Medical Simulation for the Future of the Joint Training Community

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ABSTRACT

For more than two decades, the U.S military has significantly increased its use of medical simulations for training. In 1996, the Army began structured research and development (R&D) to bridge the training gap between the traditional warfighter and the medical warfighter. From that effort, significant progress has been made that has shaped the medical simulation and training industry. The last 20 plus years saw the development and refinement of full body manikins and task trainers specifically designed for the military. It also saw the emergence of virtual environments and virtual patients. Additionally, surgical simulations advanced as visually immersive and more natural hand held devices reached technology maturation.

Many of the developments were pursued by the R&D community because they met a current critical training gap identified by the training community. As the Department of Defense (DoD) moves into the next decade, a more strategic approach is required. Resources are limited, and there is a desire to work across the Joint medical and Warfighter communities. Challenges still exist, including interoperability across simulations platforms, scaling simulation and training fidelity to the needed complexity as well as for the different levels of medical care providers, tailoring training content to the learner, objective performance measures, and natural, meaningful interactions with simulated patients.

This paper will present a brief history of successes, lessons learned and future challenges. It will focus on several projects, as representative examples, that have gone from a concept, through R&D, testing, and transition to fielded capabilities. It will also include a path forward as the medical simulation and training community moves to a more unified approach across the services.

ABOUT THE AUTHORS

Dr. Beth Pettitt is the Chief for the Medical Simulation Research Branch (MSRB) at the Army's Simulation and Training Technology Center (STTC). Dr. Pettitt is actively involved in pushing research frontiers, testing, evaluating, and transitioning relevant technologies quickly, as well as managing the cost, schedule and performance of the multi-million dollar research efforts. Dr. Pettitt has a BS in Mechanical Engineering, an MBA from Webster University and a PhD in Modeling and Simulation from the University of Central Florida. She is Program Management Level III certified through the Defense Acquisition University and is a member of the Acquisition Corps. Dr. Pettitt has been applying creative innovations to medical simulation and training technologies for over 20 years. Her current research is focused on optimizing and applying the correct level of fidelity according to the level of medical care.

Dr. Jack Norfleet is the Chief Engineer for the MSRB of the U.S. Army STTC. He plans and executes medical simulation R&D while managing a multidisciplinary team of scientists and engineers. He is currently researching methods to improve medical simulation effectiveness by characterizing human tissues, instantiating accurate anatomy, objectively measuring skill, delivering advanced haptics and implementing medical extended reality environments. Dr. Norfleet started his federal career as a GS-1 in 1984 and has 35 years of experience in modeling and simulation development for the U.S. Army and U.S. Navy. His degrees include a Ph.D. in Modeling and Simulation, University of Central Florida, 2018, a Master of Business Administration, Webster University, 2001, and a Bachelor of Science in Electronics Engineering, UCF 1990.

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INTRODUCTION

In 1996, a military research effort known as the Combat Trauma Patient Simulation (CTPS) system (Figure 1) was initiated to integrate medical simulations into warfighter training simulations. The mission was to provide a comprehensive training experience that simulated casualties for treatment from the point of injury through ascending levels of care (MB Pettitt, Goldiez, Petty, Rajput, & Tu, 1998). CTPS connected to the live Multiple Integrated Laser Engagement System (MILES) and the constructive Semi-Automated Forces (SAF). A certified medical High Level Architecture (HLA) network was created to integrate the self-compensating physiology engines of human patient simulators with SAF and MILES. Over the next two decades, the simulation Research and Development (R&D) community made significant progress towards achieving this integrated vision, but the training domains still remain segregated. Capabilities continue to be added to MILES and SAF that generate accurate medical information, such as ballistically appropriate wounding in the correct region of the body, as well as the appropriate handling and movement of the wounded. The military medical simulation community has invested heavily in research to untether and ruggedize manikins for use at all roles, to deliver fidelity that matches desired learning outcomes, and to define objective measures for automated competency evaluations.

Figure 1: Combat Trauma Patient Simulation Vision

From the original CTPS project, significant progress has been made that has shaped the medical simulation and training industry (M Pettitt, Norfleet, & Pike, 2017). Full body manikins and task trainers have been refined to meet military requirements. Virtual environments and virtual patients have emerged that demonstrate significant promise in meeting current and future medical training needs. Additionally, surgical simulations have advanced as visually immersive and more natural hand held interface devices reached technology maturation. Finally, pre-milestone decision assessments, such as usability studies and training effectiveness evaluations continue to deliver a robust flow of information to identify requirements, inform prototype improvements and affect future capability designs.

BODIES EVERYWHERE!

Since the 1990's, sophisticated patient simulators, originally developed for anesthesia training, have been incorporated in medical training (Kapur & Steadman, 1998). These simulators physically mimic the human form and often employ complex mathematical models to represent different injuries, illnesses, and treatments. Although originally developed for the civilian marketplace, Department of Defense (DoD) sponsored R&D in the late 1990's created valuable military capabilities for training medical skills from basic lifesaving to surgical interventions. These improvements included on-board bleeding and fluid secretions, life-like movement, more realistic tissues, strengthened mechanical joints to support field use, and additional physiological responses, such as biological and chemical contamination and pharmacological responses.

For task development, or learning the steps of a procedure in a classroom setting, it is more appropriate and cost effective to only simulate parts of the body, often referred to as task trainers. Task trainers exist for many individual skills, such as hemorrhage control, airway management, intravenous access (IV), palpations, eye trauma treatment, dental treatment, fasciotomy and intraosseous infusion. The user community has pushed for decreased cost and easier field refurbishment. There is also a growing desire for simple task trainers to attach to computer based instruction to enhance learning. And, similar to the evolution that has occurred with full body manikins, many of the original task trainers have been replaced with newer devices that have more realistic or lifelike skin and tissues.

Since 2010, significant work has been performed in quantifying and improving medical simulation realism. Medical simulation realism involves accurately replicating the structure, look, feel and behavior of the human body when subjected to medical treatment. Realism is being addressed at both the macro level; body size and measures at the 50^{th} percentile and at the micro level; individual tissue behaviors when subjected to force. The more human-like the simulation, the lesser the need to use live tissue or cadavers.

Methods have been developed and validated for quantifying how tissue behaves and for defining material performance standards. Standard measures are conducted as applicable for each received tissue which include: uniaxial tensile testing, biaxial tensile testing, compression, color analyses, electrical response and thermal response. Tissues are also tested for response to medical interactions. For example: human pleura is punctured using forceps during the insertion of a chest tube. The haptic pop that occurs during the puncture informs the learner that he/she has accessed the desired cavity in the body. Blunt puncture measures from fresh cadavers less than 50 years old at death resulted in a force range of 8.0-20.5N and a displacement range of 12.5-21.1mm. These measures (Figure 2) also revealed that several commonly used commercial simulators use simulated pleura that is well outside of this range (Norfleet, 2018).

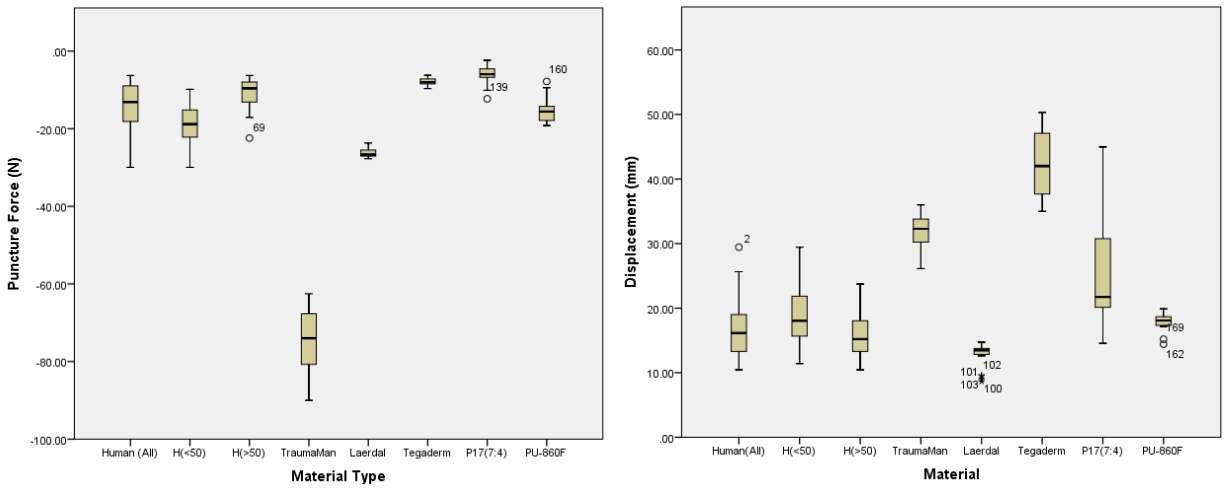

Figure 2: Puncture Force and Displacement for Pleura

The quest to improve medical simulation realism continues with procedure specific tissue characterization and anatomy replication. Detailed critical task analyses are performed on each procedure and pertinent anatomy, tissues, behaviors and cues are identified and ranked by their criticality to learning. It is vital for the virtual and physical devices to deliver anatomic accuracy and behavior cues to inform the decision making process of the trainee, injecting critical thinking in the learning process. These resulting performance standards are included in current and future military medical simulation requirements. For example: Synthetic pleura at chest tube insertion sites shall exhibit a force between 8N and 20N and shall stretch between 13mm and 21mm at failure, when punctured using 20cm curved Carmalt hemostatic forceps.

As mechanically quantifiable simulated human tissue is defined, it is also important to develop simulations with appropriate realism for the training scenario. For example, it has been shown that at the point of injury, a two dimensional tattoo type wound (Figure 3) is as effective as a three dimensional silicone wound (M Pettitt, 2017). For this type of scenario, a realistic visual with an appropriate amount of simulated blood, provides the necessary indicators for the medical provider to control the bleeding and dress the wound. As training is developed for (All-Service-Member) ASM Tactical Combat Casualty Care (TC3) and other levels of basic assessment and care, a simple and inexpensive but scalable solution is adequate and effective.

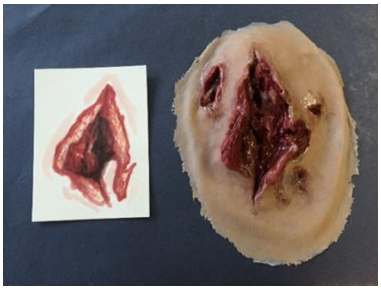

Figure 3: Tattoo and Silicone Wound

THE ILLUSIVE HOLODECK

Starting in the 1990s, fledgling immersive environments emerged as possible solutions for military combat training. These capabilities soon became associated with the "holodeck", a fictional, virtual environment from the Star Trek series of television programs (Congress, 1994). The fictional holodeck was unique for its completely immersive, natural interactions with live and virtual characters in various social and military encounters. It was used for plot advancement in the television series but it is commonly referenced in military virtual/mixed reality programs as a

desired end state. Military holodeck have progressed from the Synthetic Theater of War project in the late 90s to the current Synthetic Training Environment (STE) which is one of the top six modernization priorities for the US Army.

Fixed facility computer aided virtual environments (CAVES) became very popular for military combat simulations during 1990s and 2000s (Congress, 1994). CAVES are typically a room sized or larger enclosure surrounded by computer generated displays that deliver the visual representation of a combat environment. Trainee tracking systems and weapon engagement capabilities were integrated to allow movement through and interaction with the environment. Medical manikins were introduced to provide hands on treatment capabilities. The simplest applications occurred by placing injured manikins into combat focused environments such as the Engagement Skills Trainer (EST). More complex integrations were demonstrated by developing medical specific scenarios that forced the trainee to decide whether to treat or fight, similar to a police shoot/don't shoot scenario. CAVES have fallen out of favor in the military because of the complexities of getting soldiers to the training. A stated goal of STE is for soldiers to fight "25 bloodless battles" before seeing combat (Judson, 2008). This will be difficult to achieve if all medical personnel preparing for deployment have to travel to fixed facilities for training.

Games and virtual environments advance the plot and form the dynamic scenery of any holodeck applied to military training. Medical training is certainly no exception. The DoD has invested heavily in numerous gaming platforms, some with a very narrow focus and some with a much larger scope; all with the goal of providing inexpensive and easily accessible training. Environments have been developed that model an emergency room, medical evacuation aircraft, point of injury, triage, and medic bag packing, to name a few. Unfortunately, the speed in which gaming technology advances combined with the various platforms, languages, engines, and service specific requirements have prevented the development of a single robust and capable system. Regardless, as the military moves toward joint training, this kind of interoperability will be necessary.

Many of the past medical simulation developments were started because they addressed a critical training gap identified by the training community. As the DoD moves into the next decade with tighter financial constraints and more emphasis on providing a truly joint training experience, a more strategic approach will be necessary. Service level requirements must be defined and resources placed against them.

In the R&D domain, validation through knowledge transfer and training effectiveness studies using different technologies will be critical for informing future capability requirements. For example, is a fixed facility, CAVE system more or less effective than the latest head mounted display system? Evaluations are also needed of safety factors, such physical and mental strain in various environments induced over time. Many technical challenges still exist, including interoperability across simulations platforms, scalable fidelity, tailored training content, objective performance measures, and natural and meaningful interactions with simulated patients.

Civilian medical training significantly affects military doctors, nurses and physician assistants because these military providers are certified and credentialed through civilian boards. One recurring theme in the medical community is the need to evolve towards competency based medicine (CBM) where providers regularly demonstrate competency in order to maintain certifications and privileges. The current system is not equipped for CBM. It allows providers to certify in a different specialty early in their careers and then maintain that certification even if they don't practice the skills. This system significantly affects the DoD when dermatologists certified in emergency medicine are placed in command of combat support hospitals, even though they haven't practiced emergency medicine in decades. To address this issue, the DoD is requiring cross specialty training of individual critical tasks that are required for deployment. The R&D community is investigating automated skill evaluations using inputs from various sensors embedded in simulators and combining them with computer vision techniques, machine learning and AI to build competency frameworks. The ultimate goal of these efforts is to build tools for achieving competency based medicine.

MEDICAL IN THE WORLD OF STE

The US Army and Air Force's push for a STE that leverages the most recent technological advances and connects all domains into a unified and seamless training environment is affecting all areas of simulation and training research, development and acquisition. Medical is no exception; however at the moment Army medical capabilities

are a lower priority in the list of capabilities which provides the Defense Health Agency (DHA) and Army some time to correctly identify the needed capabilities and finalize requirements documents. The desired end state of Army STE-Medical is an integrated patient treatment capability to enable training cognitive and psychomotor medical tasks at both individual and collective levels, initially focused on TC3 ASM training, later including Tiers 2 through 4 as defined in Department of Defense Instruction (DoDI) 1322.24. This would create a comprehensive STE training experience which would address movement, engagement, communication, and treatment in the Army's virtual environment.

Part of the STE goal is virtual training that is accessible anytime and anywhere. For medical, this will limit the reliance on manikins and task trainers, which requires a robust haptic interface that provides perceptions of subtle differences in texture and force on the hands and finger tips. It also requires interoperability with the larger STE environment, multiple wounding scenarios, micro olfactory dispersion, sensors, and automated competency evaluation. Figure 4 depicts an iterative step enabling medical training in the STE.

The US Army, CCDC Soldier Center Simulation and Training Technology Center (STTC) is working closely with US Army Medical Research and Development Command (MRDC), DHA, Joint Program Manager-Medical Modeling and Simulation (JPM-MMS) and more recently the newly established DoD Medical Center of Excellence (MEDCoE) Directorate of Simulation (DoS) to insure a medically relevant and integrated approach. In 2015, the DHA established the DoD Medical Simulation Enterprise (MSE), consisting of six medical simulation programs; Joint Evacuation Trauma System (JETS), Point of Injury Training System (POINTS), Theater Hospital Operations Replication (THOR), Simulated Hospital Operations and Treatment System (SHOTS), Rehabilitation Simulation for Treatment (ReST), and Warfighter Performance, Resilience, Effectiveness and Protection (WarPREP). These six programs will utilize a medical Synthetic Training Environment (mSTE) in order to ensure integration with any Component or Service synthetic capability. Current requirements documents are already codifying the integration of DHA simulation programs and Service synthetic environments. The first example of this is the above described mSTE capability within the DHA program requirements documents. The second example is the Army Inter-Service Initial Capabilities Document (IS-ICD), and the requirements for the Army STE which include a Key Performance Parameter (KPP) to integrate with the DHA MSE.

Figure 4: STE for Medical Training

SUCCESSES

The broader success of the medical simulation efforts to date are the inclusion of realistic wounding and medical training in warfighter simulations such as SAF, MILES, Virtual Battel Space 2 (VBS2) and STE. Additionally, the medical community has leveraged many of the lessons learned and technologies from the non-medical warfighter R&D. A few of the successes of the larger medical simulation enterprise are the Medical Simulation and Training Centers (MSTC's), Multi-Amputee Trauma Trainer (MATT), untethered patient simulators such as CEASAR and the Stand-Alone Patient Simulator (SAPS) which became the commercial i-STAN, TC3Sim, medical holograms, Medical Training Command and Control (MTC2) and medical card decks. There are also emerging efforts that are worth mentioning. These include the advanced airway, Advanced Modular Manikin (AMM), POINTS, JETS, the Medical Simulation Training Architecture (MSTA), and the Learning Strategy, Tactics and Technology project.

These successes are often the result of many organizations working together. MATT, for example, began as a Small Business Innovative Research (SBIR) project in 2006, proposed and managed by the STTC and funded through the MRMC SBIR office at Fort Detrick. In 2008, through government sponsored testing, the prototype trained 300 soldiers in hemorrhage control. Because of its success as a research project and a training device, it won multiple awards through the SBIR and Modeling and Simulation communities, and it had its initial fielding to MSTC's in a mere four years. With additional funding from PEOSTRI, STTC and MRMC's Joint Program Committee (JPC1), capabilities were added to the lower MATT and an upper MATT was developed and transitioned to MSTC's in 2013.

The DoD research that had the greatest impact on medical simulation, both inside and outside of the military, was the development of the wireless, field capable full body simulator known as the SAPS. The work began in the CTPS program where lack of patient interaction was the largest and most obvious gap in medical training. At the time, commercial full body simulators cost hundreds of thousands of dollars and were used for training physicians like anesthesiologists. To address this, the STTC worked with industry to create a lower cost, military capable patient simulator. This was also an early example of scaling simulation fidelity to target a specific training population. The resultant simulator became commercially known as the METI Emergency Care Simulator (ECS) which was demonstrated in 1998 (Figure 5). The ECS became the first Army standard medical simulator in 2006 when it was fielded as part of the MSTC's initial equipment set. Testing of the ECS revealed another critical gap in the technology. The combat medical curriculum teaches only three courses of action at the point of injury; first fight, second apply a hasty tourniquet, third move the patient to safety. Moving the patient is a critical task but the electrical and pneumatic tethers on the simulator prevented it. This gap created a partnership between the STTC and MRMC which created the SAPS program, a multi-year effort consisting of two consecutive Army Technology Objectives which meant that medical manikin development became a priority of the Army Science and Technology roadmap. In the absence of approved requirements, the performance requirements of the SAPS program consisted of the critical tasks of the Army combat medic. When the SAPS program began, there were no physiologically accurate, tetherless rugged medical manikins. Now, they are an industry standard. The SAPS program ended in 2007 and the Army fielded the first tetherless medical manikin in 2013.

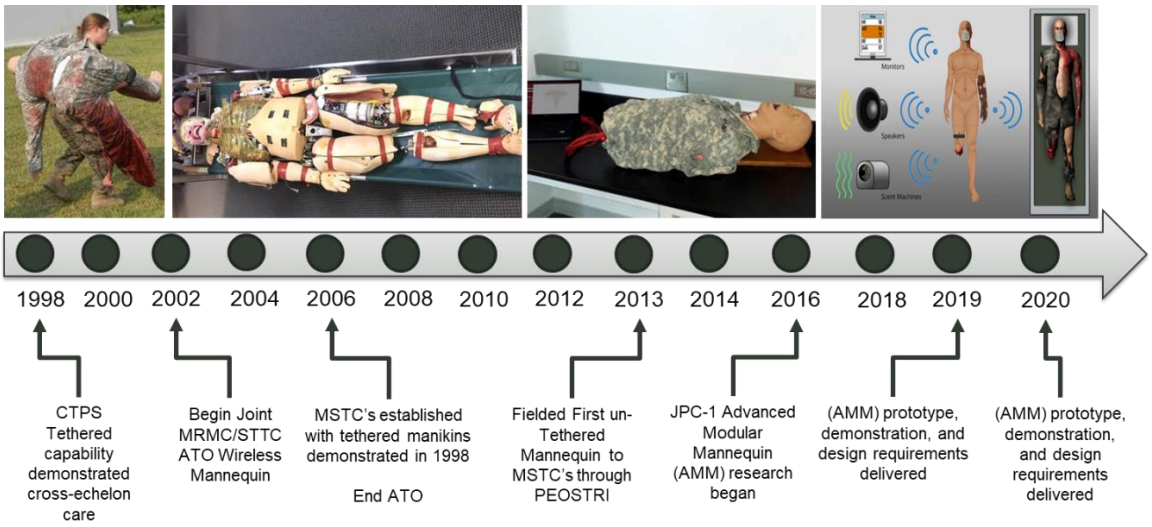

Figure 5: Medical Full Body Manikin Research, Development and Acquisition

The effect of military R&D is evident across the civilian domain. Commercial companies often follow the trends of the military research communities, through calls for white papers and proposals, and then implement the desired capabilities into their product lines using their internal research and development dollars. DoD trend following has the potential to bring new capabilities to the market quickly, but at the risk of not fully meeting the governments requirements through faulty assumptions and commercial pressures such as profit.

LESSONS LEARNED

The first lesson is that regardless of how complex and lifelike the High Fidelity Human Patient Simulators (HFHPS) are, they are useless if not properly employed. The DoD does not have formalized instructor training courses or certifications on how to effectively integrate simulations into training and testing activities. Additionally, the HFHPSs are not used in realistic (immersive) scenarios and environments. During a bottom-up review of all 21 MSTCs, MEDCoE found that 44% of the MSTCs were not using the "high tech" features of the HFHPSs, and 37% were not using them at all in testing scenarios. Training and evaluating Combat Medics is done almost the same way as it was done 25-years ago by employing the HFHPS with no injuries, on a table or on the floor of a plain room. The instructor reads a scenario, explaining what the student "sees" during the "treatment" and, then verbalizes the patient's signs, symptoms and condition. The problem is often not in the quality or fidelity of the training equipment; the problem is the way the equipment is used. Training aids, such as manikins, task trainers, and game-based training and evaluation systems are only as good as the curriculum and instructors that use them. Curricula and automated performance measures must be developed that incorporate these training aids in a manner that maximizes learning outcomes and minimizes instructor loads and disruptions.

The second lesson is that although requirements have been a challenge, both DHA and DoD are actively moving toward a resolution by developing requirements documents for the MSE programs. As a result, this barrier should no longer be a project stopper. So often when an early research concept is described, the question of requirements becomes an issue, because requirements documents do not typically leverage the full flexibility available within the Joint Capabilities Integration and Development System (JCIDS) and Acquisition systems. Research does not always directly translate to a documented requirement, but often reveals the gaps that become the requirements.

The third lesson is that JCIDS is usually too slow for effective R&D. Medical simulation and training research projects typically take eight years from concept creation to a prototype tested in a relevant environment that is ready for transition. Figure 5 shows a typical timeline. With a five to 10 year time span from the start of a research effort to a fielding, new research needs the freedom to demonstrate the art of the possible. This timeline could at times be accelerated with additional funding and manpower, but time will always be required to properly research, develop, test, and refine the next great new idea.

The fourth lesson is that medical simulation and training commercial products are civilian market driven and require much government involvement to reap the maximum benefits. New training capabilities require a detailed task analysis, consultation with subject matter experts and users, prototype development, testing in a militarily relevant environment, refinement and retesting. Without government involvement many of these steps are difficult and often are omitted because of cost. Even though companies can produce amazing capabilities, the government must verify that training aids can do what they claim to do before they are adopted. The MEDCoE DOS is tasked to coordinate this effort for Army.

FUTURE CHALLENGES

The DoD communities involved in medical simulation and training research, development and acquisition have a complex organizational chart. There are the traditional medical organizations such as MRMC, DHA, Service and Component medical departments, JPC-1, and Uniformed Services University of Health Sciences (USUHS) that provide funding, clinical expertise, research and training for medical treatment and devices. There are also the traditional DoD simulation and training organizations such as PEOSTRI and STTC who bring a unique mix of engineering and acquisition expertise to the table. There are of course many other offices that provide similar capabilities across the Services. This diverse group of organizations and expertise points to perhaps some of the greatest strengths and greatest challenges for medical simulation and training. Strengths include the fact that medical care is needed across all the services. Challenges include integrating patient care training across platforms, networks, and a variety of treatment protocols. And, there is the never ending challenge of insuring requirements and funding are in place to support the many needed advances emerging from the R&D community. The MEDCoE was recently established to bridge the gap between the military medicine and military simulation communities and is actively working to bring all relevant expertise together.

DHA was established as an office to provide a joint and central voice for military medicine. Part of DHA's mission is to also ensure that a strategic approach is applied across the operational force; and a subset of that is insuring that R&D is necessary, supported and applicable across the services. For the Army, MEDCoE has begun the arduous task of documenting medical training requirements. These requirements will support the medical Individual Critical Task Lists (ICTLs) that will be imposed at all levels of care. Prior to the formation of the MEDCoE, several draft medical simulation requirements have been started. As of the writing of this paper there are draft requirements documents for the JETS, AMM, POINTS, TC3 ASM training, TC3 Combat Lifesaver training, TC3 Combat Medic/Corpsman training, MTF Medical Modeling and Simulation equipment for day-to-day use, and for the Reduction/Elimination of Live Tissue Training. Currently, the STE Capabilities Development Document (CDD) and the 2009 MSTC Capabilities Production Document (CPD) are the only approved Army requirements that address medical simulation.

One of the challenges in tackling the joint communities' needs and expectations is still allowing research efforts to explore areas that may take many years to mature. Often requirements from the Joint user community, describe product improvements and not future capabilities. It is critical that research align with documented requirements while maintaining some independence and freedom to explore. As was shown in Figure 5, effective and complete research takes many years, and sometimes leads to unexpected conclusions. This timeline showed how initial research to modify a commercial manikin for military use, led to the need to fully untether the manikin. The untethered manikin pointed to the challenges of a single vendor, unique connectors and the lack of standards for modeling the anatomy, physiology, and injuries all of which informed the need for the AMM research project.

Competency based medicine remains one of the biggest and hardest challenges. It represents a paradigm shift in how medicine is taught. The current apprentice/master model is not optimal for the spectrum of skills required of military medical providers. The DoD is taking steps towards achieving this desired end state. Enabling capabilities include standardized curricula, and cross specialty ICTLs. Enabling technologies include smart simulations, sensor fusion, automated grading, machine learning, computer vision, human tissue characterization, and artificial intelligence.

CONCLUSIONS

There are still many opportunities for innovation and collaboration. The DoD is investigating the viability of open source standards for modular medical simulations. The concept should relieve the difficulties created by adopting commercial products and being constrained to these legacy platforms. By defining the standards for the simulation platform, the innovation can be concentrated on the area where the learning occurs.

Multiple services are looking to implement synthetic training environments to more efficiently deliver standardized training. Haptics fidelity and delivery are critical if the system has any hope of attaining true immersion. Medical haptics are even more important as most procedures require precise 3D positioning typically determined by palpation. Without accurate anatomic and tissue palpation cues, the risk of negative training rises. For example, the placement of the needle in a chest decompression is in the second intercostal space mid clavicular. If the trainee cannot distinguish the clavicle and then determine the spaces between the ribs, placement errors are inevitable.

Sensor fusion becomes critical for objectively measuring performance as advancements in sensor technologies multiply what can be measured. Printable and embedded sensors bring the promise of smart simulators that detect the location and quality of a procedure such as an incision. Combine these measures with man worn and external sensors and the beginning of a competency framework emerges.

Tissue characterization is becoming more important along with accurate anatomy. To achieve true understanding, the training media must deliver the subtle cues that an expert relies on to decide if they are progressing down the right path or if they need to adjust. Until synthetic and virtual tissues deliver these cues, simulations will remain plastic or be considered a game. There is no way to simulate the behaviors of tissue and anatomy until human tissues and anatomy are characterized under the same conditions.

The potential of simulation in general, and medical simulation and training in particular, is extraordinary! Advancements in materials, sensors, electronics and computing power are fueling the potential innovations at a remarkable pace. The military community is beginning to address the need for requirements. Organizations and funding lines are being dedicated to insuring that the MSE is functioning in a truly Joint method. The challenges include keeping the organizations and bureaucracy from overwhelming the creative and entrepreneurial engine that has fueled this community for years; always insuring that the training development and devices are what is needed by the user community; and that these devices provide the best possible learning outcomes. And of course, higher learning outcomes directly translate to saved lives on the battlefield.

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