Severe Trauma Stress Inoculation Training for Military Medics using Simulated Static and Dynamic Battlefield Injuries

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ABSTRACT

Severe trauma injuries create major challenges for front line military medical personnel. Many trained medical personnel are not psychologically prepared to encounter or treat severe wartime traumatic injuries. Current technologies for simulating severe trauma lack the realism and clinical accuracy necessary to provide fully immersive training experience for combat medical situations in a training environment.

The Virtual Reality Medical Center (VRMC) developed the Injury Creation Science (ICS) wearable prosthetic wounds in support of the Severe Trauma Simulation Army Technology Objective (ATO) managed by the Research Development and Engineering Command Simulation & Training Technology Center (RDECOM STTC). The mission of the ATO is to research and develop innovative technologies to realistically simulate the look, feel and smell of severe trauma to prepare medics, combat lifesavers and Soldiers to deal with injuries encountered on the battlefield. The prototype prosthetic wounds developed under this effort realistically simulate a number of battlefield injuries such as amputations, eviscerations, blast injuries, penetrations and burns.

This paper will discuss in detail how training requirements and the student's need to master a variety of procedural skills impacted the design of the ICS Injury Simulation Kits. The paper will also describe the criteria used to develop the overall design, as well as, the identification of specific injuries. In addition, the paper will discuss how subject matter expertise was utilized to develop metrics and processes used to evaluate the overall benefits of the program. Finally, the results from user tests and lessons learned from the development and implementation of this project will be discussed.

ABOUT THE AUTHORS

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INTRODUCTION

Modeling and simulation plays a key role in the development and refinement of Army techniques and procedures. One group that greatly benefits from the use of simulation during scenario training is military medical personnel. Their primary mission in combat is to treat the wounded and save lives. Army combat medics, also known as 68Ws, are responsible for providing medical care at the point of injury in the battlefield. Army medics must assess a situation, prioritize treatment and decide on an appropriate course of action under combat conditions. Severe trauma injuries create major challenges for front line military medical personnel. Many trained medical personnel are not psychologically prepared to encounter or treat severe wartime traumatic injuries. Realistic scenarios are the key for competency development and stress inoculation. Current moulage (wound simulation) technology for simulating severe trauma lacks the realism and clinical accuracy necessary to provide fully immersive training experience for combat medical situations in a training environment (Wiederhold, Bullinger, & Wiederhold, 2006). Since training is the primary vehicle used to enhance and maintain a medic's readiness, trainers are focusing on providing the necessary tools to augment realism in the Soldier's training experience.

The Virtual Reality Medical Center (VRMC) developed the Injury Creation Science (ICS) wearable prosthetic wounds to support realism in medical training. These prototype prosthetic wounds realistically simulate a number of battlefield injuries such as amputations, eviscerations, blast injuries, penetrations and burns. When utilizing a tool for training, it is important to evaluate its effectiveness in enhancing the training experience. Early usability evaluations with subject matter experts resulted in refinements to the overall design. This paper will discuss in detail how training requirements and the student's need to master a variety of procedural skills impacted the design of the ICS Injury Simulation Kits. The paper will also describe the criteria used to develop the overall design, as well as, the identification of specific injuries. In addition, the paper will discuss how subject matter expertise was utilized to develop metrics and processes used to evaluate the overall benefits of the program. Finally, the results from user tests and lessons learned from the development and implementation of this project will be discussed.

BACKGROUND

Simulation for the development and refinement of surgical skills has come to the forefront in recent years (Gallagher et al., 2005). Reznick and MacRae (2006) note that the earlier stages of teaching technical skills should take place outside the operating room (i.e. on surgical simulators) with practice being the rule until automaticity in basic skills is achieved. However, existing technologies for simulating severe trauma are not realistic or clinically accurate. These simulations do not look, feel, smell, act or react properly. Testimonials from Medics returning from combat convey the fact that current simulations did not prepare them for the horrific injuries they encountered on the battlefield. In order to address this gap in training, the U.S. Army Research Development and Engineering Command, Simulation and Training Technology Center (RDECOM-STTC) is currently executing a three-year (FY07-10), joint Army Technology Objective (ATO) with the U.S. Army Medical Research and Materiel Command (MRMC), entitled Severe Trauma Simulations. The mission of the ATO is to research and develop innovative technologies to realistically simulate the look, feel and smell of severe trauma to prepare medics, combat lifesavers and Soldiers to deal with the injuries encountered on the battlefield. The results from this effort will produce enhanced tools for realistic medical training enabling the Army to maintain better trained medics and to improve the ability to save lives on the battlefield.

Treating simulated injuries has been shown to be effective in improving medical skills. A 2004 analysis from the Agency for Healthcare Research and Quality discussed the effectiveness of surgical simulators. In a randomized study, Derossis et al. (2008) evaluated surgical residents and attendings and found that those trained with a simulator had greater proficiency in suturing, transferring, and mesh placement, when tested on the simulator, than did the control group. They subsequently found that when tested *in vivo* on pigs, surgeons (both attendings and residents) who had been randomized to the simulator arm were more proficient at the same skills. In addition, the use of a hemorrhage simulator has been shown to improve the time it took military medic trainees to stop severe extremity hemorrhage (Mabry, 2005) and part-task training (PTT) has been shown to be effective for many aspects of procedural training (Champion & Higgins, 2000).

The Injury Creation Science program (ICS) is focused on research and development in support of the TC3 (Tactical Combat Casualty Care) program of instruction. Tactical Combat Casualty Care, also known as TC3, is the pre-hospital care rendered to a casualty in a combat environment (CALL, 2006). The application of TC3 principles in a tactical combat environment has proven highly effective and is a major reason why combat deaths in Operation Iraqi Freedom and Operation Enduring Freedom are lower than in any other conflict in the history of the United States (Parsons, 2006). Even though Killed in Action (KIA) rate for Operation Iraqi Freedom is currently at a historically low rate (ICCC, 2009), Soldiers continue to die on the battlefield from three main causes: hemorrhage, airway compromise, and tension pneumothorax (Parsons, 2007).

Moulage is an integral part of scenario-based medical training, especially in live training. Wound simulation began in 1834 with military mass casualty exercises in which artists painted injuries on the body. Moulage filled a role more for the benefit of the organizers of military maneuvers, since the level of realism at the individual medic or corpsman level was low. Hollywood makeup and theatre techniques followed, providing elements of realism such as blood and open fractures to the training simulation. In general, however, some of the more advanced Hollywood techniques have not been used in military simulation training. Early Italian and Dutch anatomists are seen as the beginning of the spread throughout Europe of wax injection techniques for anatomic preparations applied to both the living and the dead (Schnalke, 1995). Sculpting wax is still utilized at some military medical simulation centers to create traumatic injuries. The method requires specialized expertise and significant amount of time to model a realistic wound. In addition, the wounds created to support a scenario cannot withstand more than one iteration since the wax easily slides or detaches from human skin when the wound is manipulated with pressure or a bandage, as would be done by a trainee during a training exercise or exposed to extreme climates (e.g. heat, humidity, rain, soil, etc.). This injury simulation methodology requires recreation of the injuries for every iteration of training. Trainers spend several hours every day "moulaging" actors and mannequins to support training scenarios. Another injury simulation methodology currently available involves plastic, strap-on wounds. These wounds are not visually realistic or physiologically accurate and made of a material that not very pliable and is uncomfortable to wear. Most importantly, this particular methodology does not provide an immersive experience to the trainee.

By merging the latest special effects technology with material science research, the ICS team developed prosthetic human tissue and wounds for a realistic live training capability. This technology is critical for the trauma care training being used by the Army to train combat medics. This same technology is being transitioned to assist with similar training requirements in the civil sector for Emergency Management, Disaster Management, and First Responder personnel. The ICS Simple Kit is the first product developed in response to a growing need in trauma care training. This kit allows for the application of prosthetic entry, exit, and shrapnel wounds for live training exercises focused on enhancing realism.

REQUIREMENTS ANALYSIS

The requirements analysis was a critical component in the product development. This phase of the development cycle consisted of an in-depth review and analysis of emergency medicine doctrine and protocol, recent theater injury data, and training programs and practices. Several site visits were also conducted to various emergency medicine training facilities to outline the shortfalls of current training culture and training aides. Additionally, data from the U.S. Army Institute for Surgical Research that summarized injuries encountered in recent theater operations was reviewed. This data proved to be useful in determining which injuries and procedures were of highest priority. This exercise provided an understanding of the procedures and wounds that were most frequently encountered in theatre, allowing for the development of a set of fundamental requirements that were necessary for product design.

Beyond determining which procedures and injuries would be simulated, the overarching aim of this research effort was to develop a more immersive training experience for the trainee. As a result, it was determined that importance should be placed in the development of a product that was:

- Visually and tactilely realistic
- Comfortable
- Easy to apply and remove
- Durable
- Reusable

Once the fundamental requirements were characterized, it was easier to focus on finalizing the requirement analysis with respect to:

- Prosthetic Wound Representations
- Prosthetic Tissue Composition
- Pigment
- Adhesive
- Adhesive Remover
- Makeup
- Simulated Blood
- Shrapnel
- Appliance Storage
- Packaging

DEVELOPMENT

The prosthetic wounds were designed after research and comparison with actual wounds. The prosthetic appliances were designed to affix to a human actor or mannequin as a patch, and consist of simulated skin, underlying tissue, representations of organs or structures, and a protective layer next to the wearer's skin. The initial focus was to develop static entry and exit wounds as a means of developing the ideal chemical and mechanical composition as an underlying technology for future development.

Initial research indicated that although transparent silicone appliances would be favorable in terms of flexibility and packaging in the kits, these would require specialized makeup expertise or skills for application. Inherently coloring the prosthetic wounds simplified the application process. In order to facilitate ease of use of the wounds, these would be manufactured in various skin tones that closely resemble human skin.

Simulated skin has been studied much less than simulated tissue, although animal skin has been used for injury simulation studies. Jussila (2005) notes that the significance of simulated skin has been overlooked, even though its use increases the fidelity of experiments involving injury simulation for low-velocity projectile injuries or effects such as ricochets. The research conducted under this effort revealed some important information that may be useful in the construction of simulated skin and tissue for the advanced trauma training program. In particular, we have found information that reveals both biochemical and structural clues as to how to begin to quantify the physiochemical properties of skin and tissue. For example, skin water content and elastic properties are important contributors to the look, feel, and texture of skin. In addition, some of the most important connective tissue components that have been identified provide a basis to begin modification of existing artificial substances to improve the level of realism in artificial tissue. A number of non-invasive and minimally invasive technologies have been identified that will assist in the creation of new synthetic materials that reproduce the critical aspects of tissue.

Studying human tissue using spectroscopy was critical to further developing the ICS technology. We used spectral analysis to evaluate the early ICS prototypes, and explored ways to improve them based on the quantitative data acquired during testing. With this data, we compared ICS prototypes to the properties of human skin. Further work remains in this area and possible outcomes include identifying existing materials for simulation effects, developing hybrids, and developing completely new materials and methodologies.

At the end of the design effort, the result included a kit with prosthetic wounds in various skin tones and the peripheral items required (e.g. adhesive, remover, makeup, blood, application supplies, etc.). This stand alone kit provided an Off-The-Shelf solution for highly realistic injury simulation and required minimal training and no specialized skills.

USABILITY TESTING

The prosthetic wounds were designed to be used with human actors as well as mannequins/human patient simulators. Efforts to assess the usability of the devices in the training environment when used on human actors and mannequins are described below. In addition, metrics obtained during usability testing regarding application and removal are included in the discussion.

Application of Prosthetics to Human Actors

The University of Florida Center for Simulation Education and Safety Research (CSESaR) is located on the Shands Jacksonville Medical Center campus and housed in a 24,000 square foot facility. The primary mission of this facility is to provide a simulation training center that focuses on healthcare education and patient safety. UF CSESaR faculty agreed to allow our team to design and conduct a Proof of Principal (POP) event for their Emergency Medicine (EM) Residents. An immersive training experience was developed and produced for EM Residents to provide a testing opportunity for the ICS prosthetic wounds.

The test event lasted approximately fifteen minutes and replicated the conditions and circumstances likely to take place in an emergency room situation. The goal of the effort was to solicit feedback for the ICS prosthetic wounds while satisfying a subset of Emergency Medicine Residency Program objectives.

During the debrief, the trainees reported higher levels of realistic appearance in comparison to mannequin training experiences, in particular with respect to the color and physiological structure of the wounds. The trainees who were selected to participate in the POP exercise were first, second, and third-year Residents. We found that the trainees with more years of experience were more easily immersed in the simulation exercise. The attending physicians found that the POP exercise provided them with a unique opportunity to teach soft and interactive skills development to the trainees.

During laboratory testing, it was determined that whether the prosthetic wounds were new or previously used made little difference when they were stretched. After several hours, friction from tighter clothing made edges start to peel, but the prosthetic wounds still would not come off the human skin. Even after showering, no difference was noticed in the integrity of the wound. Wearing socks and shoes all day did not affect the edges of the prosthetic wounds adhered to ankles; the edges did not lift when adhered at the ankle, whether on the top of the foot or on the crease.

After much testing of the prosthetics, we consistently recorded the times listed in Table 1 for each step involved in the use of the prosthetic wounds in human actors.

Table 1. Usage Metrics on Human Actors

Step	Time
Application	10 Minutes
Set Up Kit	10 Minutes
Removal	3 Minutes
Clean Up Kit	5 Minutes

These times were confirmed during the POP at UF CSESaR.

During a site visit to Camp Lejeune's FMTB (Field Medical Training Battalion) facility, preliminary product testing was conducted of the ICS prosthetic wounds. During this test, nine USN Corpsman squads received hands-on training using mannequins and human actors portraying injured patients. The application of prosthetic wounds was accomplished in one hour. Because the ICS prosthetic wounds are highly durable and remain intact for 18-24 hours after application, the training that usually required 10.5 hours lasted only 6 hours. The ICS prosthetic wounds remained intact during the entire day, thus eliminating the need to moulage mannequins and patients in between scenarios. Using existing products and methodologies, training the same number of squads would have required 4.5 additional hours due to the need to re-moulage in between scenarios. Human actors reported higher levels of comfort and trainees reported higher levels of immersion during training scenario. The instructors reported a significant time savings, which allowed them to focus on remediation training with some of the squads and other duties.

Application of Prosthetics to Mannequins or Human Patient Simulators

Students from the Modeling and Simulation Graduate Program at the University of Central Florida conducted an experiment during summer 2008 to assess metrics for the application of prosthetics to mannequins/Human Patient Simulators (Elbadramanv & Guay, 2008). Twenty-one students participated in the study. Individual participants were trained on how to apply the prosthetics to a mannequin and were asked to record the time they start preparing the moulage, the time for the glue to dry, the time to apply the make-up, and the time to remove the makeup, including the simulated blood. Mean time results are listed in Table 2.

Table 2. Usage Metrics on Mannequins

Step	Time
Glue Application	2.6 Minutes
Glue Dry Time	6.3 Minutes
Make Up Time	9.4 Minutes
Clean Up Kit	4.8 Minutes

The times observed during the experiment were very close to the times observed during the POP at UF CSESaR.

LESSONS LEARNED

Feedback from users indicated that it would be helpful to provide a guide to the specific locations on the body were the different prosthetic wounds should be adhered. This information would maximize the realism of the prosthetic wounds by ensuring that they are consistent with location (e.g. a fleshy wound on a fleshy body part). A sample wound arrangement chart to classify a set of specific wounds was subsequently added to the Simple Kit User Manual to provide this capability. In regard to the application of the prosthetics to human actors, it was consistently noted that the time to apply each prosthetic appliance was less than ten minutes. The process was simple and comfortable for the human actor. It was also confirmed that the prosthetic appliances withstood several iterations of the scenario intact. The trainees believed the appliances to be very realistic, and they proved to be durable. The prosthetics were easily removed and could be cleaned for future use. The removal process was not painful for the human actor and was easily accomplished without special training. The process took approximately five minutes. In regard to the application of the prosthetics to mannequins, students consistently reported that makeup did not adhere on the artificial skin the same way it was adhering to human skin as in the case of the actors. Therefore, a different kind of makeup may be needed for mannequins.

CONCLUSIONS AND PATH FORWARD

During development of prosthetic appliances, extensive testing and application of synthetic materials were used in simulating texture and viscosity that would result in realistic simulation of wounds. An objective analysis by material science experts confirm laboratory findings and no further research and development is needed regarding the silicone applied in the appliances. Realism in the coloration of the prosthetic appliances is a critical component in maximizing the realism of the prosthetics. Embedding realistic skin colors and flesh tones as three different options increases the usability of the prosthetic appliances in that the user requires minimal makeup experience. Regarding the adhesive selected for the ICS Kit, the silicone adhesive is durable and most effective on silicone prosthetics. Even though the packaging of the adhesive minimizes the skills required by the user for application, it also limits the method in which the adhesive, and thus the kit, can be transported. User feedback is needed before proceeding with any changes to this component of the kit. Since the adhesive remover is dependent on the adhesive selected, a recommendation with respect to the adhesive remover is to provide more in the kit to maximize the proper cleaning of surfaces.

Initial feedback regarding the makeup provided in the kit was obtained from one user site. Originally the makeup provided was selected primarily for ease of use and durability. A final decision regarding the type of makeup to be included in the kit will be reached after acquiring additional feedback from users. It is recommended, however, that supplemental makeup such as a sampling of bruise, charcoal, and dirt effects be provided in the kit in order to further enhance the realism of the prosthetic appliances.

After receiving initial feedback regarding the appearance of the simulated shrapnel, plans have been developed to modify the color of the shrapnel. When comparing the simulated shrapnel to actual pieces of shrapnel, the approach utilized focused too much on providing a pristine metallic sheen versus a burned, dirty, used piece of metal. Changing the color significantly changed the appearance of each shrapnel piece. Future enhancements will focus on providing larger pieces of both simulated metal and glass shrapnel.

In summary, significant feedback from multiple user sites is required to finalize the ICS Kit. In addition, feedback from multiple services or types of units to provide a more universal kit would be also very useful, since feedback from multiple users is instrumental in driving changes in requirement and design. Initial feedback has been documented and potential changes will be explored as a result of the interaction with users in the civilian and military sectors.

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