

Simulated Patients for Tactical Trauma Triage Training

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ABSTRACT

An interactive simulation has been developed to augment casualty training to non-surgical military physicians and combat medics. Virtual casualties were developed to represent blast injuries from improvised explosive device (IED) detonation, including barotraumas, brain injury, amputations, burns and shrapnel injuries. These were implemented using realistic visual and physiological models. The caregiver can interact with the patient, use medical devices, monitor physiological signs, and perform treatments. Scenarios were developed for training military medical personal how to perform effective multicasualty triage and practice initial care of casualties. These scenarios provide an evolving medical situation in potentially hostile environment. Child and adult civilian casualties are embedded with the military casualties to provide cultural context and enhance realism. It is anticipated that improving the triage and management skills among these providers will promote better clinical decision making leading to enhanced patient outcomes.

KEYWORDS

Casualty care, triage, physiological modeling, training, virtual reality, medical simulation

INTRODUCTION

Triage is the process of establishing the priority of care among multiple casualties to rationally allocate the use of limited resources. Traditionally considered the cornerstone of effective disaster management, it is an important skill for first responders who are faced with disaster situations, where available health-care resources are insufficient for the number and severity of casualties. First responders in disaster situations must deal with multiple issues, including limited personnel and/or competencies; limited facilities, equipment, and supplies; and delay in transport to definitive medical care.

In the civilian sector, the evolution of a multiple casualty scene begins with the event (e.g., explosion, hurricane, mass transit collision) with no medical personnel or equipment on scene. As emergency care providers arrive, they first assess the scene and establish control, then rapidly assess each casualty (in about 30 seconds) and tag each casualty as immediate, delayed, minor or expectant. Resources are initially given to those who need immediate care in order to survive. For casualties with minor injuries, casualties assigned to delayed care, or casualties expected not to survive, it is assumed that more help will soon arrive with personal and resources to supplant the caregivers initially on scene. Those casualties needing quick transport to definitive care are evacuated by ambulance or helicopter. Time on scene is minimized for these casualties.

In the military sector, the context and evolution of the scene may be quite different. Soldiers and marines train and operate in groups. All receive some level of training in emergency trauma care, and one or more present at the time of the event may be medics or corpsman (now called Health Care Specialists) with training in advanced first aid. These military medical providers carry medical kits packed with the latest bandages and devices for rendering field medical care based on expected injury profiles for the current conflict (Gulland, 2008). This is a clear advantage in providing immediate care, and a critical need since transport to definitive medical care may be quite delayed depending on the tactical situation. Still, the on-scene soldier-medics have limited resources in the number of medical personnel and available first-aid devices to treat all that are injured. Additional resources may not arrive on scene; as the emphasis is on transport out of the dangerous situation. Training in managing multiple casualties in the context of delayed transport with limited medical resources is all the more necessary.

The Need for Triage Training Aids

In the mid-1980s, Vayer et al. cited Butman's analysis of 51 mass-casualty incidents that identified a universal failure to execute proper triage. Like most time-sensitive, high-stakes cognitive skills that are rarely used, triage requires regular practice to maintain proficiency and confidence in decision-making. Civilian triage is generally practiced using constructive tabletop or live exercises. Tabletop exercises are more abstract and less effective in honing skills. The expense of obtaining, training, and moulaging multiple actors for live exercises usually forces triage to be incorporated into larger collective training exercises designed for the entire disaster response infrastructure. These exercises require scheduling of medical providers, trained actors, and frequently focus on organizational and logistical issues, with little practice focused specifically on medical triage. Actual disasters, such as explosions, hurricanes, or toxic exposures, occur so rarely that there is little opportunity for gaining experience during real events.

Military medical training makes extensive use of partial-body and whole body mannequins, with simulated injuries, bleeding, respiration, and other body functions, to acquire, practice, and validate first aid skills. Moulaged mannequins and personnel may be incorporated into live military exercises to offer a sense of realism and experience in a simulated battlefield environment and tactical situation. As in the civilian sector, such training can only be offered infrequently and requires extensive scheduling and expenditure to achieve. Once in theater, military medical personnel have little opportunity for multiple-casualty training to sustain their triage skills.

To meet this need, we developed Sim-Patient™ Triage, a 3-D interactive medical simulator for civilian triage training (Kizakevich et al, 2006a; 2206b, 2007). Recently, we further tailored the simulator for the military tactical environment and implemented a set of relevant multiple-casualty trauma scenarios. The current version, called Chamberlain's Challenge, was designed to provide predeployment and in-theater training in the use of new medical protocols and devices which been developed to improve the capabilities and assessment of the non-surgical physician, combat medic, and combat lifesaver. The purpose of this training is to improve clinical decision making while improving assessment and management skills in the multiple-casualty field environment.

THE SIMULATION ARCHITECTURE

The Sim-Patient™ Triage simulator is based on a series of single-casualty virtual reality simulators previously developed for emergency care training (Kizakevich et al 1998; 2002). Each casualty is an animated character situated in a virtual environment (Figure 1). The student can navigate and survey the scene, as well as interact (e.g., take a pulse) and converse with virtual patients and other characters as needed. A set of medical toolkits provide airways, bandages, drugs, and other devices for provision of medical care. Toolkits are packed according to the training objectives and context of each scenario. A learning module guides the user through standardized protocols, and interactions are recorded for review, along with pertinent physiological and behavioral data.

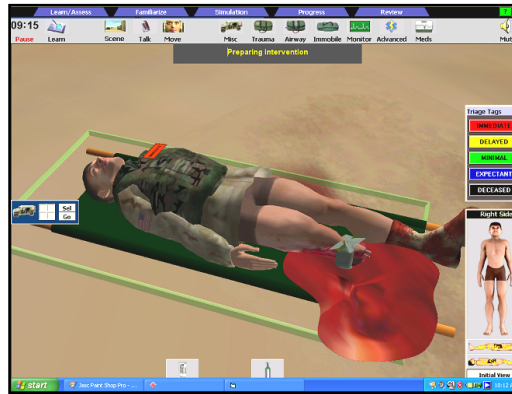


Figure 1. Single casualty in Sim-Patient.

Sim-Patient comprises a collection of software modules that are dynamically linked to construct an integrated simulation program according to the functional needs of a specific simulation application. These include an extensive scripting engine that can direct changes in the visual environment, evoke sounds and distractions, and effect state changes in the physiology and behaviors of individual simulated patients. A 3D graphics subsystem, called RTIVisualizer, provides a high-level interface to the underlying graphics rendering engine (Gamebryo, by Emergent Game Technologies) and manages support for features such as facial expression, breathing motion, and character animation. A key component of Sim-Patient is the Sim-Person™ character simulator which provides individual patient simulation as a separate executable program. Sim-Patient can invoke multiple Sim-Person executables as needed to implement a particular training scenario.

Virtual Patient Simulation

The Sim-Person™ character simulation module comprises an set of anatomical, physiological, medical, cognitive, emotional, social, behavioral, interventional, and visual models. An object-oriented “Person” executive program manages each of these models (Figure 2), loads initial conditions, manages autonomous behaviors, updates model states, responds to user interventions, evokes script-based events, and directs visual and audible representations of medical conditions and human behavior.

The physiological simulation integrates real-time cardiovascular, ventilation, and respiratory models for simulation of injuries and medical conditions, reporting of physiological signs, and generation of behavioral responses to appropriate and inappropriate interventions. For cardiovascular simulation, we extended the Research Cardiovascular Simulator (RCVSIM) (Goldberger, 2000; Mukkamala 2001; Coolahan, 2004) to include hemorrhage modeling, fluid resuscitation, emotional stimulation, and control of cardiac contractility and heart rate. These models generate real-time physiological signals including pulsatile hemodynamic waveforms.

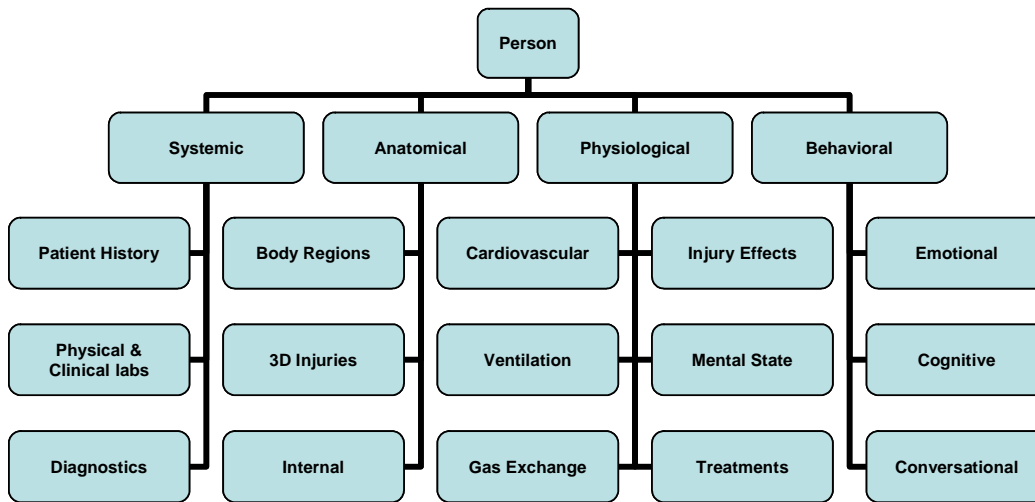


Figure 2. Collection of models and simulation components in Sim-Person

For respiratory simulation, we extended a parallel multicompartment gas exchange model (Kapitan et al, 2008) with functional degradation due to chest injuries, such as pneumothorax, hemothorax, and lung injury. For ventilation simulation, we developed a simple, single-exponential, tidal breathing model with ventilation control (Batzel, et al (2005; Yem et al, 2006) to generate real-time respiratory signals. Functional effects of airway obstruction and treatment were also simulated. Level of consciousness is modeled as parallel functions of mean arterial pressure and oxygen content.

Simulated patients have previously been developed for trauma, bioterrorism, and chemical casualties (Kizakevich et al, 2002; 2003; Hubal et al, 2007) as well as mentally disturbed individuals (Frank et al, 2002) and pediatric patients (Hubal et al., 2003). Patients portray signs and express symptoms relative to their initial and changing condition, and medical treatments such as bandaging, splints, and fluid resuscitation. Animations such as bleeding, vomiting, coughing, seizure, and convulsions relate to physiological status and interventions. The patients have dynamic facial expression, gestures, and body movement, and can portray anger, fright, confusion, or other emotions or behaviors based on cognitive, emotional, physiological, and pathological models.

Sim-Person includes a scripting engine that can direct state changes in the physiology and individual simulated patients. These include onset and severity of medical conditions such as airway obstruction, cardiac tamponade, and pneumothorax; and changes in heart and respiratory rate, including cardiac and respiratory arrest. Scripting can also set certain physiological signs, such as lack of peripheral pulses or regional pain, and be used to evoke casualty behaviors such as facial expression, calling out, and movement.

All of these features add to the realism of the training by requiring that the student integrate knowledge of diagnostic processes with the search for and recognition of visual and audible symptoms, visual reinforcement of monitoring and treatment devices, and awareness of the changes in patient conditions over time. The dynamic visuals and audio also increase the emotional involvement and enhance the sense of immersion.



Figure 3. Multiple-casualty triage in the 3D interactive training environment.

Multiple-Casualty Triage Simulation

The multi-casualty simulation has been configured to provide practice that reinforces essential knowledge, skills, and attitudes. The simulation reinforces essential knowledge by familiarizing clinical personnel with triage procedures, helps them recognize different types of injuries, and helps them anticipate complications. It reinforces essential skills by allowing them to practice and integrate triage, assessment, and treatment protocols. And it encourages essential attitudes including confidence in decision-making.

Figure 3 presents a multiple-casualty scenario in a Middle Eastern urban environment, depicting what might result from the explosion of an IED. Students must survey the scene, interact and converse with each patient, use medical devices, administer medications, monitor data, and perform interventions. Color-coded tags are used to triage each casualty, thereby designating the victim's priority of care. The triage tags are used within a four-level classification system (Immediate, Delayed, Minor, and Expectant) consistent with the Simple Triage and Rapid Treatment (START) triage method (Super, 1984). While applicable for civilian triage training, use of the START triage tags may not be applicable in tactical military scenarios. Use of triage tags, or not, is an option in Sim-Patient. Tags are simply another tool available to instructors and are used depending on the learning objectives of the triage course.

Ground or air transport is requested via a "Radio" using a verbal protocol that summarizes the casualty situation, the tactical situation, and the need for additional resources (such as oxygen equipment). Transport priority is managed on the scene for selective evacuation of each casualty. The student can manage casualty evacuations according to on-scene and arriving transport resources, with the assignment of up to four casualties per ground vehicle and two casualties per helicopter. Transport vehicles arrive independently "some time" after the student makes a request, with a random delay of 10 to 25 minutes per vehicle. During this time the student must periodically reassess the scene and manage remaining casualties with available resources until each is transported.

Casualty Case Definitions for Triage Training

The traumatic sequelae associated with blast injuries from improvised explosive device include (IED) detonation, including barotrauma, Traumatic Brain Injury (TBI), traumatic amputations, thermal burns and shrapnel injuries; have changed the face of combat medicine. The authors' mission was to develop an evidence-based instructional aid for combat casualty assessment and initial management, with case design based upon the reality of injuries encountered in-theatre. Additionally, educational material included new trauma management protocols which had been developed for military medical providers, including advancements in hemorrhage control, intraosseous fluid resuscitation, and initial evaluation and management of warfighters with TBI.

Upon establishing core learning objectives for the platform and each simulation with a subject-matter expert, the authors designed a case definition matrix (Table 1). Each case was linked with specific core objectives, interventions, medical devices, and anticipated outcomes. Thirty simulation cases were developed in this manner, based upon available clinical evidence from military medical reference data from Operation Iraqi Freedom. Descriptive case definitions, including anatomical injury pattern and acuity, were based upon abstractions from summary and categorical statistics from published casualty data. To add cultural relevance and enhance realism, gender, age, race, ethnicity, and clothing were also varied according to expected field conditions. These extrapolated results were then applied to the case definition framework.

Table 1. Demographic and injury attribute variations for case development.

Attribute	Evidence-based variations
Injury	Penetration, burn, blunt, amputation, fracture, blast lung, tympanic membrane
Location	Head, face, chest, abdomen, back, arm, thigh, lower leg
Critical condition	Hemorrhage, airway obstruction, pneumothorax, hemothorax, deafness
Gender	Male, female
Age	Adult, child
Race/Ethnicity	White, black, Hispanic, "Middle Eastern"
Clothing	US Army, American civilian, Iraqi civilian

Training scenarios were developed incorporating these casualties for practice of triage and first aid consistent with the IED-related injuries. Scenarios were implemented with one, three or six casualty cases in the scene. The severity of each case was governed to ensure a relatively even distribution among the four triage priorities, immediate, delayed, minor, and expectant. These scenarios provide an evolving medical situation with graphically intense casualties (i.e. amputations, massive burns) and deteriorating physiological status. Except for the minor category, all other cases would eventually result in death if appropriate care were not provided within 20 minutes. These challenging cases were developed to promote rapid, thoughtful, clinical decision making and to provide realistic experience. In these dynamic, chaotic scenarios there is no single right approach to scene management. Consequently, student performance is not scored; rather all physiological data and student-casualty interactions are stored for subsequent one-on-one instructor review. Should an instructor desire an automated student after-action review (AAR), then an alternative set of casualties with stable medical conditions depicting each of the four START triage categories can be selected.

EXPERIENCE WITH THE SIMULATOR

This triage simulator has been used at Fort Campbell and Fort Drum for pre-deployment training of Army medical staff. The simulation helps the medical staff prepare for the kinds of situations that they will face while in the field. The scenarios used in this training have been selected to reflect current operating conditions. One system has been deployed to Fort Bucca, Iraq for sustainment training of Army medical personnel. Systems have also been deployed to Afghanistan as a demonstration project; however any substantive evaluation on its use, utility, or effectiveness has not been conducted.

The Sim-Patient Triage simulator was integrated with a triage training curriculum at the 2006 Duke Disaster Intersession. Two hundred sixty-two Intersession students were randomly assigned one of two educational interventions: (a) constructive simulation-based triage training using verbal case presentation or (b) Sim-Patient Triage training using interactive medical simulation. Both groups received a standardized lecture, followed by thirty minutes of small group exercises during which each student enacted triage upon four simulated patients. Following the educational intervention, students were presented with moulaged standardized patients and evaluated on their ability to enact triage using the START triage method. Students in the VR group rated higher their sense of involvement, perceived value of the learning experience, and overall value of knowledge and skills development than students in the constructive simulation. Students' performance were not significantly different between the two groups.

As part of a U.S. Agency for International Development (USAID) project to enhance medical training in Iraq, we developed a "Train-the Trainer" curriculum in trauma triage. Twenty-two Sim-Patient triage simulators were delivered to the Iraqi Ministry of Health (MOH) for use in the triage course, and subsequent turn-over to the planned Centers of Excellence for training of other medical personnel. In cooperation with the MOH, select physicians were recruited to attend a short course on triage and how to use the Sim-Patient triage simulator for training other medical staff. Participants evaluated the curriculum using a questionnaire comprising qualitative measures, and requests for comments according to several categories. On a scale of 1-5 (5 being excellent), participants rated the overall quality and experience at 4.38, better than very good. Overall the received comments were rated as 93% positive.

CONCLUSION

Sim-Patient Triage, a "serious games" medical simulation system, has been developed to augment casualty training to non-surgical physicians, nurses, paramedics, medics, and corpsman. The simulator can familiarize emergency providers with multiple-casualty triage protocols, assess their competence to recognize and treat specific conditions, and help them gain experience in coordinated disaster response. The architecture integrates interactive 3D game technologies with trauma injury modeling, physiological simulation, medical care, and learning management. It is anticipated that improving the triage and management skills among these providers will promote better clinical decision making leading to enhanced patient outcomes.

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