Simulation and the Future of Military Medicine

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The U.S. military currently faces serious difficulties in training medical personnel in peacetime for the tasks of war. The military beneficiary population comprises fit young service men and women, their dependents, and retirees. Their peacetime care, although vital, does little to prepare military medical personnel for war. Medical commanders have instituted an array of training programs to compensate for this shortfall, but there remains a large gap between operational medical needs and training opportunities in peacetime. The military has begun to examine whether simulation can fill this gap. An array of commercial, off-the-shelf technologies are already being used with varying degrees of success, and major initiatives are under way in both academia and industry, supported by the military, to develop virtual reality products for combat medical training. Even as the military exploits emerging technology and begins to articulate a simulation strategy, there is a growing interest in civilian medicine in the potential for simulation to affect patient safety—how medical simulation might mitigate the injuries and deaths caused by medical errors—and how it might also improve the quality of medical education and training.

The Training Dilemma

As we enter the 21st century, military medicine struggles with an array of issues critical to its future, the most important being how to train in peacetime for the realities of conflict. This is not a new problem. Ever since medicine took to the field of battle, doctors, nurses, and medics have struggled to retain their essential combat medical skills and to train their acolytes in peacetime. Hippocrates' famous aphorism, "He who would become a surgeon should join the army and follow it," may have been an exhortation to those who would be skillful physicians, but the consequences of this learning process have echoed in the "lessons learned" reports of almost every war in history. At the end of the 19th century, the distinguished physician, medical historian, and inventor of the clinical thermometer, Sir Clifford Allbutt, wrote of the Crimean War: "How wide and varied is the experience of the battlefield and how fertile the blood of warriors in raising good surgeons."[1] Of the Korean War, a senior military physician, BG Crawford Sams, offered, "Our younger men were thrown into combat without a day's training—similar to taking a boy out of a drugstore and saying 'I'll give you a gun, go fight the Koreans.' We did this to our young doctors."[2]

Within recent history, many attempts have been made to bridge this training gap. The Vietnam War, arguably the high water mark of military medicine, saw the U.S. military bring to the battlefield almost every available and emerging medical technology to support the soldier. Many innovations developed in that war have shaped civilian medical practice from then until the present, particularly in the field of trauma care. Preeminent among these advances, helicopter medical evacuation on demand appeared to many to be the technological solution to the problems of combat casualty care. But it rapidly became apparent that although rapid helicopter evacuation to state-of-the-art surgical hospitals had a significant impact on morbidity and mortality rates, more needed to be done. The state of battlefield care and evacuation early in the war was harrowingly related by a Marine Corps doctor, Al Levin, in 1966: "I remember the sense of timelessness. Except for the helicopters I might as well have been in the mud in Gettysburg or Valley Forge. . . that's how much I could do for these guys."[3]

The key lay in two initiatives. The first was the introduction of helicopters equipped to care for the wounded in flight; the Army provided dedicated air ambulances, the Navy and Marines used transport helicopters. The second was the expertly trained and well-equipped "medic" at every level of care, but particularly the "first responder" at the point of wounding. The dilemma was how to train the medic before deployment, to give him the skills needed to save lives in combat, often under fire and a long way from the expert care available in a hospital. Great efforts were made to improve the quality of training, and it appears from the myriad anecdotes to be found in Vietnam War histories that the medics who went into combat from 1968 onward, at least, were better prepared than any in previous wars. However, given the state of training technology at the time, the problem was never fully resolved, and like their forefathers in previous wars, the medics learned most of their skills by trial and error in the field.

Twenty years later, the U.S. military faced the same challenge. Despite the time available for preparation and training, the medical lessons learned from the Persian Gulf War showed that the majority of medical personnel deployed lacked the medical skills deemed necessary for combat. An after-action report from that time offers a terse comment: "Only a few doctors have worked in metropolitan emergency rooms and have experienced wounds made by knives, bullets, and explosions."[4] RADM Ben Eiseman, USN (Ret.), offered two even more pithy observations on the state of training for Operation Desert Storm: "The vast majority of both active duty and civilian clinicians are largely inexperienced in caring for the injured. . . . The problem is further complicated by mistaking civilian trauma care with that of the experience in the combat zone.[5]"

A full 25 years after the Vietnam War, and despite the lessons of the Persian Gulf War and vast technological innovation and advances in war-fighting capability in the military at large, it is very probable that the young doctor or medic facing combat in the 21st century would echo Levin's thoughts on Valley Forge. We are failing to train them in peacetime for the tasks of war,

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and there is an urgent need to address the problem using all available resources. The issue has become serious enough to warrant comment at the highest levels. In April 1998, the General Accounting Office reported that "military medical personnel have almost no chance during peacetime to practice their battlefield trauma care skills. As a result, physicians both within and outside DOD [Department of Defense] believe that military medical personnel are not prepared to provide trauma care to the severely injured in war."[6] More than 3 years later, the DOD has done little to resolve this problem. In the absence of a clear strategic policy on training from the DOD, the Surgeons General must design and resource medical readiness training from within their own budgets and balance this against the ever-increasing demands of peacetime health care.

Current Solutions

In recent years, there has been a drive to enlist the skills and experience found in modern civilian emergency medical systems (EMS) and trauma centers (only a handful of military medical treatment facilities now provide trauma training in peacetime). A recent pilot project at the Ben Taub Hospital in Houston, Texas, designed to train field surgical teams and supporting medical staff proved successful, and others are planned in various trauma centers around the country.[7] Although this offers at least an opportunity for military medical personnel to experience the care of real trauma cases, there are a number of limitations. First, the range of injuries seen in war is different from that seen in peacetime, even in the trauma centers of major cities where gunshot wounds are commonplace. War wounds are predominately caused by shrapnel from bombs and shells; where gunshot wounds occur, they are from high-velocity weapons rarely seen in civilian life. Second, the context (austere environments and limited resources) in which these injuries must be managed in war is different. In peacetime, in all but the most remote areas, patients are managed initially using sophisticated EMS equipment and evacuated to treatment in state-of-art acute care facilities within 1 hour.

In this regard, Eiseman's comments on civilian trauma care and care in the combat zone hold true today. He echoes Sir Heneage Ogilvie, a senior military surgeon of the British Army who, in his introduction to the medical history of World War II, wrote, "A fallacy that appears in all literature on war surgery is that war surgery and traumatic surgery are synonymous. They are not. War surgery is traumatic surgery applied under conditions of war. And those conditions cannot be dictated by the surgeon or even the high command."[8]

Third the numbers of military medical personnel to be trained and their skills sustained far outweigh the resources available. There are more than 90,000 active service medical personnel[6] in the U.S. military and many thousands more in the reserves. Some have argued that this latter issue is an exaggeration of the problem and that many will never see a casualty in combat. This may be true, but deciding who will and who will not be involved in combat and "rationing" training accordingly is a novel approach beyond the scope of this article.

It would be misleading to suggest that nothing is being done to improve medical training other than the limited use of trauma centers. All three services have long used the Advanced Trauma Life Support (ATLS) course for advanced training of physicians and other medical specialties. However, ATLS was designed specifically for the treatment of patients in a high-tech environment with plentiful resources and is inappropriate in the austere environments expected in combat. Plans to develop a more appropriate course for combat casualty care on the lines of the Battlefield(B) ATLS[9] course currently used in the United Kingdom Special Forces are under way. In time, some of this training may be adopted by the majority of military medical personnel. Recently, too, the Army has overhauled its basic combat medical military operational specialty, the 91B, and introduced the 91W, which will involve more rigorous and detailed training in combat casualty care and other operational medical skills. The Navy and Air Force are also revisiting their medical training needs, particularly for medics and corpsmen.

Even with these new initiatives, there remains a gap between the quantity and quality of training available in peacetime using currently available resources and what is required for war and operations other than war. It is simply impossible in peacetime to replicate the conditions and experiences a medic will face in combat using contemporary training resources and technology.

A Lesson from History

Faced with a similar training challenge in the 1930s, the nascent aviation industry developed the concept of flight simulation, based on the ideas of a futurist aviator named Edward Link. The original Link Trainer was designed to do little more than teach pilots the basic management of yaw and pitch in flight before they got off the ground and risked not only their own lives but also their instructors in a crash. The technology was rudimentary, but the idea was revolutionary. The fundamental concepts Link envisaged are used to train pilots in almost every form of flying today. In civil aviation, air crews perform almost all of their training on simulators. In military aviation, pilots and crews spend many more hours "flying" simulators than real aircraft and generally agree that it is a vital aspect of modern combat air operations. Ground forces too have grasped the training opportunities offered by simulation. Given the high costs of modern ammunition and missiles and the safety issues involved in their use, it is essential that a more cost-effective and safer means of training be found. Almost every weapon and vehicle in the Army and Marine Corps armamentaria today has simulation built into it. The Army in particular has so embraced simulation for training that the Vice Chief of Staff of the Army issued orders in 1996[11] that all future military systems and weapons have simulation embedded within their capabilities. In the light of these advances in the military in general, it seems logical that military medicine should examine if, where, and how simulation could bridge the gap between how we train in peacetime and what we need to be able to do in war.

Application of Simulation

If simulation is to be of value to military medicine, and in particular combat casualty care, it must satisfy a number of key demands. First, simulators must be able to teach and maintain medical skills, particularly those requiring hand-eye coordination. Second, they must be able to create the peculiar wounds of conflict and allow the user to train in the full spectrum of casualty management. Third, they must be able to recreate the unique conditions of combat. Finally, simulation must be available to all who need it, from the medic in the field to the surgeon in a deployed hospital. This implies a range of equipment based on cost, sophistication, capabilities, and numbers.

Many observers would argue that medical simulation is already happening and that the military need only state its needs to an eager industry and all of its demands will be met. True, there are currently in the United States and worldwide myriad medical simulation projects and programs, many of which incorporate proven commercial, off-the-shelf (COTS) technologies. Simulators are currently being used to train a wide variety of medical professionals in both civilian and military medicine in an array of skills from first aid to anesthesiology and minimally invasive procedures. Work is also well advanced in more cutting-edge technologies aimed at producing the sort of virtual reality necessary to create the true conditions of combat medicine. However, there is no military medical equivalent of the overarching strategy or vision that underpins simulation in war fighting and other military training.[12]

Broad Areas of Medical Simulation

Despite (or perhaps because of) the lack of an overarching strategic approach to military medical simulation, developments continue at a rapid pace. They can be identified within four broad functional areas.

Area 1: Personal Computer-Based Interactive Systems

As their title implies, these are training systems built upon personal computers (PCs). They range in approach from the Gameboy interactive video style of skills training to the more formal and traditional teaching style of a virtual classroom. There are already a considerable variety of programs on the market and in use within and outside of the military. They are aimed at teaching a range of skills and have much merit, particularly in learning and rehearsing processes in clinical care. The costs of this technology make it ideal for individual use. As PCs become smaller, more powerful, and cheaper, the capability of these systems to provide useful training through simulation will increase. Already, small hand-held PCs known generically as personal digital assistants are capable of managing gigabytes of information and, when connected to Internet-based training programs incorporating streaming video, can be use to teach and rehearse an array of medical skills far from the traditional classroom, laboratory, or clinical grand rounds. As with many contemporary "distance-learning" and Internet-based training instruments, the major limitation is the lack of quality assurance, particularly in the verification of the clinical curriculums and protocols that the programs contain. There is an urgent need to establish formal quality assurance procedures for this form of simulation and distance-learning technology.

Area 2: Digitally Enhanced Mannequins

This concept uses the mannequins that have been in use as medical trainers for many years, particularly for teaching airway management. During the past decade, as advances have been made in materials technology, mannequin "realism" has improved and their utility as training aids has widened. A number of commercial ventures have produced models with detailed anatomical structures connected to PC-based systems, enabling the mannequins to demonstrate signs and symptoms of disease and injury and to react to precise clinical interventions. These more sophisticated computerized systems are relatively expensive, but they may become less so with further development and manufacture. Their cost limits their use for individual training, but they have much utility in team training. As yet, their major function is in teaching airway and circulatory system management, but efforts are under way to broaden their capability, particularly to integrate them into wider systems for team task training. An array of less-sophisticated, inexpensive, rugged, and highly capable training mannequins has recently appeared on the market aimed at training for the austere environment and peculiar injuries of combat. A number of extremely innovative smaller projects are also under way. Falling under the rubric of partial-task trainers, they are designed to teach and practice a specific skill under supervision. An example is the pelvic examination device, a female pelvis with a series of pressure-sensitive pads arranged internally and connected to a PC display. It enables a pelvic examination to be displayed on the PC screen to show both pupil and teacher exactly what part of the internal anatomy the pupil is palpating. Similar devices are being developed for rectal and breast examinations.

Area 3: Virtual Workbenches

So-called virtual workbenches represent the first steps in the use of digitally generated images to create a medical training environment. Complex algorithms generate a virtual three-dimensional anatomy on a graphic display screen. Similar algorithmic techniques produce a sensation of touch in instruments as they move around the image; this is known as haptic feedback. A third, yet more complex computer program enables the interaction of instruments and virtual anatomy to create a virtual clinical procedure, the image responding to the instrument and operator in almost the same manner as a real event.

The technological innovation involved in virtual workbenches shows that it is possible to create machines that can reproduce virtual anatomical images and touch, interacting with sufficient fidelity to be useful training tools. But the underlying science requires much development; currently, the anatomy is relatively gross and the sense of touch or haptic effect is limited to instruments. Even at this early stage of development, a number of very useful training tools have been produced with varying degrees of sophistication. Machines that enable the teaching and practice of such procedures as proctoscopy, urethroscopy, and cardiac catheterization are already commercially available.

Area 4: Total Immersion Virtual Reality

The next step from the virtual workbench is to create an all-encompassing virtual environment known as total immersion virtual reality. This will expand the current three-dimensional anatomical image and display it outside of the traditional graphic display screen in a holographic form. It will also require the combination of digital anatomy with digital physiology and the development of the haptic effects to enable true touch by human hands. For instance, when the virtual liver is palpated, the gloved hand must feel it and the organ must respond. When the surgeon's knife cuts tissue, it must bleed, and when pressure is applied, the bleeding must stop. All this must take place in a virtual environment designed to replicate conditions from the high-tech peacetime operating room to the field surgical team tent in the desert.

This concept is a long way from the technology currently available to train tank crews, fighter pilots, or even astronauts, and given the state of the underpinning science, there is much farther to go before medical teams will train in peacetime using virtual battlefield trainers. However, advances in virtual reality technology are being made almost daily in other fields, such as the movie industry, and it would be unwise to guess when the next breakthrough will come.

Program Architecture

A recent study of the feasibility of simulation in combat trauma training[12] concluded that stand-alone simulators, no matter how sophisticated, cannot fully meet the needs of combat medicine or any other type of medical training. This is best exemplified in the arena of flight simulation, where students are not simply allowed to take the "aircraft" on a free flight; rather, they are required to log a conventional flight plan before a simulated mission. Instructors require the student to follow the flight plan and often connect multiple students together, requiring a team approach to flying. Medical simulation should embrace the same disciplines. G.A. Higgins (personal communication, September 2000) contends that individual simulators could be integrated to provide collective training for medical teams responding as they would in an operational environment. A networked training system would allow providers across the spectrum of combat casualty care to interact in real time on a single patient or a number of patients. As an individual patient is encountered and dealt with at the point of wounding, the corpsman would deliver all necessary and possible first aid and the results would be logged on the virtual patient. The same would happen during transit and throughout the continuum of care. Such a system would enable care given by individuals and teams to have a continuous impact on the virtual patient and would enable the effect of care on outcomes to be measured at every level.

Grand Rounds on the World Wide Web

H.R. Champion (personal communication, June 2000) contends that even the use of simulators in networked teams fails to exploit the full value of simulation. He argues that, where possible, medical simulation should be supported by an online database of clinical cases accessible to simulation centers and even individual PC-based teaching tools. He envisages Internet sites that would provide an interactive electronic "Grand Rounds on the Web" of combat casualty cases that could be downloaded and used to program simulators to create a specific case. Patients would respond to the interventions of those under training and, if required, interactive online mentoring could be provided. A database of combat casualty and related operational medical cases is already under construction by Champion, using data from Vietnam to Chechnya, Kosovo, and the West Bank. The next stage will be to use the data to construct on-line cases for training.

The First and Next Steps

The U.S. military has already taken the first deliberate steps to launch simulation as the core of future combat medical training. The National Capital Region Medical Simulation Center has been established under the aegis of the Uniformed Services University of the Health Sciences at the Forest Glen Annex of the Walter Reed Army Medical Center in Maryland.[14] A number of other simulation centers are also being developed, most notably at the Army Medical Department Center and School in San Antonio, Texas, and at the Special Operations Medical Academy at Fort Bragg, North Carolina. One of the first medical simulation centers, developed by the Army National Guard at Fort Indian Town Gap, Pennsylvania, has made great progress in medical training for reservists using a digitally enhanced mannequin simulator. In 1999, the nation's first Tri-Service Joint Trauma Training Center was established at Ben Taub General Hospital in Houston, Texas, where military trauma teams from the three services rotate for a 30-day immersion in a high-volume level I trauma center. The aim is to capitalize on the extensive experience of the hospital staff and the high levels of trauma typical in a major city and its environs. The task of the center is to train military field surgical teams before operational deployment. To meet this aim, the training staff uses a combination of simulator training and hands-on real trauma cases. A simulation center is being developed on site using a range of simulators from existing COTS technology.

Concurrently, the U.S. Army Medical Research and Materiel Command, along with the Army's simulation proponent, Simulation Training and Instrumentation Command, have begun to develop and fund a joint strategic plan for medical simulation as a key training tool for combat casualty care. Under their aegis, the Telemedicine and Advanced Technology Research Center is leading a series of integrated research teams tasked to bring together the state-of-the-art developers in medical simulation. The integrated research team forum enables scientists and strategic planners from the DOD, academia, medicine, and commerce to meet and plan the development of next steps in medical simulation. Details of the most recent meeting are available on the Internet.[16]

The aim is to develop an overarching strategy; it might best be called the Defense Human Simulator Project. In broad terms, the concept is to attract funding for existing COTS technology such as PC-based simulators and digital mannequins, exploit them to their optimum, and bring them into service use as quickly as possible. Concurrently, funding is being focused, from federal and commercial sources, for research and development of the essential technology for total virtual reality. Although the initiative is being lead by the DOD, there are clear opportunities for broader strategic development and cooperation not only within the U.S. government, business, and academic institutions, but worldwide as well. A number of nations in Europe, the Middle East, and southeast Asia have particular expertise in the areas of simulation, and such a program would greatly benefit from their involvement.

Where might such a project lead? History shows that the military, and particularly the DOD, have led the way in many recent scientific innovations that have had historic impacts; flight simulation, the Internet, and telemedicine are a few examples. It is possible that simulation in medicine could be the next major technological innovation.

To Err Is Human

A recent report by the U.S. Institute of Medicine, *To Err is Human*,[17] detailed the prevalence of errors in contemporary medicine. This report suggested that as many as 98,000 people a year die in the United States as a result of mistakes in medical practice. Many more suffer distress and injury. The former U.S. Surgeon General, C. Everett Koop,[18] wrote an editorial in a major newspaper commenting on this report. He asserted that humans are prone to error and that modern medicine in particular is highly complex. Anyone who has ever witnessed a physician attempting the relatively common but difficult procedure known as the spinal tap recognizes that the skill is not a "divine ability": it has to be learned, sometimes at the cost of pain and suffering on behalf of the patient. *To Err Is Human* does not detail how many medical mistakes result from the way we teach physicians and other health care providers, but the authors' experience and anecdotal evidence from interviews with experienced physicians and nurses suggest that there are many, although thankfully few are lethal.

The timing of *To Err Is Human* is fortuitous for many in medicine attempting to bring about change. It raises questions about the way we have done things for a long time. Although not every error is a result of teaching, many are. It is time we ended some old, established practices, particularly the education dictum "see one, do one, teach one" using the patient as the teaching medium. The future of medicine is one of greater complexity. Medical specialization is narrowing, multidisciplinary care is becoming more common, and training will be based less on experience. Unless fundamental changes are made in how we teach and practice, it is likely that the opportunity for error will increase.

In his editorial, Dr. Koop[18] comments on the mistakes caused by fatigued interns and residents. He asserts the need to limit their working hours but also recognizes the need to gain a great deal of clinical experience and training within a short time and, equally important, to learn to cope with stress and fatigue. In aviation, simulation is used to train pilots who are fatigued and under duress without endangering their passengers. It is possible that simulation for medical training could do the same for doctors without risking patients. Could simulation have an impact on the error rates in contemporary medicine? At this point, lack of evidence requires caution, but there is every reason to be optimistic.

The U.S. military and its partners in academia and business are leading the way in a technological breakthrough that may change not only the way we train for war but also the way we teach medicine in peacetime. It is very possible that in the near future simulation will be used in medical schools, hospitals, and EMS centers to teach and to hone skills safely, to develop and practice new techniques with minimal risk to patients, and even to ensure that those who have practiced for a long time still have the essential skills to provide safe, quality care.

Conclusion

The U.S. military currently faces a serious dilemma regarding how it trains its medical personnel in peacetime for the tasks they will face in conflict. Many of the diseases and injuries commonly seen in war are rare in the United States in peacetime. The military beneficiary population comprises fit young service men and women, their dependents, and retirees. The latter in particular take up a great deal of the day-to-day military health care effort, but their care does little to prepare military medical personnel for war.

To redress this imbalance, medical commanders have instituted an array of medical training programs, particularly in trauma care. However, there remains a large gap between operational medical needs and training opportunities in peacetime. The military has begun seriously to examine whether simulation can fill this gap. These are early days, but the possibilities are encouraging. An array of COTS technologies is being used, and research is being advanced in state-of-the-art virtual reality. Even as the military exploits emerging technology and begins to articulate a simulation strategy, a new and equally contentious problem has emerged, the issues of errors in medicine. Detailed and critical consideration is now under way throughout the health care professions regarding how medical simulation might mitigate the injuries and deaths caused by medical errors and, in doing so, improve the quality of medical education and training. The stage is set for another revolution in health care.

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