A New Era in Medical Training Through Simulation-Based Training Systems

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ABSTRACT

The mission of the Telemedicine and Advanced Technology Research Center (TATRC) is to "explore medical science and engineering technologies ahead of programmed research, leveraging other programs to maximize benefits to military medicine." One of its major research portfolios is Medical Simulation and Training Technology. The vision for this portfolio is to facilitate a paradigm shift in medical training, from a subjective mode of skills assessment to a curriculum-aligned, metrics-driven, objective system to assess proficiency of skills -- both cognitive and psychomotor – from the foxhole to the operating room and beyond.

Based on a strategic plan developed on input from a 70-person Integrated Research Team in 2000, our technical strategy is to identify and develop "enabling technologies' into components that can be integrated into ***SYSTEMS*** *of simulation-based training, then assess them to determine the degree to which they transfer skills learned via simulation to the delivery of actual health care. Examples of enabling technologies include real-time in vivo tissue property measurement, haptics, tool-tissue interactions, graphics and visualization, learning systems, and metrics development.*

TATRC is funding and managing research in four broad categories: PC-based interactive multimedia, digitally enhanced mannequins, part-task trainers, and total immersion virtual reality. This presentation will identify examples of enabling technology projects as well as representative projects within these four categories, identify their goals, report on progress toward milestones and, if data is available from two studies underway, they will be presented. A few examples that may be included are:

- *Enabling technologies: High-Fidelity Computer Modeling of Epithelial Tissue; Ultra-High Resolution Display for Army Medicine*
- *PC-based interactive multimedia: Multi-player Role Game for Chemical-Biological-Radiological-Nuclear Event Training; Simulation-based Planning Tool for Pandemic Influenza; Advanced Distributed Learning in Support of Maintenance of Certification for Surgical Skills; Rapid Trauma Training Skills; Scene and Patient Management following Blast Injury from Improvised Explosive Devices.*
- *Digitally enhanced mannequins: Combat Medic Training System (autonomous mannequin); Assessment of Mannequin-based Training to Improve Combat Medic Proficiency in Airway Management, Hemorrhage Control, Tension Pneumothorax*
- *Part-task trainers: Exsanguinating Hemorrhage; Virtual Reality Cricothyroidotomy; Compartment Syndrome; Simulation-based Open Surgical Training System*
- *Total immersion virtual reality: Discussion on expectations and implementation issues.*

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14. ABSTRACT
The mission of the Telemedicine and Advanced Technology Research Center (TATRC) is to explore medical science and engineering technologies ahead of programmed research, leveraging other programs to maximize benefits to military medicine. One of its major research portfolios is Medical Simulation and Training Technology. The vision for this portfolio is to facilitate a paradigm shift in medical training, from a subjective mode of skills assessment to a curriculum-aligned, metrics-driven, objective system to assess proficiency of skills -- both cognitive and psychomotor from the foxhole to the operating room and beyond. Based on a strategic plan developed on input from a 70-person Integrated Research Team in 2000, our technical strategy is to identify and develop enabling technologies into components that can be integrated into SYSTEMS of simulation-based training, then assess them to determine the degree to which they transfer skills learned via simulation to the delivery of actual health care. Examples of enabling technologies include real-time in vivo tissue property measurement, haptics, tool-tissue interactions, graphics and visualization, learning systems, and metrics development.

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To address this challenge for both combat medics and surgeons, formal evaluation studies are underway. The Winter Institute for Simulation Education Research (WISER) in Pittsburgh will begin data collection for training effectiveness study in October 2009. They are studying the degree to which mannequin-based training affects demonstrated proficiency to respond to airway management, hemorrhage control, and tension pneumothorax. For surgeons, William Beaumont Hospital in Royal Oak, Michigan is conducting a project to optimize surgical skills to enhance training and assessment. Some US Army surgeons will participate in the study, and a reset training protocol will be designed that could be used by surgeons in pre-deployment training and by surgeons returning from deployment to identify and remediate skills that have deteriorated after prolonged absence from specialty-specific experience.

1.0 INTRODUCTION

The objective of this paper is to provide a high-level, non-technical presentation to inform the Human Factors and Medicine Panel (HFM) about the mission and vision of the Telemedicine and Advanced Technology Research Center (TATRC), a subordinate agency of the U.S. Army Medical Research and Materiel Command (USAMRMC). TATRC's mission is to identify and fill gaps in medical simulation and training technology either thru congressional special interest programs, innovative research, or partnerships with other government agencies, industry, and academia. Its vision is to continue to be a major catalyst in **accelerating the development and transition** of medical simulation and training technology, systems and devices to Army, DoD, and civilian institutions. One of its major research portfolios is Medical Simulation and Training Technology. There are two goals of the "Med Sim" research effort. The first goal is to improve trauma training, based on the need to train 100,000 military medical personnel to practice battlefield trauma care skills as identified in a 1999 report from the General Accounting Office [1]. The second goal is to reduce medical errors. The goal to reduce errors was driven, in large part, by the 1999 Institute of Medicine (IOM) report, "To Err is Human: Building a Safer Health System," which said that, "at least 44,000 deaths and perhaps as many as 98,000 Americans die in hospitals each year from medical errors. Even when using the lower estimate, deaths in hospitals due to preventable adverse events exceed the number attributable to the 8th leading cause of death. Deaths due to preventable adverse events exceed deaths attributable to motor vehicle accidents breast cancer, or AIDs [2]. Recommendation 8.1 of the IOM report stated, "Patient safety programs should… establish interdisciplinary team training programs for providers that incorporate proven methods of team training such as simulation" [3]. A more recent report, published in "HealthGrades" in 2008, claimed that Patient safety incidents cost the federal Medicare program $8.8 billion and resulted in 238,337 potentially preventable deaths during 2004 through 2006", according to HealthGrades fifth annual Patient Safety in American Hospitals Study [4].

The long-term vision is to facilitate a paradigm shift in medical training, a "grand challenge" revolution, from a subjective mode of skills assessment to a curriculum-aligned, metrics-driven, objective system of assessment based on demonstrated proficiency to perform skills for which health care personnel have been trained. The scope includes both cognitive and psychomotor skills and spans the continuum of care from the foxhole to the operating room and beyond.

In February 2000, the Telemedicine and Advanced Technology Research Center (TATRC) and the U.S. Army's Simulation, Training, and Instrumentation Command (STRICOM) co-hosted a conference at the Morningside Inn, a remote facility ensconced among the rolling pastureland of Frederick County, Maryland, USA. Actual and potential end users, researchers, and representatives from materiel developers and other government agencies – thirty-three (33) of them, presented their concepts, needs, and challenges about how modeling and simulation should be developed to meet military – and private sector -- medical needs. IN the keynote address delivered by Major General John Parker, Commanding General, Medical Research and Materiel Command, MG Parker compared the potential impact of the Medical Modeling & Simulation (MM&S) field to that of the human genome. By meeting's end, there was a strong feeling that the MM&S potential to improve healthcare training was higher than originally envisioned. The skyrocketing growth of the MM&S community of interest since that time has confirmed that belief.

Almost every year since 2000, we have reviewed the technical strategy out of a commitment to the end user community to identify and respond to their needs. For the "foxhole", combat casualty care end of the spectrum, we have convened an Integrated Product Team meeting held in conjunction with the Advanced Technology Applications for Combat Casualty Care (ATACCC), organized by the Research Area Directorate II, which focuses on Combat Casualty Care. For the "fixed facility" care (mostly surgery), we have facilitated various meetings / workshops in conjunction with the Medicine Meets Virtual Reality (MMVR) conference, organized by Aligned Management Associates, Inc. We are now in 2010, eleven years after that first strategic planning meeting. Based on the strategic plan developed by a handful of government representatives as a result of this 70-person Integrated Research Team (IRT), our technical strategy continues: to identify and develop "enabling technologies' into components that can be integrated into *SYSTEMS* of simulation-based training, then assess them to determine how effectively they transfer skills learned via simulation to the delivery of actual health care. Examples of enabling technologies include real-time *in vivo* tissue property measurement, haptics, tool-tissue interactions, graphics and visualization, learning systems, and metrics development.

In April 2008, we convened a special Integrated Product Team meeting – again at the Morningside Inn – to review the strategy thoroughly in response to update briefings from medical training leaders in the combat medic, surgical residency programs (focusing on the US Army's Central Simulation Committee at Madigan Army Medical Center, Ft. Lewis, Washington, USA), other DOD agencies (Air Force, Navy, and Marines), and some other U.S. government agencies. At the end of three days' presentations and discussions, three conclusions were conveyed by the review panel: 1) the four categories identified in the original strategy were verified as "still relevant", 2) emphasis on curriculum-driven development, while already being emphasized, should be emphasized even more, and 3) that TATRC's active role of integration among DoD medical agencies – even if informal – should be emphasized more as well.

2.0 ENABLING TECHNOLOGIES: TWO EXAMPLES

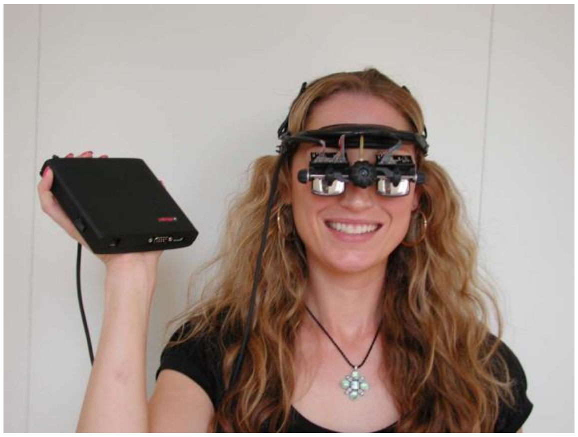
2.1 High-Fidelity Computer Modeling of Epithelial Tissue

Crowley-Davis Research, Eagle, Idaho, USA, (Principal Investigator [PI] Dr. Timothy Otter, PhD) is engaged in congressionally sponsored research dealing with cellular-level simulation. Their objective is to enable high fidelity medical simulation with dynamic realistic response through tissue modelling using biologically inspired computation. Scheduled deliverables are to demonstrate the system's response to perturbations, to simulate realistic cell behaviour, metabolism and genetics. Further, the project will develop internet access to simulation tools. One of the next steps is to seek initial verification against published data.

2.2 Ultra-High Resolution Display for Army Medicine (UHRDARM)

The eMagin Ccorporation, Hopewell Junction, New York, USA, with headquarters in Bellevue, Washington, USA, is developing the UHRDARM using Active Matrix Organic Light Emitting Diode (AMOLED) technology. The PI is Dr. Ihor Wacyk, PhD. The project's objective is to develop a head-mount display

(HMD) with ultra-high resolution to 1920 x 1200 color pixels, field of view between 60 and 80 degrees while only consuming less than 2 watts of total power consumption.



Figures 1 and 2: Photos courtesy of eMagin Corp.

3.0 FOUR BROAD CATEGORIES OF RESEARCH

In addition to the "enabling technologies" research underway, TATRC is funding and managing research in four broad categories of medical simulation: 1) PC-based interactive multimedia, 2) digitally enhanced mannequins, 3) part-task trainers, and 4) total immersion virtual reality. The basis for the variation is that there are multiple training needs and that multiple technologies / systems are required to meet those varying needs. In the remainder of this article, I shall identify several representative projects in each of these four main categories.

3.1 PC-Based Interactive Multimedia

As predicted, this category has grown rapidly, both in user number as well as types of applications. This is likely due to its low cost and broad availability. Below are several examples of active work in this area.

3.1.1 Medical Simulation Training for Chemical, Biological, Radiological, Nuclear Event (CBRNE) Training

Forterra Systems, Inc., recently purchased by SAIC, under the leadership of their PI, Laura Kusumoto, just completed work funded through the U.S. Army's Small Business Innovative Research (SBIR) program. Due to successful Phase I and Phase II efforts, Forterra was awarded additional funding to move toward commercialization. The OLIVE (tm)-based trainer is based on Massively Multiplayer Online Role-Playing Game (MMORPG) technology, and its purpose is to expand and improve medical first-response to CBRNE events. Curriculum was developed by Stanford Medical School, and a virtual emergency room was built with sufficient fidelity to model both sick and injured patients in a CBRNE-based mass casualty. Its projected use is between "book learning" and live exercises.

Benefits are believed to lie in a more economic and safer means of event rehearsal compared to live exercises. Also, the OLIVE (tm) software platform can extend to other medical training applications, including distributed learning.

Figure 3: Screen shots courtesy of Forterra Inc.

3.1.2 Simulation-based Planning Tool for Infectious Disease Outbreak, i.e. Pandemic Influenza

Funded by the Department of Defense (DoD) SBIR program, two companies are engaged in Phase II research. Their common objective is to develop sim-based strategy game to teach MTF personnel how strategic planning and tactical decisions training can support quicker, more effective responses. Military relevance is identified in the areas of force protection and military readiness. Their approaches are somewhat different, however.

3.1.2.1 SimQuest International LLC Silver Spring, Maryland, USA (PI: Dr. Dwight Meglan, PhD)

SimQuest is developing a PC-based real-time strategy game that will evaluate users' ability to recognize early warning signs and track their strategic planning and decision making when presented with actual events.

Figure 4: Screen shot courtesy of SimQuest International LLC.

3.1.2.2 Total Immersion Software, Alameda, California, USA (PI: Michael Becker)

Total Immersion Software is developing a simple, intuitive interface so non-programmers can generate a virtual representation of their facility. They are leveraging rapid software authoring tools developed in DARPA's RealWorld program and customizing the generation of buildings and Artificial Intelligence (AI) tools.

3.2 Digitally Enhanced Mannequins

The CIMIT SimGroup, PI: Dr. Steve Dawson, MD, is developing an “autonomous” mannequin called the Combat Medic Training Systems (COMETS). NOTE: CIMIT stands for the Center for Integration of Medicine and Innovative Technology. CIMIT is a vibrant community of highly motivated collaborators who learn from each other and identify gaps in healthcare where known and emerging technologies can solve clinical problems. **This community includes scientists, engineers, and clinicians from the CIMIT consortium (non-profit institutions from Boston teaching hospitals and engineering schools), and companies, foundations, and individuals interested in accelerating the impact of technology on patient care. [5].**

The COMETS project is being done in response to direct consultant feedback from the U.S. Army’s Directorate of Combat Medic Training (DCMT, Ft. Sam Houston, Texas). It is designed to train “68W” combat medics in triage and treatment of injuries seen during combat. It is designed to make training a “force multiplier” by lessening the burden of simulation management on combat medic instructors. It is designed to be “instructor-independent.” COMETS will allow physiologically realistic training (breathing, bleeding, living, dying) without requiring animal use. It will be fully mobile, so training can occur through the continuum of care, from point of injury to casualty evacuation. More information about COMETS can be obtained from the CIMT web site [6]: http://www.cimit.org/about-stories-simulation.html.

Figure 5: Combat Medic Training Systems (COMETS), photos courtesy of CIMIT SimGroup.

3.3 Part-Task Trainers

Part-task trainers (sometimes referred to as Virtual Workbenches) are sometimes used to practice high-risk, high-cost, high-consequences tasks or “maneuvers.” In medicine, part-task trainers are often used to simulate various medical or surgical procedures.

Several examples are presented below:

3.3.1 Compartment Syndrome Simulation System

Touch of Life Technologies, Aurora, Colorado, USA (PI: Dr. Karl Reinig, PhD), has been selected for advanced work under the SBIR Commercialization Pilot Program. The objective is to produce a highly adaptable virtual environment for training diagnosis and treatment of compartment syndrome. This is intended to result in a production prototype of the system. It will include an easily adaptable VR-based simulator in which to practice diagnosis and treatment (including fasciotomy) of compartment syndrome of multiple extremities, including the leg.

**Figure 6: Fasciotomy Procedure,
Photo courtesy Touch of Life Technologies.**

**Figure 7: Common Platform Simulator,
Photo Courtesy Touch of Life Technologies.**

3.3.2 Rapid Trauma Training Skills

Performing Organization: Operative Experience Inc., Elkton, Maryland, USA
PI: Dr. Robert Buckman, MD

Operative Experience is developing a realistic simulation-based course for open trauma surgery at lower cost and greater availability than animals or cadavers, using a goal-directed curriculum, instructional videos, operations on artificial body parts, and objective metrics for evaluation.

Photos are not shown, to honor Intellectual Property restrictions.

3.3.3 3D Virtual Cricothyroidotomy

Performing Organization: National Capital Area Medical Simulation Center, an agency of the DoD's medical school, the Uniformed Services University of the Health Sciences (USUHS), Forest Glen, Maryland, USA.
PI: Dr. Alan Liu, PhD

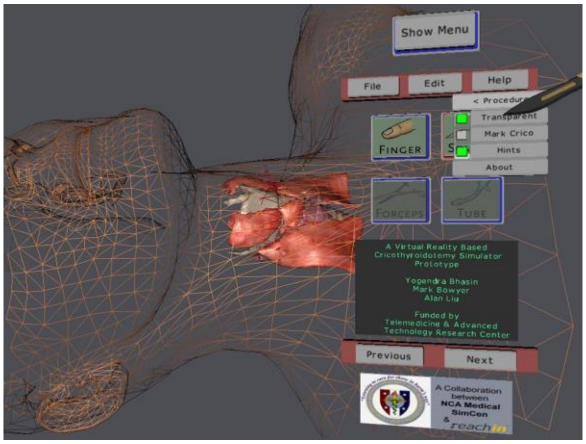


Figure 8: 3D Virtual Cricothyroidotomy. Screen shot courtesy of the NCAMSC.

3.3.4 Exsanguinating Hemorrhage Simulator

Performing Organization: SimQuest International LLC, Silver Spring, Maryland, USA
PI: Dr. Howard Champion, MD

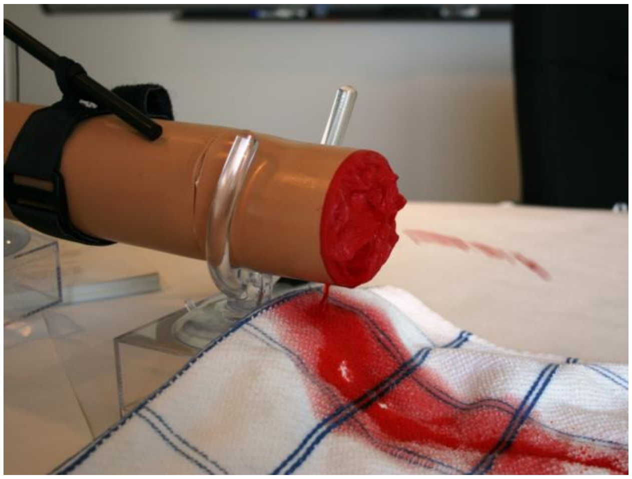


Figure 9: Exsanguinating Hemorrhage Simulator. Photo courtesy of J. Harvey Magee.

3.3.5 Next Generation Injury Creation Science, Prosthetic Arterial Wound

Performing Organization: Virtual Reality Medical Center, Orlando, Florida, USA
PI: Dr. Mark Wiederhold, MD

Figure 10: Prosthetic Arterial Wound. Photo Courtesy of Virtual Reality Medical Center.

4.0 TRAINING ASSESSMENT STUDIES

4.1 WISER Assessment of 68W Combat Medic Performance of Critical Life-Saving Skills

The Winter Institute for Simulation Education Research (WISER), University of Pittsburgh Medical Center, Pittsburg, Pennsylvania, USA. Under the direction of Dr. Paul Phrampus, MD, PI, the WISER team began a training effectiveness study in October 2009 which examines the degree to which mannequin-based training affects demonstrated proficiency to respond to airway management, hemorrhage, control, and tension pneumothorax.

To validate the effectiveness of mannequin-based training, scenario design and performance measures will use existing Army curriculum. Scenario design and performance measures were designed with Directorate of Combat Medic Training (DCMT) leadership input. Independent expert reviewers will assess randomly selected videos and score the performance of the medics. Results will compare those scores to the ones completed by the study facilitators.

4.2 Data Driven Optimization of Surgeon Skills for Enhanced Training, Simulations and Assessment

The William Beaumont Hospital team, Royal Oak, MI, under the direction of Dr. Charles Shanley, MD, is working to optimize surgical skills to enhance training and assessment. Using their surgical test bed for physically-based robotic and laparoscopic simulations, they are adding motion tracking and sensor data capture and an augmented reality system to model new and challenging scenarios. Built in sensing systems provide error-tracking capabilities for trainee feedback; and automatic data collection methods will be used to define task-specific metrics for each component of a surgical skills task set lists. A unique component is the creation of augmented reality by adding to the simulated surgical environment with virtual objects added graphically to the live video. Expert surgeons will provide baseline data on specialty-specific tasks. This will allow assessment of the skill levels of the existing surgical pool and benchmark parameters for training of novice surgeons. Some US Army surgeons will participate in the study. A reset training protocol will be designed that could be used by surgeons in pre-deployment training and by surgeons returning from deployment to identify and remediate skills that have deteriorated after prolonged absence from specialty-specific experience

The views and opinions expressed in this manuscript are those of the author(s) and do not reflect official policy or position of the U.S. Government.

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