Virtual Reality Simulation for Multicasualty Triage Training

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ABSTRACT

Multicasualty triage, establishing the priority of care among casualties in disaster management, is generally practiced using constructive tabletop or live exercises. Live exercises require scheduling of medical providers, trained actors, and frequently focus on organizational and logistical issues, with little practice of medical response. Actual disasters, such as explosions, hurricanes, or toxic exposures, occur so rarely that there is little opportunity for gaining experience during real events.

The triage simulation described in this paper is the result of over a decade of development of virtual reality systems for medical care training, including trauma, bioterrorism, and chemical agent casualties. These simulators present scenarios comprising a scene and one or more virtual patients. Each casualty has its own injuries, physiological simulation, and signs and symptoms that change with the evolving condition. Animations such as vomiting, tearing, coughing, seizure, and convulsions relate to physiological status and interventions. The caregiver can navigate the scene, assess and converse with the patient, monitor diagnostic data, and apply medical devices, medications, and other interventions. Scenarios were developed for training military physicians how to perform effective multicasualty triage and practice initial care of casualties consistent with improvised explosive device (IED) injuries. These scenarios provide an evolving medical situation with graphically intense casualties including amputations, penetrations, massive burns, chest wounds, and blunt trauma. Child and adult civilian casualties are embedded with the military casualties to provide an engaging urban disaster scenario. Caregivers assign the virtual casualties a triage priority and administer immediate care as indicated. A learning module guides the user through standardized protocols, and interactions are recorded for review, along with pertinent physiological and behavioral data. This triage simulator has been used at Fort Campbell and Fort Drum for pre-deployment training of Army medical staff, and at Fort Bucca, Iraq for sustainment training. User surveys have been requested from medical personnel for usability and face value comments. Available summary results will be presented.

ABOUT THE AUTHORS

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Robert Furberg is a Health Analyst within the Technology Assisted Learning Center at RTI. A practicing paramedic with over ten years of experience in emergency services, Mr. Furberg maintains multiple instructorships and an active role in national prehospital education, training and research. His current affiliations include Orange County (NC) Emergency Management and he is an active Medical Reserve Corps member. Mr. Furberg holds a BS in Prehospital Emergency Medicine and he is a Masters of Public Health candidate at the University of North Carolina at Chapel Hill..

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INTRODUCTION

Triage for Disaster Preparedness

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
- Delay in transport, delay in definitive care

Both the war in Iraq and Afghanistan and disasters in the United States including September 11 and recent hurricanes have increased the recognition of the importance of training for disasters.

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. Triage is generally practiced using constructive tabletop or live exercises. Constructive tabletop exercises are more abstract and less effective in honing skills. On the other hand, the expense of obtaining, training, and moulaging multiple actors for live training exercises usually forces triage training 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.

THE SIMULATION ARCHITECTURE

The triage simulation described in this paper was developed by leveraging several virtual reality systems developed for medical care training, including trauma, bioterrorism, and chemical agent casualties, together called Sim-Patient. The following sections describe the basic components and how they were combined to support triage training.

Virtual Patient Simulation

The basis for the triage simulator is the virtual patient simulator shown in Figure 1. The simulated patient is an animated 3D avatar situated in a 3D scene. The simulation includes 3D visual models of the full range of medical devices available to the student, including bandages, drugs, and monitoring devices. The effects of various treatments are simulated by a physiological model.

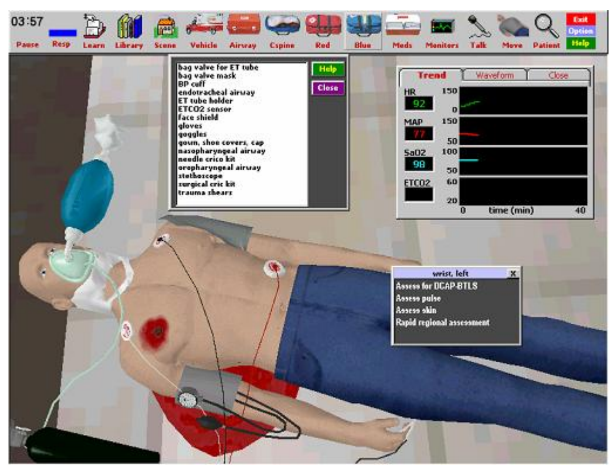

Figure 1. Trauma patient simulation with associated medical devices.

The simulated patient can be configured for a practice session with a variety of injuries and will exhibit appropriate signs and symptoms that change with the evolving condition of the patient over time. Animations such as vomiting, tearing, coughing, seizure, and convulsions relate to physiological status and interventions.

The student can navigate and survey the scene, as well as interact (for example, take a pulse) and converse with the virtual patient. The caregiver can also use medical devices, administer medications, monitor diagnostic data, and perform treatment interventions. Medical providers can sharpen their assessment and decision-making skills and to develop an appreciation for patient responses to appropriate and inappropriate treatment.

Simulated patients have been developed for trauma, bioterrorism, and chemical casualties (Kizakevich et al, 2002; 2003) as well as mentally disturbed individuals and pediatric patients (Frank et al, 2002; Hubal et al., 2003). Animated patients portray signs and symptoms relative to their initial condition and any of the treatments supported by the simulation including bandaging, splints, and administration of drugs or fluid replacement. The patients have dynamic facial expression, gestures, body movement, and can portray anger, fright, confusion, or other emotions or behaviors based on cognitive, emotional, physiological, and pathological models. The following attributes help provide an effective portrayal of disaster casualties:

- Dynamic skin texturing of clinical signs & injuries (e.g., burns, amputations)
- Multi-layered, deformable & removable clothing
- Breathing chest motion integrated with real-time physiology
- Interactive body regions for patient assessment (e.g., wrist, chest)
- Pharmacokinetic modeling and physiology response of medicines
- Dynamic speech production (text-based and prerecorded speech with lip shaping)

All of these 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 increase the emotional involvement of the student.

Virtual Patient Physiological Simulation

The physiological simulation integrates real-time cardiovascular, respiratory, and pharmacokinetic models. A supervisory layer provides overall control of the simulation, controls the BODY™ physiology model (Advanced Simulation Corporation, Point Roberts, WA) and stores data for subsequent review.

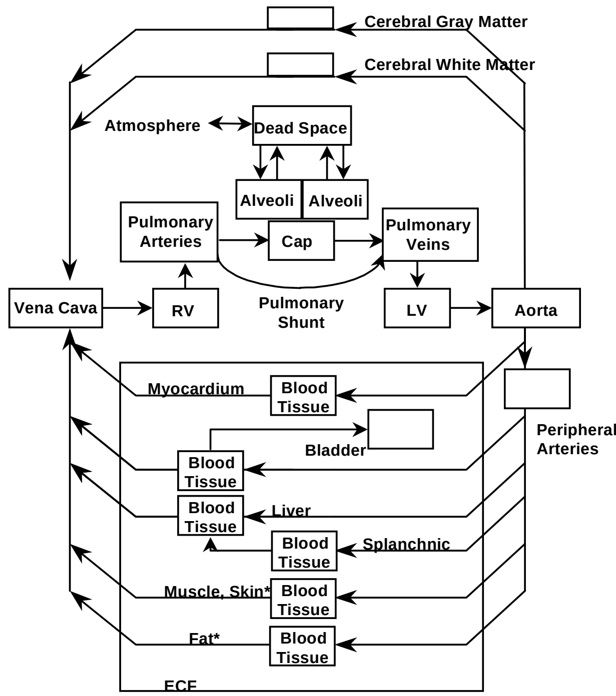

Figure 2. Multiple-compartment transport model.

The multiple-compartment BODY transport architecture represents physiological functions and pharmacological actions and interactions (Figure 2).

Just like the human body, the physiology model centers around a cardiovascular model that consists of a beating heart; blood with which to transport gases, ions, chemicals, drugs, etc.; and compartments such as the brain, heart, and liver. The pulsatile cardiac function provides blood pressures and flows that resemble the real cardiovascular system and adds to the realism of the simulation.

Multiple-Casualty Triage Simulation

This virtual patient simulation has been enhanced to provide triage training with multiple-casualty scenarios. Each casualty has its own injury models, physiological simulation, and signs and symptoms that reflect the patient's physiological condition. A simulation supervisor determines whether casualties will present with stable or unstable physiological conditions in accordance with training or evaluation objectives. Animations of the virtual patients provide realistic representations of symptoms and medically-based responses to caregiver-casualty interactions.. These animations are triggered by the relevant physiological condition, including concentrations of treatment drugs or environmental chemical exposures.

SUPPORT FOR TRIAGE TRAINING

The Simulation-Based Triage Training course teaches the skills needed to be an effective medical responder to a multiple-casualty incident and reviews and practices the skills needed to perform effective mass casualty triage. While the primary purpose of this program is to teach triage, elements of pre-hospital patient assessment and trauma care are included as supplementary material. The multiple casualty triage simulation is the core tool used to teach this course. The simulation has been extended to integrate learning content according to a Familiarize, Acquire, Practice and Validate (FAPV) training model (Frank et al, 2003).

The multi-casualty simulation has been configured to provide practice that reinforces essential knowledge, skills, and attitudes. Figure 3 shows a screenshot of the simulation in a scenario with multiple civilian casualties in an urban environment. The multicolored window along the right margin is used by the student to apply a triage tag on each casualty, thereby designating the victim's priority of care.
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.

Providers can survey the scene, interact and converse with each patient, use medical devices, administer medications, monitor data, and perform interventions. The triage tags are used for assignment of patient priority within a four-level classification system (Immediate, Delayed, Minimal, Expectant) consistent with the Simple Triage, Rapid Treatment (START) triage method. Ground or air transport may be requested and transport priority may be managed on the scene for selective evacuation.

Scenario Definition for Triage Training

Case-based training requires careful design of the scenarios to meet specific learning objectives and development of virtual patients for those scenarios.

Table 1. Casualties developed using ATLS criteria

Case	Primary Injury	Complications	Treatment Notes
1	Head, blunt trauma	Closed head injury	Evacuate
2	Head, penetration	Minor bleeding	First aid
3	Burn	Airway obstruction, fluid loss	airway and fluid management
4	Chest penetration	Pneumothorax, hemothorax	Thoracentesis, chest tube
5	Blunt trauma abdomen	Internal bleeding	Evacuate
6	Severe Orthopedic: pelvic and longbone	Internal bleeding, extremity function	Splint, evacuate
7	Thigh penetration: exit wound	Arterial bleeding, possible fracture	Pressure dressing, splint
8	Amputation	Arterial bleeding	Tourniquet
9	Panic	Anxiety reaction, hyperventilation	Calming, Rx, O_2

A Scenario Studio tool was developed to create patient scenarios for both trauma and medical patient simulations. All scenario and simulated-patient specification data are held in a hybrid object-oriented and relational database.

Scenarios were developed for training military physicians in triage and practice initial care of casualties consistent with IED-related injuries. These scenarios provide an evolving medical situation with graphically intense casualties including amputations, penetrations, massive burns, chest wounds, blunt trauma. Child and adult civilian casualties are embedded with the military casualties to provide an engaging urban disaster scene. Caregivers assign triage category and administer immediate care as indicated. A learning module guides the user through standardized protocols, and interactions are recorded for review, along with pertinent physiological and behavioral data. Table 1 shows the set of casualties developed using the Advanced Trauma Life Support® (ATLS) criteria.

Learning Management

The triage trainer integrates didactic learning content, knowledge assessment, and the case-based triage scenario simulator. The training implements the FAPV method for self-paced learning by doing with various levels of scaffolding to assist the learner. The scaffolding starts with knowledge to be familiarized, and provides increasingly more difficult case-based scenarios for the student to acquire and then practice skills. The trainer monitors student activity against protocols and provides guidance and feedback just when support is needed. Because the student actively learns the material, the new knowledge and skills may transfer more readily to an operational (live) environment.

Student Assessment

The triage trainer tracks student activity and fulfillment of learning requirements for continuing education recordkeeping. The trainer provides a hierarchical course-module-segment structure. It provides context-sensitive informational training aids by displaying HTML, pdf, and MS-Word documents. Within a course segment, learning objectives are further organized according to an extended FAPV paradigm. Assessment questions (e.g., multiple choice) and 3D simulation scenarios are linked to training information. Reference materials including job action sheets, tools (e.g., protocols, guidelines), and web links may be provided.

Assessment Strategies

In real life, injuries and the associated patient condition are dynamic, time-varying and nonlinear processes, so deciding on a course of action for a multiple casualty scenario is impractical. Although there may well be one best answer or track of decisions, the use of such information is unlikely to be useful for effective

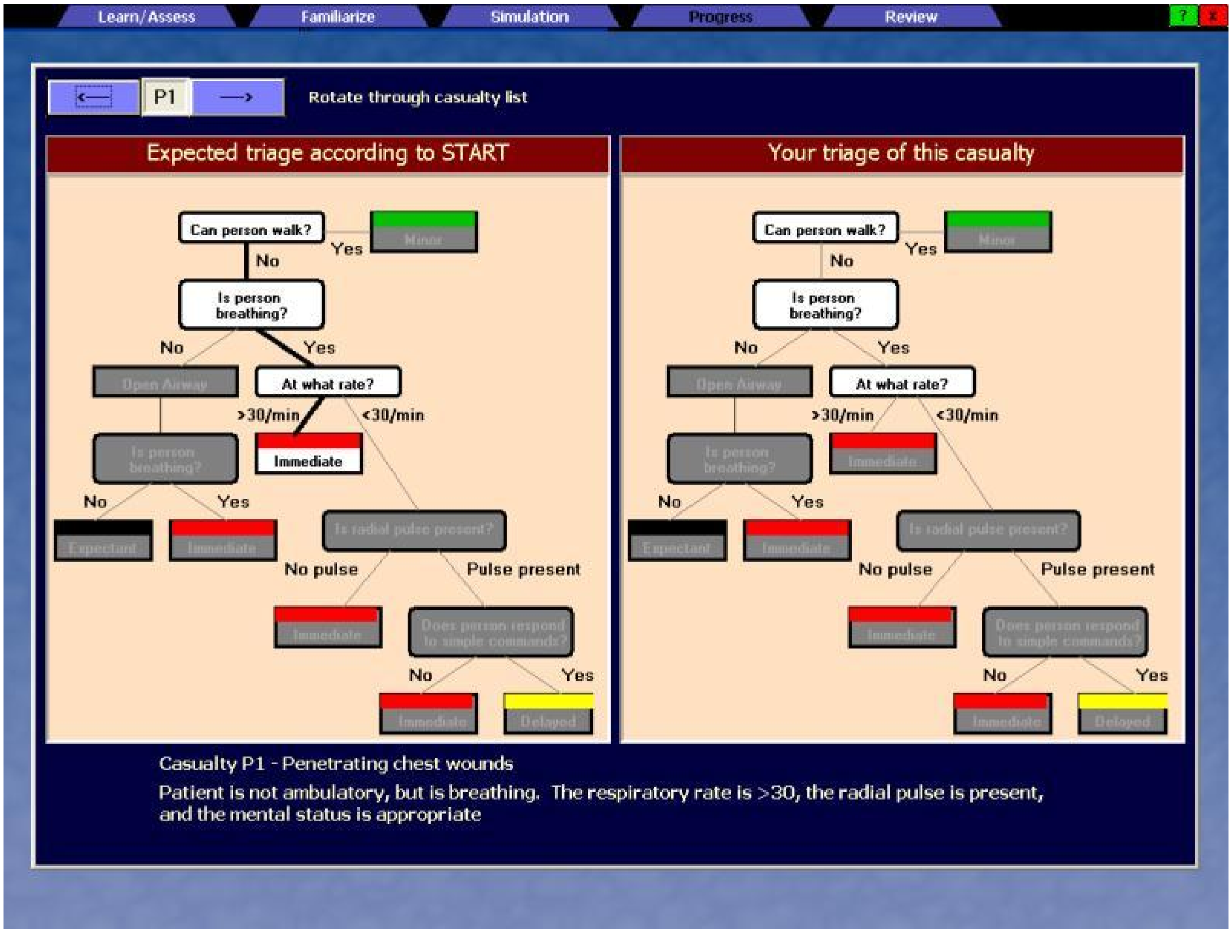

Figure 4. START algorithm used as an AAR. For stable casualties, the expected triage assessment (left) and the student's ongoing assessment (right) are presented and compared. A summary of the relevant physiological parameters are display for further guidance and review (bottom).

training. How one physically approaches a scene, for example, will have an effect on his or her triage process. Once the unhurt and walking wounded leave the scene, the remaining patients would be approached based upon their proximity to the rescuer. So whether one enters a scene from the South or from the North affects the processes regardless of the set of injuries. The important issue is whether the triage process is followed correctly, and that the correct triage decisions are taken per casualty based on the state of each casualty assessment.

To address this issue, the simulator estimates the triage status for each casualty dynamically in real time. An automated triage process, based on the deterministic START triage algorithm, is executed once per second after the physiological data are updated. Each casualty is classified as Immediate, Delayed, Minor, or Expectant according to his/her current physiological condition. The running triage status is saved in the data log and printed along with the vital signs in the simulation data log. The user's triage determination can then be compared against the automated determination and the vital signs during after action review.

After Action Reviews

The START triage method used in this simulator identifies seven paths that might be followed before tagging a casualty. For example, one of the first actions a first responder should take is to ask out loud for all 'ambulatory' casualties to walk to a separate area. These are the "walking wounded" and according to START can be tagged as Minor. Farther down the flowchart, the first responder should assess mental status, normally by asking the casualty to respond to simple commands. If the casualty is able to respond then s/he can be tagged as Delayed, otherwise s/he should be tagged as Immediate.

The simulation tracks the student's actions and compares them against the START protocol. At the end of each scenario the application presents an AAR showing the student's actions highlighted against the expected actions (see Figure 4).

EXPERIENCE WITH THE SIMULATOR

Military Pre-deployment Training

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.

Simulation-based triage training is particularly important for Army Health Care Specialists (the 91W military occupational specialty). Unlike many military occupations, 91W soldiers are distributed throughout the force structure and many serve in low-density assignments, Furthermore, the majority of Reserve Component 91W soldiers do not practice medical care in their civilian employment, and those with medical occupations are rarely engaged in emergency trauma care. They are able to install the triage simulation on their personal computers and practice disaster medicine skills without the need to schedule and travel to frequent collective training exercises.

Military Sustainment Training

The game-like virtual reality of the triage trainer, the self-paced nature of the training, and the intense concentration required to successfully complete the scenarios makes the simulation a useful aid for sustainment training. For many Army Health Care specialists in the field, there are long periods of boredom separated by short bursts of intense high-stress functions.

One system has been deployed to Fort Bucca, Iraq for sustainment training of Army medical personnel. Unfortunately, operational conditions have prevented our receiving feedback on use, utility, or effectiveness.

Civilian Disaster Response Training

Medical students at Duke University participate in five, one-week-long "Intersessions" spaced throughout the academic year, giving them an opportunity to get intensive training in topics not covered in the regular curriculum. In 2005, a Disaster Intersession was devoted to teaching medical students the basic concepts of disaster management. Given the universal appeal and relevance of the topic, the Intersession was opened in 2006 to other health care students, including those from the nursing and physical therapy programs for the first time in the University's history.

The simulator was integrated with a triage training curriculum for this year's Duke Disaster Intersession. Two hundred sixty-two students were randomly assigned one of two educational interventions: (a) constructive simulation-based triage training using verbal case presentation or (b) virtual reality-based triage training using interactive 3D medical simulation. Both groups received a standardized lecture, followed by thirty minutes of facilitator-mediated 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. Individual performance was scored using evaluators who were masked to participants' educational intervention. Data are being analyzed at the time of publication.

FUTURE WORK

Early experiments conducted to date indicate that it is possible for the technology to support multiple providers coordinating triage, patient assessment, and initial medical care by viewing and interacting in the common scenario using networked computer workstations. When this approach is used for collective training, each student may move about and view the common scenario from his/her own perspective and interact with any patient or scene element. The application of devices, the physiological responses to interventions, and the overall patient outcome is reflected to all providers. Such simulations could enable team training for incident command and be delivered via either LAN parties or over the Internet.

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