

Simulation-based medical training: the Medical Readiness Trainer concept and the preparation for civilian and military medical field operations

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Abstract: Deficiencies in adequate level of medical preparedness are among the principal sources of medical errors in both civilian and military medicine. While training is often the solution, the access to sophisticated training resources among personnel operating in rural and remote regions is virtually non-existent. Combining Human Patient Simulation, immersive and semi-immersive virtual reality, and 3-D telepresence, the Medical Readiness Trainer allows the trainees from anywhere on the globe to access and actively participate in sophisticated, real-time training conducted by leading experts in emergency and trauma medicine. The principles of Medical Advanced Distributed Learning and Interactive Simulation (MADLIS) under the development by the Medical Readiness Trainer Group constitute the first effective step permitting the creation of global medical education, training, and treatment systems using combined VR, 3-D telepresence, medical simulation, and advanced telecommunications technologies.

1. INTRODUCTION

While “Practice makes perfect” [1] is an admonishment frequently heard at medical conferences and frequently read in medical literature [2,3,4], it is also common knowledge that previously learned medical skills vanish unless rigorously retrained [5]. Moreover, skills that have never been trained properly and must be suddenly put to practical use [6] may, under certain circumstances, lead to lethal errors [7]. Thus, while the observation that “training is good” and may save lives [8] is almost trivial, speculation on the nature of what constitutes effective training is certainly not.

Medical schools spend very substantial amounts of money, effort, and time on the development of maximally effective methods to teach medicine [9].

Yet, studies still show deficiencies in execution of diagnostic procedures [10] or interpretation of clinical data [11] both at the under-, graduate, and even postgraduate levels. Several issues concerning the adequacy of training and competence of medical personnel are unquestionably common for both the civilian and the military worlds. However, the tangled nature of the post-Cold War world vastly increased the complexity of medical issues faced by the Armed Forces of the USA and her allies. Until quite recently, the NATO medical doctrine centered on operations in the environment of a large-scale war. Today, the Armed Forces face virtually all and any of the medical encounters that can be envisaged [12]. The nature and level of medical preparedness required for a prolonged, “classical” armed conflict [13,14,15,16] is vastly different from conflicts “other than war” [17], disaster and humanitarian relief [18,19,20], or acts of international terrorism using chemical/biological warfare agents [21,22,23]. Hence, the military medical services must be continuously ready to face any of the potential conflicts at any time, anywhere, and with undiminished level of efficacy. For this reason alone, the need for a broad-based, sustained, and effective training of military medical personnel

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is, most likely, even more acute than that among their civilian colleagues.

2. MEDICAL READINESS IN THE FIELD: A CONTINUOUSLY PAINFUL ISSUE

Away from the base hospital, the activities of today's military medic or physician may combine the art and original tradition of battlefield medicine mixed with travel- [24], rural or remote region- [25,26], and industrial medicine [27]. In addition, the austerity of field operations [20,28] dictate that several specialties need to be represented in one person, e.g., emergency and trauma medicine, surgery, pediatrics, gynecology and obstetrics, etc. Thus, the nature of modern military medicine imposes the demand for a very high degree of training excellence needed to assure better than adequate performance in the operational setting. Yet, several recent authors indicate substantial training deficiencies among the medical personnel of the Armed Forces at all levels of expertise [29,30,31,32,33,34]. When combined with a significant, and not always well - founded confidence of the military medical personnel in their abilities [29; and MRT, in preparation], the substandard level of skills/diagnostic training is the prescription for subsequently substandard patient outcomes [30].

In order to be effective, medical training needs to be realistic [35]. It also must provide the trainee with a medical problem whose clinical solution requires critical thinking [36] combined with diagnostic and skills competence [37]. In addition, effective training needs to be supported by realistic stressors, e.g., time limits, physical and sensory distractions [37] or even overload. Finally, training must be directed with equal efficiency at individuals [38], teams of individuals [39], and large numbers of individual, simultaneously engaged teams participating in exercises that involve complex, multi-level medical planning and mission tasking [40] seen not only in combat but during natural disasters relief operations in which military forces participate with an ever increasing frequency.

While electronic and information technology-based teaching/training and/or medical knowledge referencing methods, such as CD-ROM discs [41,42], video conferencing [43], Internet and web accessing tools [44], computer-based platforms [45,46] etc., are effective, they satisfy but a few requirements of high efficiency/high flexibility training capable of preparing medical personnel to deal effectively and competently with a wide range of sickness and often complex injury. Outside the real world, the most critical missing component,

i.e., the highly realistic setting where the trainee "actually perspires, the heart rate goes up, and he reacts in a manner that is consistent with what he would do in a real environment" [47] can be arguably obtained only through the application of virtual reality (VR). However, it is only Hyper-Rich Immersive Virtual Reality provides the platform where "real life" stress of a busy ER or treatment of a casualty under enemy fire can be fully recreated [48,49,50].

3. VIRTUAL REALITY IN MEDICAL TRAINING

The concept of virtual reality as a medium for medical education and training is not new [51,52,53]. VR-based training has been embraced with particular vigor by the surgeons [54], with the European Association for Endoscopic Surgery envisioning virtual reality simulation as one of the principal methods of training new personnel [55]. Several forms of VR simulation of endoscopic surgery and its supporting tools have been developed [56,57], and while only some needs of the trainee are fully satisfied [58], the overall results of VR-based training are very positive [59,60]. Although virtual reality laparoscopy appears to be the predominant application of the VR, other training tools have been developed with equal success, e.g., a system for positioning of bone fragments in craniofacial surgery [61], surgical simulator for minimally invasive gynecological surgery [62], a VR-based device for training of IV catheterization [63,64], ECG lead placement [65], retinal coagulation [66], etc. Virtual reality is also suggested as the ideal environment for rehabilitation following major trauma and subsequent neurological impairment, e.g., brain injury [67,68]. The major disadvantage of all medical VR systems currently implemented is their limitation to a single technique or to an approach that does not allow exposure of the trainee to multisystem injury seen at the level of the emergency department, trauma center, or a combat casualty receiving station. Yet, it is in these environments that the need for correctness of diagnosis and initial management is most evident [38], and where stress, miscommunication, deficiencies in medical team cooperation, or lack of medical leadership play the most critical role as the precursors of often fatal errors. It is in these environments, and under these circumstances, that small failures set chain reactions exploding into catastrophic outcomes [39]. It is then obvious that, in order to train for medical events involving complex interaction of medical skills (manual and diagnostic), behaviors, critical time limits, and

stress, a platform incorporating all of these elements into a mirror image of “real life” is needed. In order to be effective, such platform must allow simulation of high-risk, rapid pace environments where mistakes will lead to medical disasters but, if even is such mistakes occur, they can be used as the background for improving learning and competence rather than disciplinary prosecution. The concept of the Medical Readiness Trainer offers such near-perfect training tool.

4. MEDICAL READINESS TRAINER – THE STAND ALONE CONCEPT

In its basic version, the Medical Readiness Trainer comprises of two critical components: the Human Patient Simulator (HPS) providing the haptic component, and the envelope of the Hyper-Rich Fully Immersive Virtual Reality environment [49,50].

In most cases, the Human Patient Simulators (FIG. 1) are computer-operated, life-size manikins capable of physiologically faithful reproduction of human disease signs typically encountered by an emergency/trauma physician [50]. The outputs of these devices provide realistic chest and heart sounds, pulses, pupillary and laryngeal reflexes, and allow monitoring all vital signs in a manner identical to the clinical setting. Fully equipped HPS permits execution of several procedures, e.g., intubation, insertion of drainage tubes and catheters, relief of pneumothorax, cricothyroidectomy, etc. Appropriate physiological response (e.g., relief of pneumothorax restores chest sounds and chest excursion on the affected side, normalizes ECG and blood gas status, etc.) reflect successful execution of manual procedures. Most of the drugs used at the level of ER/OR can be administered either in form of intravenous drips or as syringe-injected bolus, and the “drug treatment” given to a simulator induces a correct, dose dependent systemic response. Importantly, improper or delayed implementation of the required intervention may result in an adverse outcome or a “fatality”. Hence, the student is simultaneously exposed to the realism of the medical event (severely ill patient presenting with all appropriate symptoms), the demand for instantaneous marshalling of all intellectual resources required to perform the initial diagnosis, and the demand to execute correct intervention. Just as a physician at the emergency room, the student will also feel the ever-present stress of the time limits since many urgent conditions, when uncorrected, may rapidly deteriorate to the critical level.

The Virtual Reality component utilizes the CAVE™ functions generating variable, situation-based environments and psychological stressors appropriate for any given scenario. Thus, the CAVE is the source of a practically unlimited range of scenario-relevant, virtual representations of the physical world (e.g., a hospital setting, a sickbay of naval vessel, rescue helicopter, ambulance, a scene of a natural disaster, etc.) all of which can be amplified by stress or distraction-generating elements, such as realistic sounds (noises of an ER, gunfire), movements (rolling ship, earthquake), flashes of light (flames, intermittent loss of electrical power), etc. The prototype MRT (FIG. 2) operates several fully immersive environmental models: a patient bay of an existing emergency room at the University of Michigan Hospital, a generic operating suite whose architecture can be arranged to fit a particular scenario, and a sick bay in a 270 ft. US Coast Guard cutter. Additional medical training content is provided by a series of bit map flip books used to produce short video clips displayed on floating, two-dimensional virtual billboards that are suspended within the virtual immersion space. The billboards are also used to present scenario-relevant ultrasound clips, instructional video clips, web pages, the latter depicting clinical medical records accessed such as CareWeb (University of Michigan Patient Database), Medline references, and other web-based medical education tools. Finally, virtual light boxes capable of projecting digitized and converted DICOM diagnostic quality x-rays, and a virtual vital signs monitor complete the set of standard diagnostic tools. All images and billboards can be moved in and out of the direct field of view depending on the the desired level interaction.

The result of the seamless integration of the Web-based material, video, diagnostic imagery, and virtual “physical” reality with the haptic input and pathophysiological reality of a severely ill patient provided by the HPS, is a novel Hyper-Rich Action Information environment that integrates and presents the wealth of mixed media medical information at a hitherto unattainable level. This type of environment allows the student to acquire mastery of practical clinical skills, while providing simultaneous, unencumbered access to the vast body of supporting (theoretical) knowledge. It is also this type of environment that permits to train management of very difficult scenarios in which the “reality” of life and death outcomes is a direct consequence of the chosen treatment regimen, which, as it often happens, must be selected and implemented under the extreme environmental

stress frequently encountered at a very busy ER, or in the battlefield. As shown by several studies, it is the same environment that is essential for the effective training of medical intervention teams [37,38,39, 40]

The fusion of HPS and VR permits elevation of the training level to an unprecedented level of verisimilitude needed when the management of ultra-complex medical situations, e.g., severe burns (FIG. 3) is practiced. Under current development, the burn management scenarios will be directed at the training of the the entire medical team, whose individual members must perform precisely assigned functions, and where the combined outcome of all individual activities decides the fate of the patient. In this (and other similar scenarios), the HPS provides physiological output scaled to the intensity of the burn, the area affected, etc. In addition to the physiologic response to burns, the HPS allows superimposition of other data characterising collateral injuries that might have taken place simultaneously, e.g., trauma caused by munition fragments, blast injury, etc. The VR component of the MRT provides the visual “burn element” that correlates with HPS-generated physiological responses permitting the practice of the physical management of the burn. When fully developed and combined with appropriate haptic and olphactory stimuli, the “burned patient” scenario complex will constitute one of the most advanced simulation environments providing unprecedented degree of realism that is essential for training (and desensitization) in the complex art of effective treatment of thermal injuries.

As a teaching/training platform, the MRT functions as a hyper-integrated system for the fused delivery of medical content and applications. As such the MRT can incorporate emerging new tools that, in their own right, serve as the legitimate training devices, e.g., systems to train IV line insertion, optical simulators, broncho- or laparoscopic simulators, laser escharotomy instruments, or even 3D anatomical models complete with sound and deformation feedback under simulated surgery. The MRT serves thus as an open-ended foundation that brings together each of the current and future training tools and concepts into a common learning and instruction environment. However, in order for all of these “subcomponent” trainer parts to be useful within the envelope of a single medium, they need to be federated into a unified system that allows the instructor to choose a set of environmental factors and patient attributes that can be run simultaneously and cooperatively on each training device. For example, if the scene of trauma

involves a fire where the patient suffers full thickness burns and smoke inhalation, the required training environment must start with the skin model simulating burns. However, the curriculum library must also contain appropriate criteria that will set the HPS airway configuration to reflect the effects of smoke, establish potential characteristics for the available models of surgical approaches, and to incorporate the supporting patient medical record material as to reflect any appropriate ancillary tests and studies.

Clearly, in the MRT context, the classical “standardized patient” assumes an entirely new level of sophistication and permits a complex fusion of medically relevant content with a curriculum library, the latter enabling training of both specific and general skills.

In addition to allowing the student to train their own specialty-typical skills, the level of integration required in the MRT concept must permit introduction of the curricula that span time continuum of a medical event, and that are not limited to a particular clinical specialty. For example, a target-focused curriculum can be designed to educate non-medical personnel in providing effective help to the injured above the absolutely basic level in situations when trained medics are not available. The scene of the actual event (e.g., injury sustained following collapse of a building during an earthquake, wounds caused by street fighting) can be transformed into a sequence involving the evacuation, transfer to the Level I facility, followed by subsequent evacuations to the rear. If the subsequent rehabilitation of the casualty is envisaged as a part of the training continuum, even a scenario of home-based recovery can be included. The ability to simulate these environments longitudinally allows each provider-level to train not only within their appropriate sphere of competence but also to witness the events at the level of “hand-offs” that occur between the consecutive levels of treatment. Such training increases the awareness of all providers to the complexity of the preceding events, allows training in broad-minded anticipation and preparation for potential problems, and enhances subsequent efficiency of performance in “real life” field operations.

5. MEDICAL READINESS TRAINER: THE TRAINING NETWORK

As a basic unit, the Medical Readiness Trainer has already entered its operational testing [69]. As a collaboration environment, however, the prototype MRT is in its infancy. Currently, and at its simplest level, a small team can share a common experience

within the MRT. However, as the devices within the MRT are federated, they can be easily distance-enabled and provided with remote control attributes. Still, it must be borne in mind, that while the operational network of MRTs is an unquestionably alluring concept, the creation of such a system introduces a new, and much higher, level of complexity.

Presently, the collaborative virtual reality is considered to be one of the most challenging areas of research in the field [70]. Nonetheless, a significant and pioneering work has already been done in the area of networked CAVE applications. [71, 72,73] and it is such network that will allow the medical teams to train together in a virtual space, where each team member experiences and interacts with identical environmental and patient scenarios simultaneously.

The capacity of a large MRT network provides the platform for contemporaneous training of a variety of medical and disaster response skills. The exercised skills and capabilities may range from triage and individual patient management, through team leadership and I Echelon facility management, to the efficient allocation and use of all supporting medical resources such as supplies, personnel, medical transport, routing to appropriate or available facilities, patient-record tagging, etc. Confounding elements, e.g., fluidity of the situation on the ground, weather factors or political considerations and barriers, etc. can be easily fused into these “large-scale” scenarios of ever increasing complexity and realism. In summary, the federation of “parts” trainers combined with the ability to support their remote control can be leveraged to create a web of interconnected devices whose complexity ranges from the simple procedure unit to the full-complexity MRT, all participate in a concerted and coordinated manner. The coordinated action of such a web provides for large scale training exercises where some teams operate in fully immersive MRTs, some are working on “stand-alone” HPS units, or use specific “parts” trainers, while others are interacting with computer based simulations and truly virtual patients (FIG. 4).

The information output of all activities that may take place at vastly different locations but are, nonetheless, simultaneous, is handed to the action directing levels (e.g., procedure nurse – team leader – attending physician – unit commander – area commander – etc.) At the “command level” information streams from subordinate layers are collated, analyzed, and the critical decisions

directing future performance of the virtual “medical operations area” (which can range from a small village to the entire country) are made, and disseminated within the command as operational orders.

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Hospital, Puerto Rico (RRNHPR). The simulator is under remote control of a senior emergency medicine physician at UoMED, the IDC trains at RRNHPR. Despite nearly 2,500 miles distance between the expert and the trainee, the training session is conducted as if both were in the same room. The remote teaching expert controls the training session using real time, bi-directional voice/video link and HPS remote control. The medical expert in Ann Arbor views the continuous physiological data output generated by the HPS at the same time as the trainee sees them on a standard (Eagle) ER vital signs monitor. If HPS is not available at the training site, the trainee(s) can gain access to a remote HPS unit using remote control system developed by the Medical Readiness Trainer Team. Although the physical contact with the HPS is lost, recent studies conducted by the MRT Team (in press) showed that a highly effective training in casualty management can still be performed, particularly when executed under the guidance of remote expert teachers.

7. FIGURES



Fig. 1 US Navy Independent Duty Corpsman (IDC) defibrillating Human Patient Simulator (METI, Version “C”) during a training exercise conducted by the MRT Team between the Department of Emergency Medicine at the University of Michigan Health Center in Ann Arbor, MI UoMED).and Roosevelt Roads Naval



Fig. 2 “Hyper-rich” MRT environment. The Human Patient Simulator (METI, Version “B”) is surrounded by a fully immersive virtual reality environment depicting a patient bay at the ER of the University of Michigan Department of Emergency Medicine. The CAVE™ allows creation of unlimited physical scenarios with highly complex characteristics (e.g., multi-axial VR movement, realistic sound, smells, etc.) that permit convincing (and stressful) rendition of real life environments such as ships in seaway, aircraft in turbulence, or land vehicles moving across rugged terrain. Apart from the HPS, all other objects shown in the illustration are VR renditions. Seen from left to right are: DICOM scenario-relevant X-ray images, vital signs monitor with the ultrasound monitor screen below, instrument pillar with a variety of instruments attached to it, a floating billboard with the relevant patient data extracted

from patient data bank, another floating billboard with a video clip of showing the execution of a treatment-relevant procedure (intubation). Floating billboards can be moved in and out of the trainee's view by means of the control device (wand) resting on the abdomen of the HPS. CAVE environments are particularly suitable for training medical management teams, and in the process of acclimatizing them both to a variety of physical settings and to the relevant stressor elements shown to affect both individual and team performance under operational conditions.

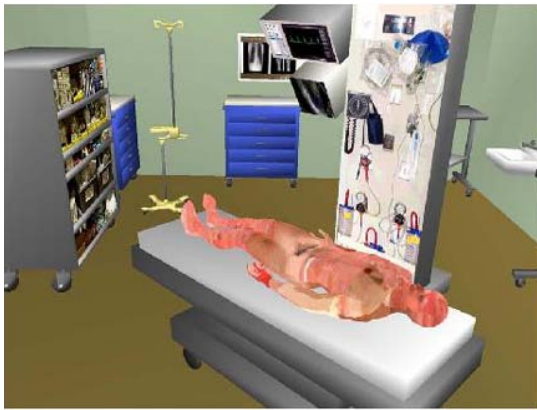


Fig. 3 Arguably the world's first severely burned VR patient in a VR patient bay seen also in Fig.2. In order to produce high quality print, the illustration is made as a 2D (compare to the slightly fuzzy image in Fig.2 – in the immersive environment “shutter glasses” are used and the otherwise poorly focused environment shown in Fig.2 is seen as sharply as that in Fig.3). Combination of advanced simulation and modeling with advanced VR visualization techniques under current development at the Medical Simulation, Modeling, Advanced Research and Training Laboratory at the University of Michigan, will permit creation of ultra-complex models of severe multisystem injuries suitable for advanced training and skills refreshment. Currently, adequate training in the management of serious trauma (e.g., massive burns, combat trauma, chemical warfare agents, etc.) can be obtained only through either theoretical lectures or direct exposure to the affected patients. Due to their computer-based nature, interactive simulation and modeling systems are preeminently suitable for advanced distributed learning/distributed interactive simulation (ADL/DIS) training at very long (>>1000 miles) distances.

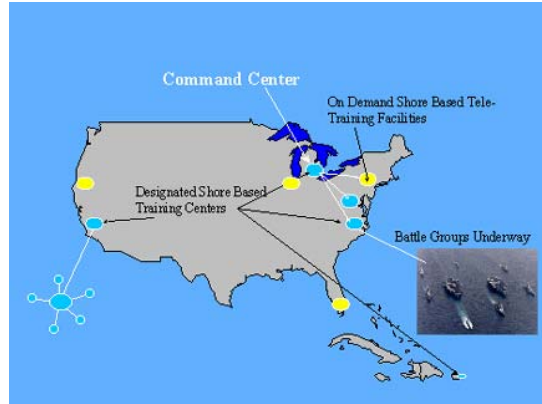


Fig. 4 Diagram of an MRT network representing layers of hierarchical of complexity. “Designated Shore-Based Training Centers” consist of immersive VR (CAVE) facilities equipped with all training resources described in the paper, similar to those shown in Fig. 2. On Demand Shore Based Teletraining Facilities allow remote access to their training environment based on telepresence and the extensive use of auto-stereoscopic displays at the remote user site (e.g., battle group underway.) The bottom tier of On Demand sites may be based on nothing more than a remote-operations-capable Human Patient Simulator with an extensive scenario library that can be controlled from a remote site. All training centers in the network can communicate with each other using DSL-based access to Internet. However, access scalability permits the use of Shore-Based Teletraining centers using POTS up- and download speeds (e.g., ref. 69). Importantly, the CAVE-based MRTs are interlinked, allowing exercising sophisticated medical functions (e.g., training of senior medical personnel at the attending physician/unit commander level). In addition, the medical input from lower level systems can be transmitted to- and fused with other pertinent data (e.g., weather, availability of transport resources, ground conditions, etc.) at the level of the Command Center, where medical command of large area medical operations can be realistically trained. High mobility of the latest versions of HPS units combined with advanced telecommunications technology (e.g., VSAT systems), visualization (3-D displays), and remote control systems makes them particularly suitable for field deployment and exposure to large numbers of forward-deployed personnel. When needed, the much more expensive but very highly sophisticated immersive environments (CAVEs) can be accessed from the field as well. Apart from advanced individual training, CAVEs are preeminently suited for sophisticated training of medical teams, pre-

deployment preparation, and as environment acclimatization systems within the concept of “just-in-time” training. In a networking MRT, a single medical expert located at the Command Center can simultaneously instruct a very wide range of personnel located practically anywhere. The MRT network allows maximum flexibility in the use of scarce technology resources (HPS and CAVE systems), and permits expert-directed routine training of personnel in remote locations that would otherwise have no immediate access to the traditional training centers (Advanced Distributed Learning, ADL). Prior to the development of the MRT concept, such training was not available without major interruptions of the routine operations.