Military Medical Modeling & Simulation in the 21st Century: An Update “Supporting the Science”

by

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NOTE: This update is based on an article published in the proceedings of the Nov 2000 Interservice/Industry Training, Simulation and Education (I/ITSEC) conference. The original article, “Military Medical Modeling & Simulation in the 21st Century”, was co-authored by Mr. J. Harvey Magee, Dr. Gerald Moses, Lieutenant Colonel John J. Bauer, Mr. Robert Leitch, and Dr. Steven L. Dawson. For the convenience of the reader, the abstract of the original article is presented below:

Abstract of Original Article

As we enter the 21st century, military medicine struggles with critical issues. One of the most important issues is how we train medical personnel in peace for the realities of war. In April 1998, the General Accounting Office (GAO) reported, “military medical personnel have almost no chance during peacetime to practice battlefield trauma care skills. As a result, physicians both within and outside the Department of Defense (DOD) believe that military medical personnel are not prepared to provide trauma care to the severely injured soldiers in wartime...” With some of today’s training methods disappearing, the challenge of providing both initial and sustainment training for almost 100,000 military medical personnel is becoming insurmountable. The “training gap” is huge, and impediments to training are mounting. For example, restrictions on animal use are increasing, and the cost of conducting live mass casualty exercises is prohibitive. Many medical simulation visionaries believe that four categories of medical simulation are emerging to address these challenges: PC-based multimedia, digital mannequins, virtual workbenches, and Total Immersion Virtual Reality (TIVR). TIVR is the most effective solution, although it is the most expensive and will take the longest time to develop. To address the TIVR challenge, the Medical Simulation Training Initiative (MSTI) is a visionary military program that seeks to develop a multi-functional simulation platform based on a Personal Computer, with 3-D holographic imaging of anatomic compartments and/or body structures. We envision the interface to be an exoskeletal robotic device, haptic gloves and other interactive surgical devices. Success requires several key components. First, a strategic plan. Second, single-agency integration of research efforts. Third, research in “enabling technologies”, e.g., tissue modeling, haptics integration, physiological representations and overall systems architecture. This is necessary to develop realistic representations of medical procedures as a basis for simulation. Fourth, careful efforts among domain experts in their own fields, e.g., physicians, nurses and “combat medics”, working side by side with engineers, computer scientists, designers, experts in education and training, human factors engineers, and managers, to ensure useful products for end users. MSTI will provide a risk-free, realistic learning environment for the spectrum of medical skills training, from buddy aid to trauma surgery procedures. This will, in turn, enhance limited hands-on training opportunities and revolutionize...
the way we train in peace...to deliver medicine in war. High fidelity modeling will permit manufacturers to prototype new devices before manufacture. Also, engineers will be able to test a device for themselves in a variety of simulated anatomical representations, permitting them to “practice medicine.”

Since the TATRC simulation portfolio began to take shape as a result of the Medical Modeling & Simulation (MM&S) Integrated Research Team (IRT) meeting in February 2000, there have always been three pillars in the “inside circle” of TATRC’s MM&S portfolio: 1) Integrated strategic plan, 2) Excellent science, and 3) Sound business processes during all phases of the research and development process. TATRC remains committed to those foundations, although funding limitations make the challenges more difficult.

A highlight of recent developments is the VIRGIL Chest Tube Simulator prototype. On September 25th, 2000, at the Advanced Technologies Applied to Combat Casualty Care (ATACCC) 2000 meeting, the Center for Integration of Medicine and Innovative Technologies (CIMIT) Simulation Team led by Steven L. Dawson, MD (MGH), offered to produce a prototype simulator to demonstrate how the individual design elements of CIMIT’s larger research program could be unified into a working system. This was done in direct response to a critical request from Special Operations medical personnel. On September 10th, 2001, Dr. Dawson and his team demonstrated the VIRGIL Chest Tube Simulator prototype trainer to...
Major General Parker, Major General Kevin Kiley, Colonel James Kirkpatrick and Colonel Robert Vandre, among others, during the ATACCC meeting. The coincidence of this successful demonstration of a combat care training system designed to Special Forces specifications on the night before the tragic events of September 11, 2001 continues to haunt the members of the CIMIT Simulation Team.

The VIRGIL chest trauma training system incorporates haptics, tissue-tool interactions, real-time graphics and augmented reality to present a realistic experience of assessing and treating penetrating trauma in a simulated battlefield scenario. A free-standing but integral web-based and CD-compatible educational curriculum accompanies the training system, presenting treatment doctrine based upon the standards expressed in Tactical Medicine in Naval Special Warfare, Tactical Management of Urban Warfare Casualties in Special Operations, the Defense Medical Readiness Training Institute (DMRTI) C4 Handbook, Army Medical Department handbooks, and the 1988 NATO Manual. The entire system is portable and can be run on standard 110 volt AC power or as a free standing unit for field training using an integral 12 volt DC power source.

In an era of constrained funding, three TATRC-authored topics were approved by the Department of the Army Small Business Innovative Research (SBIR) Program in FY 01: 3-D Volumetric Floating Image With Haptics, Needle Thoracentesis Simulation Workstation, and Catheter Insertion Simulation Workstations for Epidural Anesthesia and Spinal Tap. In addition, a Central Venous Catheterization Simulation System was approved under the Small Business Technology Transfer (STTR) Program.

To “Support the Science” in key scientific domains, TATRC either sponsored or co-sponsored four key workshops in 2001:

- Stanford Workshop on Surgical Simulation, June 20-22
- Metrics for Objective Assessment of Surgical Skills Workshop, July 9-10
- The Digital Human: Open Source Software Framework for Organ Modeling and Simulation, July 23-24
- Sixth PHANToM Users Group, October 27-30
Here are highlights of the four events that occurred in the summer of 2001. Virtual proceedings are posted on the TATRC web site (http://www.tatrc.org).

**Stanford Workshop on Surgical Simulation, June 20-22,2001**

The Stanford Workshop on Surgical Simulation (SWSS) was hosted at Stanford University by Dr. Ken Salisbury (PhD), Dr. Tom Krummel (MD), and Dr. Jean-Claude Latombe (PhD) and organized by Dr. Remis Balaniuk and Mr. Federico Barbagli. It was co-sponsored by TATRC and the Stanford Computer Forum, in association with the Stanford Robotics Laboratory and the Center for Advanced Technology in Surgery at Stanford (CAPS).

This exciting workshop assembled researchers and developers worldwide who focus on modeling and simulation of deformable materials for applications requiring real-time interaction. Of particular interest was medical applications including simulation-based training, skills assessment and planning, as well as other non-medical domains where real-time interactivity is needed. Presentations and discussions helped to define the status of the field and to articulate future directions and possibilities that focus on algorithmic, modeling and real-time issues that
affect the fidelity and applicability of deformable material simulation to medical and other applications.

More than 30 presentations were given over 3 days in tissue modeling techniques, simulation methods for deformable objects, collision detection and handling involving deformable bodies, topological changes on deformable models (cutting, suturing, cautery), tissue-tool-use, bio-fluid modeling, non-medical deformable material modeling, immersive visualization methods, and haptic interaction methods.

Considerable discussion focused on the level of fidelity necessary to achieve a positive transfer of training to practice. Dr. “Srini” Srinivasan, Massachusetts Institute of Technology Touch Lab, put this in perspective in his presentation: “In medical training, the bad news is that we will never be able to simulate tool-tissue interactions exactly in real time. The good news is we don’t have to!”

In a reflective moment, Dr. Salisbury noted, “This conference far exceeded my expectations. I believe this meeting, combined with upcoming meetings on metrics, software standards, and haptics will serve to define and refine the national agenda needed to bring simulation-based medical training into a practical reality.”

Virtual proceedings and agenda are available at: http://robotics.stanford.edu/~swss/

**Metrics for Objective Assessment of Surgical Skills Workshop, July 9-10,2001**

On July 9-10, 2001, the Metrics for Objective Assessment of Surgical Skills Workshop convened. It was planned and moderated by Dr. Rick Satava of Yale University School of Medicine and a consultant to TATRC. It was an international assemblage of both subject matter experts in objective assessment of surgical technical skills and of representatives of numerous official bodies involved in surgical education, evaluation and certification.

Recent advances have been made in the educational science of objective assessment and the technology of modeling and simulation (with surrogate tissue, abstract objects or virtual reality [VR] systems) for training of technical skills. However, no infrastructure exists to objectively assess technical skills. This has been revealed by the focus on identifying and preventing medical errors, the need for objective criteria for assessment of surgical skills, and the increasing demand for accountability to the public. While numerous investigators are validating many different systems for training and evaluation, they are using different tests, criteria, validation methods and even nomenclature. This workshop was an attempt to establish a standard of nomenclature and assessment methodologies so the surgical education, training and evaluation community can communicate with a common language and have a common basis to compare statistical results. The results of this workshop are to be considered a first order approximation from the community of subject matter experts that can provide a “straw man” for refinement.

The purpose was to establish a consensus on a baseline set of metrics from which future education, training, evaluation and research in the technical aspect of surgical and procedural
skills can be measured. The goals were to identify the validated, relevant measurements for technical surgical skills, to evaluate the currently available systems that have been validated in peer-reviewed publications, and to propose a set of objective training and evaluation tools for technical surgical skills that can be used by surgical educators and program directors. The objectives were to derive definitions, taxonomy, analysis of current systems, functional components for a core curriculum, and list the validated systems available for a core curriculum and identification of areas of needed research.

It is mandatory to understand that the result of this objective assessment of technical skills is not capable of solely distinguishing the surgical or medical competence of an individual; rather, it is but one (small) measure to support the overall assessment of competence. It is fully acknowledged that the measurement tools derived are limited to the technical skills and do not account for the larger and more important cognitive and social/behavioral components of operative and procedural competence.

The derivation of the data followed a modified Delphi methodology using the experts indicated above. Consensus on definitions led to establishment of a taxonomy of abilities, skills, tasks and procedures that comprise the lexicon of technical skills assessment. This was clearly a first approximation and will require further vetting to become all-inclusive. The criterion of validity (face, concurrent, construct, content, and predictive) and reliability (inter-rater and test-retest) were reviewed for the candidate systems that have been reported in the literature. Subsequent steps derived matrices which identified which of the currently validated objective assessment systems corresponded to the various abilities, skills, tasks and procedures, and which systems could be used for different levels of training and evaluation (basic, intermediate and advanced). Also presented was a definition of levels of overall competence that could be applicable to the subset of technical skills. This five-level hierarchy is novice, competent, proficient, expert and master.

The workshop results fall into five domains: definitions, taxonomy, list of systems, levels for curriculum development and research opportunities.

There were three distinct areas for research identified during the workshop. 1) A number of surgeons identified a need for a skill called “tissue handling”. None of the systems measure such a skill. 2) There are only a few exercises which evaluate fundamental abilities; it is known that there are many such tests available in the non-medical arena and, therefore, these should be identified and validated. 3) Comparison and integration of the various available exercises of the different systems into a single coherent “core curriculum”. It was also generally recognized that broad research is needed in the field of haptics and all the fundamental abilities.

With the completion of the workshop report, it was proposed to conduct an Open Forum on Metrics for Objective Assessment of Surgical Skills. The purpose of this forum will be to widely advertise the forum, provide this report to interested participants and conduct the forum to solicit (inter)national participation by the surgical and education communities as a whole to vet the results of the original report.
Workshop proceedings are being posted on the TATRC web site (http://www.tatrc.org) as they become available. Just click on “Metrics” in the Past Meetings section.


“The Digital Human: Open Source Software Framework for Organ Modeling and Simulation” convened July 23-24, 2001 at the Lister Hill Center, National Library of Medicine, hosted by Dr. Gerry Higgins and Dr. Henry Kelly. This workshop convened due to the urgent need to engage the larger biomedical community in the development of open source standards for organ modeling and simulation at multiple levels of hierarchy, including molecular biology, cell biology, bioengineering, systems physiology, and anatomy. These first steps involved gathering researchers together and soliciting input on the development of a process for development of an open source framework. The next issue of The TATRC Times will provide a more complete workshop summary.

To be successful and adopted broadly by the professional medical community, medical simulation developers must use models and simulations that have been validated using common standards and tools. The open source software environment, allowing developers, clinicians, and researchers to exchange models and simulations and emphasizing the use of peer review for validation, is critical for this emerging field to be successful.

While much progress has been made in diverse domains such as molecular modeling, cardiac simulation, and diagnostic image modeling, there are few coherent standards and resources for exchange and integration of models. The work of Dr. Steve Dawson and his team at the Center for Integration of Medicine and Innovative Technologies (CIMIT) in Boston and others developing tools such as the Common Anatomical Modeling Language (CAML) are testament to the importance of this approach for the creation of valid and verifiable medical simulators.

The Digital Human project will support the development of a common, open source framework for the modeling and simulation of organs and tissues. The goal is to facilitate the creation of an open source community that will create, review, and continuously improve software components for modeling and simulation in this domain.

From a software development perspective, the most important first task and focus was to develop a consistent language for expressing biological objects and functions in a language easily translatable to software objects, interfaces, and event passing. One key issue was the creation of a hierarchy of objects that inherit characteristics from more generic objects, e.g., the left coronary artery is derived from a vascular stem cell. It was suggested that the heart be first examined as a model system in which to develop this software architecture.

One of the outcomes of the “Modeling & Simulation in Medicine: Towards an Integrated Framework” meeting held in 2000 at the National Institutes of Health (Higgins et al, 2001) was that the research and development community has reached a critical juncture where further progress cannot be made unless the community can come together to develop open source
software that can be used by all researchers and developers. In the short term, there is an urgent need to develop common technical resources that can be used to facilitate the exchange of information, models and simulations between researchers and developers, including the development of an open source framework. The long term vision of a “Digital Human” is the development of accurate, validated and integrated models and simulations of molecules, cells, tissues, organs and organ systems that can serve as a reference for experimental analysis, patient care, and training in biology and medicine.

The Digital Human Project is based at the Federation of American Scientists in Washington, DC. This organization has 49 living U.S. Nobel laureate scientists serving as its Board of Sponsors (see http://www.fas.org/sponsor.htm).

A web site is being established to support collaborative interaction, including mailing lists and code development. Several topic areas have generated early interest, and these areas may provide a basis for initial collaborative interaction and subsequent team development. These include:

- Ontology (including cell and organ modeling)
- Model interoperability and technical framework
- Cardiac modeling (already a well organized group of collaborators)
- Lung modeling
- Anatomy training
- Surgical simulation

Virtual proceedings of presentations are available at http://fas.org/dh/conference/proceedings.php If you wish to participate in the ongoing discussions, please contact Gerry Higgins (Telemed1@home.com) or Henry Kelly (hkelly@fas.org).

Sixth PHANTom Users Group, October 27-30, 2001

One of the “enabling technologies” being developed to support surgical simulation is haptics, the sense of touch feedback. Haptics is still in its infancy and rapidly evolving. There are two major reasons for the continuing rapid development: 1) fundamental paradigms for displaying the feel of models are still being envisioned, and 2) continued rapid increase in computer processor capabilities constantly expands what can be practically implemented. By focusing on the researchers that are developing haptic applications, the PHANTom Users Group (PUG) conferences bring together a group with common core concerns. Using the PHANTom as the common platform for discussion removes much of the abstraction in the presentations. The conference was jointly sponsored by TATRC, Novint Technologies Inc. and SensAble Technologies Inc.

Additional information and virtual proceedings at the PUG 2001 web site: http://www.cs.sandia.gov/SEL/conference/pug01/index.htm
Validation, Validation, Validation

Simulation leaders around the world have long recognized the need to validate the effectiveness of medical simulation training systems. In the introduction to “Simulator Limitations and Their Effects on Decision-Making,” Dr. Colin Mackenzie and others note, “The use of simulators for skill evaluation is common in a number of fields, but the effect that various characteristics of simulators have on subject performance is not fully understood.” Recognizing the need to establish objectively the effectiveness of simulation training in medicine, TATRC contracted with Dr. Howard Champion, MD and Dr. Gerry Higgins, PhD, to chair a Simulation Working Group (SWG). The SWG, represented by several trauma surgeons, combat medics, and human factors experts, was charged to develop a robust scientific methodology and instructional framework for demonstrating the value of simulation-based training. The SWG project is in progress as of the writing of this article.

The first application of the SWG methodology will be to the Combat Trauma Patient Simulation (CTPS) System, managed by U.S. Army Simulation, Training and Instrumentation Command (USASTRICOM) under the executive oversight of TATRC, an agency of the U.S. Army Medical Research Materiel Command (USAMRMC). The CTPS is developing robustly, funded by Congressional Special Interest funding. While the SWG methodology is being finalized, Phase I of an Independent Testing and Evaluation (IT&E) plan began at the Center for Total Access, Ft. Gordon, Georgia. Phase I is the Verification phase (Does it work according to design specifications?) and was completed in the fall of 2001. Final report results are not yet available, but the CTPS system was verified to perform quite successfully when compared to the engineering specifications.

Phase II of the IT&E will begin in January 2002, to assess the training effectiveness of the Combat Trauma Patient Simulation System.

Conclusion

Our original strategy in 2000 was embodied in several bullet statements: Assess the landscape (and a “meta-analysis” resulted). Engage the experts. Converge the worlds of medicine and simulation. Support the science. Develop and honor “best business practices” at all stages of the research and development process.

Our maturing strategy expands our consortia of research partners to address the core problems facing simulation, as we seek to constructively collaborate on essential research domains. To “support the science,” we are seeking to expand funding sources to support research. At the same time, we have invested in several focused conferences within the various domains of engineering and medicine. Underlying the strategy is a realization that the purpose is not to develop the “coolest” simulator; rather, it is to develop training systems that positively enhance training outcomes. The goal remains the same: to revolutionize health care delivery by improving the way providers train to deliver it.