based learning objectives, as well as corresponding evaluation methodology detailing participant demographics, simulation study protocol, and survey components. The paper then reports the results of the evaluation and an analysis of the VR curriculum to meet educational objectives, alongside practical considerations for implementing VR in current ASRC training paradigms, establishing evidence for this novel simulation technology to be used for operational medicine education and training.

ABOUT THE AUTHORS

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BACKGROUND AND PROBLEM

ASRC Readiness

Noncompressible torso hemorrhage (NCTH) persists as the primary preventable cause of battlefield mortality, often resulting in death within 30 minutes post-injury (Stannard et al., 2013). Current countermeasures, such as whole blood transfusion and resuscitative endovascular balloon occlusion of the aorta (REBOA), are effective, with early administration of blood products demonstrating a potential mortality reduction of up to 80% (Rees et al., 2018). The intricacies of austere surgical and resuscitative care (ASRC) in combat scenarios necessitate that all operational medical teams undergo rigorous, specialized pre-deployment training. This training integrates both the medical and tactical dimensions essential for ensuring teams can safeguard themselves and their patients effectively within a hostile environment. However, sustaining proficiency in surgical trauma skills during non-deployment periods presents formidable challenges, compounded by the perishability of critical life-saving skills (Cannon et al., 2020; Dalton et al., 2022). Continuous, realistic training and intra-theater personnel rotations are imperative to maintain clinical expertise, yet these are frequently impeded by logistical, financial, and temporal constraints.

Special operations surgical teams (SOST) exemplify the specialized requirements of this training. Comprising multidisciplinary medical personnel, such as surgeons, anesthesiologists, emergency physicians, and critical care nurses, SOSTs are trained for rapid deployment in high-risk, resource-deficient settings to administer urgent surgical and trauma care. Their integration with special operations forces is crucial, significantly enhancing the immediate medical response capability on the battlefield and, thereby, troop survivability in adverse conditions (Beckett et al., 2022). This readiness challenge demands a dynamic and comprehensive training approach to ensure medical personnel are proficient in the high-intensity surgical procedures and rapid deployment of critical care required in austere battlefield conditions.

Traditional training modalities demand extensive resources, including personnel, equipment, and time, often surpassing logistical capabilities. Achieving high environmental fidelity to mimic the unpredictable nature of combat settings in training simulations is challenging, yet critical for effective preparation. Without regular and realistic practice, the advanced skills required for ASRC are prone to degradation, which poses risks during actual operations. Additionally, the widespread distribution of teams complicates synchronized training efforts, impacting unit cohesion and operational readiness. Financial constraints frequently limit the frequency and expansiveness of live training exercises, and scaling such training to accommodate multiple or large teams simultaneously often proves prohibitively expensive.

Current ASRC Training Modalities

Traditionally, ASRC training has heavily relied on physical simulators and manikins. While these tools offer some level of practical engagement, they are often constrained by their inability to swiftly adapt to new medical procedures and findings. Classroom-based learning and tabletop exercises, although beneficial for theoretical knowledge acquisition, lack the immersive experience required for practical skill development under combat conditions. Field exercises attempt to simulate battlefield environments but are expensive and complex to organize, limiting their frequency and, by extension, their effectiveness in ensuring skill retention.

The adoption of virtual reality (VR) training mitigates these challenges by enabling complex procedural rehearsals in a controlled, cost-effective manner. VR technology facilitates frequent, intensive training sessions that offer a high degree of realism and procedural repetition without the associated risks and logistical burdens of live training. This innovative approach not only enhances training accessibility and standardization across dispersed teams but also aligns with fiscal prudence by reducing resource expenditure. VR training systems offer significant advantages for ASRC preparation. Virtual environments can simulate a diverse array of medical scenarios—from routine interventions to complex trauma care under varied environmental conditions—with an ease and rapidity that traditional systems cannot match. These simulations can be updated swiftly to reflect the latest medical guidelines and real-time battlefield feedback, without physical alterations to the setup. They reduce the financial burden associated with traditional exercises, as VR simulations, once developed, can be deployed repeatedly at minimal additional cost. These systems support remote training capabilities, allowing for synchronized, team-based exercises across geographically dispersed units, thus eliminating the need for costly and time-consuming travel. VR's adaptive learning environments can permit the modification of scenarios in real-time based on learner responses, providing customized training experiences that improve individual and team performance. Furthermore, the immersive realism of VR, which engages multiple senses and replicates stress-inducing combat environments, prepares medical personnel for the physical and psychological challenges of battlefield care.

However, the use of VR in ASRC training is not without its challenges. While VR offers a high degree of flexibility and scalability, there are concerns about the procedural fidelity in replicating hands-on medical tasks. The tactile feedback from VR simulations is currently limited, which can affect the training effectiveness for procedures that require precise manual skills. Additionally, prolonged use of VR equipment can cause physical discomfort, such as eye strain and motion sickness, which might limit the duration and frequency of training sessions. There is also a learning curve associated with using VR technology, which can be a barrier for some personnel. Moreover, the initial setup and development costs for high-quality VR training systems can be substantial, although these are often offset by the long-term savings over traditional methods.

Objectives

The primary aim of this initiative was to develop a comprehensive VR medical simulation training curriculum for ASRC teams. This framework is designed to ensure that medical personnel are thoroughly familiarized with essential equipment, transportation platforms, and specific medical protocols necessary for their roles. By replicating training scenarios within a virtual environment, the project seeks to equip ASRC teams with the skills required to perform effectively under the diverse and demanding conditions typical of their operational mandates.

METHODS

The groundwork laid for this project came from prior research efforts between SimX and the United States Air Force, which was focused on identifying training requirements that would most benefit from a VR medical simulation solution.

Curricular Design and Specification

In the specification phase, the learner population was first identified. SOST are highly specialized units designed to provide life-saving medical care in austere and combat environments. SOST teams consist of a multidisciplinary group of medical professionals, including surgeons, anesthesiologists, emergency medicine physicians, and critical care nurses, who are trained to deploy rapidly and operate in dangerous and resource-limited settings. Their primary mission is to perform damage control surgery and provide advanced trauma life support to stabilize critically injured patients before they can be evacuated to higher-level care facilities. SOST members are equipped to work in tandem with special operations forces, often accompanying them on missions to ensure immediate medical intervention is available. Training of these elite teams can be cost-prohibitive in terms of required travel and material expenses. With future conflicts likely to include a lack of air superiority necessitating prolonged care in austere settings, SOST teams were identified as a group who could largely benefit from a cost-effective, repeatable and customizable training solution.

The development of the VR curriculum for ASRC training was systematically approached through a detailed needs assessment, initiated to accurately determine the specific training requirements for military medical personnel. This process involved the identification and consultation with key stakeholders such as military surgeons, anesthesiologists, emergency physicians, combat medics, and medical educators. Data was collected through structured interviews and surveys aimed at identifying existing training gaps and requirements.

The design phase culminated in mapping the required competencies for ASRC personnel, which encompassed both technical and non-technical skills essential for effective performance in combat environments. This competency framework guided the structuring of the curriculum to ensure comprehensive coverage of all critical skills and knowledge areas, as evidenced by the needs analysis. Drawing on results from these projects allowed for the creation of a targeted approach to the creation of a novel, integrated learning program specifically covering ASRC topics which included elements of advanced resuscitative care, use of the REBOA catheter, and prolonged casualty care (PCC) (Joint Trauma System, 2020). To identify injury patterns most pertinent to the subjects in question, military subject matter experts (SMEs) were chosen to solicit feedback and provide recommendations on case content. The six cases selected were identified as having a greater clinical benefit based on the opinion of these experts. Injury/illness patterns included both blunt and penetrating trauma, complex facial and airway trauma, burn injuries, sepsis, as well as severe metabolic derangements. Accordingly, this interdisciplinary team developed a comprehensive set of objectives designed to ensure a well-rounded development of both technical and collaborative skills under diverse operational conditions. At a high level, these objectives included the following:

1. *Development of Non-Technical Procedural Skills* - The curriculum places a strong emphasis on cultivating non-technical skills needed to conduct successful operational medic. This includes leadership, communication, and resource management, all of which are critical for managing the unpredictable nature of battlefield medicine. Trainees are engaged in exercises that challenge them to manage logistics and personnel under pressure, mirroring real-world scenarios that require quick thinking and adaptive strategies.
2. *Enhancement of Clinical Decision-Making* Abilities - Central to the curriculum is the enhancement of the trainees' ability to make rapid and accurate clinical decisions. Through interactive simulations that incorporate dynamic medical emergencies, participants are required to diagnose conditions, choose appropriate interventions, and modify treatment plans as scenarios evolve. This component is designed to strengthen the decision-making confidence of medical personnel, ensuring they are prepared to face any situation on the field.
3. *Integration of Team-Based Training Dynamics* - The training framework acknowledges the critical role of teamwork in military medical operations and is tailored to support both co-located and remotely coordinated team activities. The training uses virtual environments to simulate the necessity for synchronous operations and decision-making, fostering a robust understanding of how to function cohesively as a unit without requiring colocation for team training.

ASRC Scenarios

The educational design team specified a series of detailed scenarios designed to simulate the challenging conditions faced by SOST personnel and are intended to develop the clinical skills and decision-making abilities in a team-based environment. The descriptions below outline the scenarios integrated into the curriculum:

1. *Difficult Airway* - This scenario involves a 24-year-old female US soldier who has sustained a high-velocity gunshot wound to the face, leading to significant soft tissue damage. The scenario focuses on managing a compromised airway in a forward surgical tent, where the patient presents with substantial oropharyngeal bleeding.
2. *Penetrating Thoracic Injury* - A 24-year-old male local national presents with a gunshot wound to the left chest. The scenario covers the application of chest seals and decompression needle placement to manage potential complications such as pneumothorax, along with the administration of tranexamic acid (TXA).
3. *Mounted Blast Injury* - Medics respond to a 24-year-old female US soldier who has been involved in a vehicle rollover following a mounted IED blast. The scenario requires rapid intubation due to a diminished Glasgow Coma Scale (GCS) and the initiation of whole blood transfusion to address hypotension.
4. *Junctional Wound* - A 30-year-old male local national has a gunshot wound to the right groin. The training scenario emphasizes the management of active bleeding where previous tourniquet application has been ineffective, requiring direct pressure and rapid decision-making.
5. *Dismounted Blast Injury* - This scenario describes a 22-year-old female US Marine who has sustained multiple traumatic injuries from a dismounted IED blast, including bilateral lower extremity amputations.

Medics must manage a complex airway and hemorrhage control effectively, alongside initiating appropriate transfusion protocols.

6. *Extremity Injury with PCC* - Featuring a 22-year-old male US soldier with a prolonged tourniquet application following a gunshot wound to the thigh, this scenario focuses on the complications of prolonged field care, such as potential compartment syndrome and pain management.

Virtual Asset Design

The design of virtual environments involved a systematic approach to ensure accurate simulation of military operational settings. The initial step in this process was the detailed mapping of environments needed to support the training scenarios, such as field hospitals, combat zones, and mobile surgical units. These environments were conceptualized based on input from subject matter experts to reflect the physical layout and conditions typical of military operations. Each environment was then digitally prototyped, with attention to spatial dynamics, ambient elements, and contextual accuracy. This included the simulation of lighting, weather conditions, and background noise, which are crucial for replicating the sensory challenges present in real combat settings. The prototypes were developed using advanced 3D modeling tools and were iteratively refined through consultations with military experts to ensure realism and functionality. The programming also ensured that each environment could support the specific medical procedures and scenarios outlined in the curriculum.

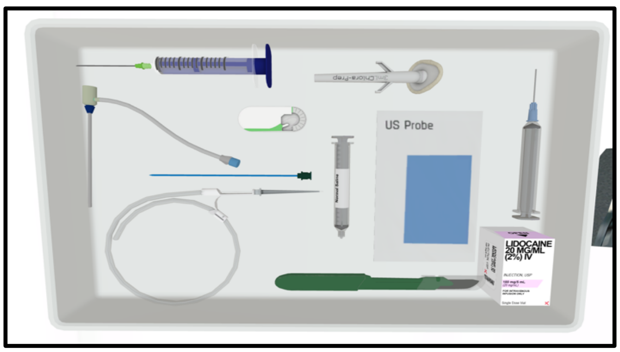

Figure 1. Example Tool Asset Kit for Central Line Insertion.

The design of virtual tools for the ASRC curriculum required meticulous attention to detail to ensure that each tool not only looked realistic but also behaved in accordance with its real-world counterpart. The process began with the identification of all medical tools and equipment needed for the training modules, such as surgical instruments, diagnostic devices, and emergency treatment kits. For each tool, detailed digital blueprints were created, specifying dimensions, textures, colors, and mechanical properties. These blueprints served as the basis for the 3D modeling process, where each tool was digitally constructed to exact specifications. Special attention was given to the tactile and interactive aspects of each tool, ensuring that they could be manipulated within the VR environment in ways that mirrored real-life usage. Following the modeling phase, each tool underwent a detailed interaction design process. This involved programming the tools to respond to user inputs via VR controllers or gesture recognition systems, allowing for realistic and intuitive handling.

REBOA Procedure

The development of the resuscitative endovascular balloon occlusion of the aorta (REBOA) procedure within the VR system was designed to capture the procedural fidelity required for the learning objectives. The setup began with a thorough configuration of the virtual environment, specifying essential medical supplies and equipment. Items such as the REBOA catheter package, sterile drapes, and personal protective equipment were strategically placed to simulate their real-world applications and accessibility during the procedure in a far-forward surgical environment.

The design of the patient character was critical in facilitating realistic procedural interactions, particularly around the femoral and groin areas required for catheter placement. Enhancements included detailed anatomical features and interactive elements such as ultrasound probes, which are crucial for the precise placement of the catheter. This part of the setup aimed to mimic the tactile and visual aspects of medical procedures, providing learners with a realistic platform to practice the initial steps of the REBOA procedure, including identifying the correct insertion sites using ultrasound guidance.

The procedural steps were carefully sequenced to guide learners through the process of catheter placement and balloon inflation, which are central to the REBOA technique. Starting with the opening of the REBOA kit and the preparation of the sterile field, learners were led through detailed simulations of needle insertion, guided by real-time ultrasound feedback. Following this, the guidewire and catheter were introduced, with each action accompanied by interactive feedback mechanisms that provided both tactile and visual cues. The final steps involved the inflation of the balloon within the aorta, with immediate virtual feedback on physiological effects such as changes in arterial pressure. This comprehensive approach not only adheres to the technical precision required for the REBOA procedure but also ensures that learners are prepared to perform under realistic conditions that mirror the pressures and constraints of actual medical emergencies.

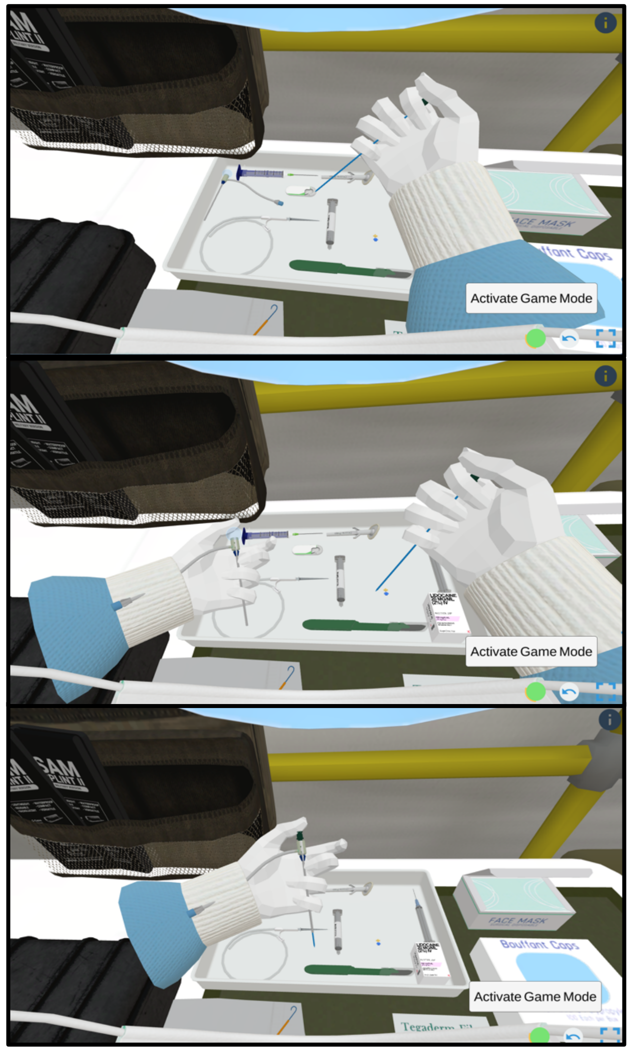

Figure 2. Example Tool Interaction Schema.

Scenario Implementation

The scenarios, environmental overviews, and performance tracking metrics were then designed in a three-step manner. In the first step, a content outline request was sent to US Air Force stakeholders detailing their goals and learning objectives for the cases, in addition to the desire for general flow for case progression. The stakeholders completed these forms, which were reviewed by a member of the SimX Medical Oversight Board (MOB), a physician with specific training in the area of interest, for further review and clarification. The MOB member expanded on the details and requests of the collaborators and created a training that maximized the learning goals desired while remaining within the constraints of what is feasible in a VR setting. All necessary tools, settings, and patient/non-playable character information required for the case were explicitly stated in the concept outline. Once completed, this document was also presented to the collaborator for approval and review. Any specific changes requested by the collaborator were addressed through iterative feedback until all requests/recommendations were fulfilled.

Once the collaborator approved the proposed case flow, concept, and tracking metrics/critical actions, Step 2 involved internal collaboration between the MOB and VR production specialists. This process involved detailing specific case layouts, available tools, and design and functionality. If necessary, specific patient information was scoped and developed to align with learning objectives. Once both parties reached an agreement on the case specifications, the process entered Step 3, in which a VR production specialist distilled the information into a standardized tabular data document. This document was the source that case developers use to implement the specific case. For cases in which new tools were required, VR specialists worked with members of the quality assurance (QA) team to design and test the tools for the scope of their expected functionality. Following the generation of all tools and assets, the documentation was distributed to the engineering team, who then developed an initial version of the case. Once the case was developed, the internal QA team met with the MOB members to test each scenario for content, case flow, and bugs. Once the cases were in a state deemed complete, they were returned to the collaborator for approval. Any changes recommended were then discussed and addressed before final case sign-off.

Once the cases were complete, they were accessible by the collaborator and could be run at any time, as many times as desired, for the duration of their contract. The tools required include a laptop or computer, a 12x12 or 20x20 foot area space (depending on the case), as well as a VR headset. After completion of said scenarios and testing by US Air Force personnel, the need for standardization with their currently existing readiness tracking system was noted, as well as a request for direct recording of each session for playback learning purposes. Then these tools were created and implemented into each scenario.

Curricular Coverage and Evaluation

The final curriculum included many complex aspects of military care. To better assess the degree to which the curriculum incorporated Clinical Practice Guidelines (CPGs), a survey was created using the Resuscitative Endovascular Balloon Occlusion of the Aorta CPG (CPG ID: 38). The goal of this survey was to assess the curriculum's ability to meet all knowledge, skill, and ability recommendations set forth in the CPG. The CPG was broken down into sections based on the Learning Objectives initially, with questions specifically addressing each subsection's content. The survey included 98 questions requiring a "Yes" or "No" response for alignment with current recommendations (see Table 1).

Table 1. Evaluation of Adherence to JTS REBOA CPG

Competency Area	**Checklist Items**
Current Recommendations	**16**
Initial Management	**14**
Alternative Therapies	**3**
Resuscitative Thoracotomy	1
Trans-abdominal Aortic Occlusion	2
REBOA Procedure	**37**
Arterial Access	6
Arterial Line Attachment	1
Balloon Position/Inflation	5
Balloon Securing/Monitoring	4
Operative/Procedural Bleeding Control	2
Balloon Deflation	3
Sheath Removal/Complications	6
Documentation/Monitoring	5
Coordination/Patient Movement	5
REBOA Use by Non-Surgical Resuscitation Teams	**8**
REBOA Pitfalls	**8**
REBOA Indications & Contraindications	**6**
Aeromedical Evacuation Considerations	**6**

Subject Matter Expert Analyses

To assess the CPH adherence, a group of SMEs were invited to participate complete the survey following live assessment of the VR curriculum. A candidate was considered a SME if they met two criteria. The first was either prior or current active duty military experience. The second was having done one of the following:

1. Individual had attended one of the in-person REBOA-based trainings, including the American College of Surgeons' Basic Endovascular Skills for Trauma (BEST) course or the 'Resuscitation Adjuncts: Prehospital Transfusion & REBOA' (RAPToR) Course
2. Individual had placed a REBOA catheter in a clinical setting.
3. Individual had placed a REBOA catheter in a live-tissue model.

Participation was voluntary. The SMEs would view video of a real-time training using the simulated training environment by members of the MOB at SimX who had assisted in creation of the curriculum, and as such had a strong foundation of knowledge as to the mechanics involved and available tools. They would have access to the survey, and in real time could ask the MOB member to perform all available tasks and record answers regarding whether the task, learning objective, or other clinical content in question could be assessed or not. The curricular content, which included information regarding critical actions to take during the case, specific case flow diagrams, and debrief tools were also reviewed with SMEs.

There was a total of three SMEs who participated in the evaluation, each of which was performed individually. The subject matter experts evaluated the simulation platform's comprehensive approach to recognizing indications for REBOA through various trauma scenarios. These scenarios were designed to help identify clinical situations in which REBOA was appropriate based on the patient's overall condition and trauma location.

Following completion of this survey, SMEs were invited to fill out the Likert questions regarding their perceptions of the overall quality and aims of the curriculum, as well as provide constructive comments. This section was a 21 question Likert scale (1 to 7, with 7 being strongly agreed) survey to evaluate the integration of didactic elements and hands-on components, as well as the accuracy and utility of the training for sustaining skills in the deployment and troubleshooting of REBOA.

1. *Recognition of Indications for REBOA* - The simulation includes scenarios that help identify appropriate indications for REBOA based on patient condition and trauma location.
2. *Simulated Ultrasound Availability* - The platform simulates ultrasound-guided access for common femoral artery (CFA) visualization and cannulation.
4. *Equipment Simulation* - The simulation includes all necessary REBOA equipment such as ultrasound machines, arterial sheaths, and REBOA catheter assembly kits.
5. *Arterial Access and Sheath Insertion* - Users can practice gaining arterial access using percutaneous methods.
6. *Balloon Inflation Monitoring* - The system allows for management of balloon inflation volumes and the observation of hemodynamic changes.
7. *Management of REBOA Deployment* - Users can practice the deployment of REBOA in Zone 1 and Zone 3 scenarios with appropriate timing and indications.
8. *Complication Handling* - The platform provides scenarios to diagnose and manage REBOA complications such as limb ischemia, arterial damage, or improper balloon placement.
9. *Trauma Scenarios* - There are comprehensive trauma scenarios that include both blunt and penetrating injuries where the use of REBOA might be indicated.
10. *Interdisciplinary Team Interaction* - The simulation supports multi-disciplinary team training for roles such as surgeons, anesthesiologists, and nurses.
11. *Dynamic Response to Treatment* - The platform dynamically responds to user interventions, allowing for real-time changes in patient status based on the management steps taken.
12. *Debrief Tools* - The simulation provides detailed debriefing tools that offer feedback on the user’s performance, decision-making, and adherence to the REBOA guidelines.
13. *Documentation Practice* - Users can practice the proper documentation of REBOA procedures as required, including placement time, pre/post-placement blood pressure, and REBOA insertion distance.

RESULTS

Accomplished efforts yielded the following: 1) the development and implementation of key SOST environments, REBOA catheterization procedure support, and expanded casualty support; 2) the development and implementation of additional medical assemblage, equipment, and procedures; 3) six SOST Advanced Resuscitative Care scenarios implemented and operational on the SimX platform.

Curricular Coverage

The SMEs responded positively regarding the curriculum’s focus on the importance of early hemorrhage control and resuscitation in accordance with JTS guidelines. They also appreciated the emphasis on the utilization of ultrasound for assessing cardiac activity and ensuring the proper sheath insertion site. There was consistent agreement that the curriculum included a thorough review of indications and contraindications for REBOA, along with the accurate, stepwise completion of the procedure. Additionally, they noted the curriculum's emphasis on determining the accurate insertion depth of the balloon, adjusting the inflation volume based on this depth, and ensuring the correct balloon placement zone based on the injury pattern was appropriate.

Potential areas for improvement were also similar across SME evaluations. They noted the absence of thoracotomy as an option in relevant cases, which could limit the comprehensiveness of the training. Additionally, the curriculum lacked the ability to perform stepwise sheath insertion, such as starting with a 5 French sheath (smaller) and converting to a 7 French sheath (larger) if the patient's condition deteriorated. Experts also suggested the inclusion of partial and/or intermittent balloon occlusion techniques to provide a more complete understanding of REBOA procedures and utilization techniques. Furthermore, they noted a lack of inclusion of training on indications and procedures for balloon takedown. Lastly, it was noted the curriculum should include scenarios that address potential complications, such as the inability to pass the wire or vascular injury, to better prepare users for real-life challenges.

The SME evaluations of the REBOA-based curriculum also highlighted several strengths and again noted areas for potential improvement (see Table 2). The curriculum scored very highly in several key areas, with scores of 6.7 for the recognition of indications for REBOA, management of REBOA deployment in both Zone 1 and Zone 3, comprehensive trauma scenarios, dynamic response to treatment, and interdisciplinary team interaction. The simulation of ultrasound availability and balloon inflation monitoring also received strong scores of 6.0, while equipment simulation and debrief tools scored 6.3. The arterial access and sheath insertion component received a slightly lower score of 5.7, and documentation practice scored 4.0. However, the handling of complications was notably low, with a score of just 1.3, indicating a significant area for improvement. In addition, troubleshooting potential complications was notably low (1.7), indicating another area where further enhancement is needed to ensure thorough preparation and troubleshooting abilities for users.

Table 2. Curricular Survey Results

	Likert Score (7-point Scale)			
Competency Area	**SME 1**	**SME 2**	**SME 3**	**Average**
Recognition of Indications for REBOA	6	7	7	6.7
Simulated Ultrasound Availability	5	6	7	6.0
Equipment Simulation	5	7	7	6.3
Arterial Access and Sheath Insertion	4	6	7	5.7
Balloon Inflation Monitoring	4	7	7	6.0
Management of REBOA Zone 1 Deployment	6	7	7	6.7
Management of REBOA Zone 3 Deployment	6	7	7	6.7
Complication Handling	1	2	1	1.3
Comprehensive Trauma Scenarios	6	7	7	6.7
Interdisciplinary Team Interaction	5	7	7	6.3
Dynamic Response to Treatment	6	7	7	6.7
Debrief Tools	5	7	7	6.3
Documentation Practice	5	3	4	4.0

The usability evaluation indicated a moderately high degree of usability (see Table 3). The platform allows users to practice REBOA skills in high-fidelity simulation environments, scoring 6.3 for this aspect. The curriculum includes modules and scenarios that can replicate organized REBOA training courses, like the American College of Surgeons' BEST course, scoring 5.5 in this area. It also ensures comprehensive training through hands-on skills components, with a score of 6.0, and uses anatomically correct models for accurate CFA access training, scoring 6.7. The curriculum is deemed very useful for REBOA skill sustainment, scoring 7.0 for indications and 6.7 for deployment.

Table 3. Usability Evaluation Results

Questions	7-Point Likert Scale Average (n=3)
This simulation allows users to practice REBOA skills in high-fidelity simulation environments that mimic real-life scenarios.	6.3
The platform offers scenarios that allow for the application of knowledge in both didactic and hands-on skills components, ensuring thorough preparation before actual utilization of the REBOA device.	5.0
The platform includes modules/scenarios that replicate organized, curriculum-based REBOA training courses such as the American College of Surgeons' Basic Endovascular Skills for Trauma (BEST) course or the "Resuscitation Adjuncts: Prehospital Transfusion & REBOA" (RAPToR) Course.	5.5
Hands-on skills components are included in this curriculum to ensure comprehensive training in the use of REBOA.	6.0
Anatomically correct models are used within the simulation to ensure accurate training of CFA access skills.	6.7
This curriculum is useful for REBOA skill sustainment purposes in regard to the indications for its use.	7.0
This curriculum is useful for REBOA skill sustainment purposes in regard to the deployment of the catheter system.	6.7
This curriculum is useful for REBOA skill sustainment purposes for troubleshooting potential complications.	1.7

DISCUSSION

The implementation of VR in ASRC training represents a significant advancement in medical education, particularly for SOST personnel who operate in high-risk, resource-constrained environments. This study explored the efficacy and practicality of VR training modules to enhance the clinical and tactical proficiency required in combat scenarios. The VR training modules provided a controlled, immersive environment where medical personnel could repeatedly practice complex trauma resuscitation procedures. This mode of training is crucial, especially when traditional methods, such as live tissue training and field exercises, are constrained by logistical, ethical, or financial issues. The flexibility of VR to simulate diverse medical scenarios—from routine interventions to complex trauma cases—allows for a comprehensive training experience that is both cost-effective and scalable. The VR scenarios were designed to challenge the participants' clinical skills and adaptability, requiring them to perform under conditions that closely mimic those encountered on the battlefield. This aspect of training is vital for maintaining the high level of readiness expected from military medical personnel.

The evaluations of the REBOA curriculum indicate a satisfactory focus on early hemorrhage control and detailed procedural guidance, with strong usability scores in high-fidelity simulation environments and the use of anatomically correct models. However, there are identified areas for potential enhancement, including the inclusion of thoracotomy and advanced sheath insertion techniques. Additionally, the curriculum appears to provide less comprehensive training on managing potential complications. While demonstrates REBOA indications and deployment, it could benefit from strengthened coverage of complication management and troubleshooting to enhance its practical applicability.

Limitations

Despite the benefits observed, several limitations were identified in the current scope of VR training implementation. The VR curriculum predominantly focused on the surgical environment, addressing specific segments of ASRC medical decision-making. This limited scope may not fully encompass the breadth of situations that SOST teams might encounter, which can vary widely in real combat operations. Moreover, the tactile feedback provided by VR simulations remains a significant limitation. The current technology does not fully replicate the haptic sensations of medical procedures, which can hinder the training effectiveness for tasks requiring precise manual dexterity. This limitation underscores the need for continuous technological advancements in VR to enhance the realism of medical simulations. Another critical limitation is the lack of comprehensive data linking VR training directly to improved field performance. While improvements in procedural knowledge and confidence were noted, the translation of these skills to real-world efficacy needs further validation.

Future Testing & Evaluation

An observational study will assess the effectiveness of VR training modules for team-based trauma resuscitation. Following a brief familiarization period with the VR setup, trauma teams will execute the scenarios, which will be recorded for detailed analysis. Performance will be quantitatively assessed using a nontechnical skill in trauma scoring system and scenario-based intervention timestamps, providing objective data on team performance and decision-making speed. Additionally, post-scenario surveys will gather participant feedback on the training experience, focusing on the realism and applicability of the VR environment. The study will compare outcomes across teams with varying levels of experience. For experienced teams, the research will track improvements in benchmark scores over multiple sessions, while for less experienced teams, the focus will be on the rate and extent of performance improvements. This comprehensive approach aims to quantify the impact of VR training on enhancing trauma resuscitation skills, aiming to validate the effectiveness and adaptability of VR in medical education.

A feasibility study will evaluate the practical aspects of integrating VR simulations into established medical training programs. It will focus on assessing the infrastructure needs, such as hardware, software, and physical space requirements, to ensure that VR technology supports the curriculum's educational goals. The study will also examine how the VR content aligns with existing training objectives, the readiness of educators to employ this technology, and the institutional willingness to adopt these innovative teaching methods. Additionally, a cost-benefit analysis will be conducted to determine the financial viability of implementing VR simulations, considering both the initial investments and ongoing operational costs. This evaluation aims to provide a detailed framework for educational institutions contemplating the adoption of VR to enhance training in advanced resuscitative care.

CONCLUSION

In this report, we detail an evaluation of a simulation curriculum designed to meet the critical defense-related mission need of providing medical simulation training on ASRC for SOST. This evaluation comprises a preliminary step toward the overall objective of this collaboration to enhance the decision-making capabilities of elite medical personnel across operational medicine through deliberate integration of VR technologies. The scenarios simulate the high-stakes environments that SOST teams operate in, aiming to improve their proficiency in ASRC under combat conditions. Our evaluation has indicated that this VR curriculum is sufficient for certain components of medical simulation training for ASRC techniques, tactics, and protocols (TTPs) including REBOA.

However, the extent to which these simulations impact real-world operational performance remains under critical review. While the project reports a significant expansion in training opportunities and a reduction in training costs, these factors alone do not fully demonstrate an enhancement in the overall effectiveness of ASRC training. The adaptation of medical TTPs into the virtual scenarios was achieved with considerable success, yet the translation of these simulated experiences into tangible battlefield medical outcomes needs further empirical support. As the curriculum progresses into further evaluations with units, it is imperative that these assessments focus not only on the quantitative expansion of training capabilities but also on the qualitative improvements in medical care that the training purports to enhance. The need for a consistent, methodological approach to evaluate the effectiveness of training outcomes remains critical. Future efforts should aim to directly correlate training scenarios with improvements in patient survival rates and operational decision-making in both military and civilian contexts.

ACKNOWLEDGEMENTS

We would like to thank the many collaborators of the VALOR program at the US Air Force (including the USAF Air Force, 24th SOW, AFLCMC/WIS, AFVentures), the University of Alabama-Birmingham, and SimX, Inc. for their ongoing assistance with our work. This material is based upon work supported by the United States Department of the Air Force. The content of this document does not necessarily reflect the views or policies of the Department of Defense or the US Government. Mention of trade names, commercial products, or organizations does not imply endorsement by the US Government.

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