Required Fidelity of Simulated Wounds at the Point of Injury

M. Beth H. Pettitt
Army Research Laboratory
Human Research and Engineering Directorate
Simulation and Training Technology Center
Orlando, Florida
Merry.b.pettitt.civ@mail.mil

ABSTRACT

At the point of injury, critical medical tasks include finding and identifying the injury as well as applying the appropriate initial care. A considerable amount of research and development has already occurred to increase the fidelity of simulated wounds for training, primarily at the point of injury. As material and moulage techniques mature, and as more relevant data is collected on tissue properties, it is worth examining what fidelity is really required for training at the point of injury. This effort will explore the current state of wound simulation and propose a basic test methodology to assess what fidelity is adequate. Secondly, this effort will analyze the differences in technology effectiveness of two and three dimensional (2D and 3D) wound moulage. Other factors that will be examined including cost comparisons between the average 2D wound and silicon-based 3D wound, as well as the time to apply each type of moulage. Finally, conclusions will be discussed on the training effectiveness of the two types of moulage and recommendations will be made on the appropriate use of each in medical training.

ABOUT THE AUTHOR

Ms. Pettitt is a graduate of Old Dominion University with a degree in Mechanical Engineering. She also holds a Master of Business Administration degree from Webster University and a Masters in Modeling and Simulation from the University of Central Florida. She is currently pursuing a PhD in Modeling and Simulation at the University of Central Florida and plans to graduate in 2016. As the Chief for the Medical Simulation Research (MSR) Branch, Ms Pettitt is actively involved in pushing research frontiers, test and evaluation, and quickly transitioning relevant technologies.

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INTRODUCTION

The art and science of depicting simulated wounds for the purpose of training or moulage, has been around since ca. 2050 B.C. Egypt, but appears to have been documented and refined in the early 1700's by Abraham Chovett in London (Micozzi, 1997). According to Merriam Webster, the term moulage is of French origin and means to build mock injuries from a mold or from a molding process. Wax has historically been used to provide the basic shape of wounds (Schnalke, 1995). Prior to the 1990's, the only option for synthetic wounds or moulage, was to use molded plastics or to individually craft pieces using the ancient practice of hand worked wax. The plastic moulage pieces, although durable were not realistic visually (Figure 1). The wax moulage was typically very visually realistic (Figure 2), but could only be used until a bandage compressed the wax, or until temperatures were high enough to cause the wax to deform (Figure 3). Additionally, wax moulage had limited re-use as each wound was uniquely created by a specially trained artist using special tools, wax and paints. From 2007 to 2010, driven by the Severe Trauma Army Technology Objective (Norfleet, 2006), a revolution in moulage development and production occurred with the maturing of silicon sculpting, coloring and manufacturing. This Army funded effort funded and encouraged the research and production of very realistic dimensional and bleeding moulage for training.

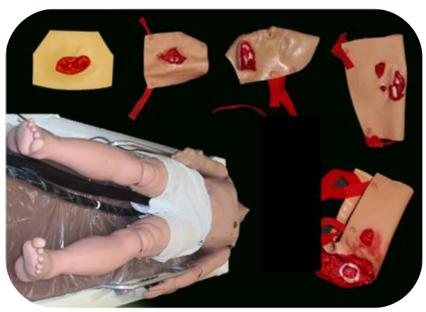

Figure 1: Plastic Moulage

Figure 2: Creation of Wax Moulage

Figure 3: Wax Moulage after One Use

As material and moulage techniques continue to evolve, and as more relevant data is collected on tissue properties, it is worth re-examining what fidelity is really required for training at the point of injury. At the point of injury, critical medical tasks include finding and identifying the injury as well as applying the appropriate initial care. Appearance and sometimes the feel of the injury contribute to identifying and providing the appropriate care. This effort will:

- Explore the current state of wound simulation;
- Analyze the differences in technology effectiveness of two and three dimensional (2D and 3D) wound moulage;
- Assess the costs of silicon and tattoo moulage;
- Assess the application time of silicon and tattoo moulage;
- Propose a basic test methodology to assess what simulated wound fidelity is adequate for training at the point of injury; and
- Discuss the possible appropriate uses of tattoo moulage.

BACKGROUND

As background for continued research and development into trauma training aids, the need for better simulations at the point of injury will be explored, followed by documenting some of the research and development that has been done to enhance severe trauma. Next a brief discussion on the validity and history of using patient actors, mannequins, cadavers and live tissue for medical training will be presented. Finally the history and use of temporary tattoos will be examined.

The Need for Better Simulations at the Point of Injury

Reviewing the causes of death at trauma centers (Acosta et al., 1998) reveaos that incorrect identification of injuries during the initial diagnosis accounts for 30% of deaths at a typical trauma center. Other previous studies (Trunkey & Lim, 1974) have focused only on preventable deaths, and have therefore overlooked critical information regarding initial diagnosis and treatment at the point of injury. The 1998 Acosta study is more relevant to the military's point of injury diagnosis and care because it reviewed eleven years' worth of patient data of all patient deaths including those who died on the way to the trauma center or within the first few moments of arriving at the trauma center. The study revealed that there was a higher mortality rate for penetrating wounds than for blunt trauma. It also showed that the cause of death changed greatly as the minutes and days passed. Initially death was more typically caused by rapid blood loss and/or lack of oxygen. As time passed, death was more related to multiple injuries and secondary effects.

Further demonstrating the need for better training tools, a series of military trauma cases were photographed and documented in 2008 (Nessen, Lounsbury, & Hetz, 2008), giving numerous examples of the severity of injuries and the need for better training. With 80 case studies, severe injuries are shown on almost all areas of the body, demonstrating a need for a wide range of medical skills and procedures, and consequently training devices and systems. This book also gives a thorough and realistic pictorial reference of various injuries when replicating trauma and creating synthetic wounds.

Another study based on the "The Joint Theater Trauma Registry" (Owens et al., 2008) analyzed 1,566 combatants with a total of 6,609 combat wounds from the Iraq and Afghanistan conflict. Eight percent of these wounds were on the head, 6% to the eyes, 3% to the ears, 10% to the face, 3% to the neck, 6% to the thorax, 11% to the abdomen, and 53 % to the extremities. Gunshot wounds accounted for 18% of these wounds. Explosions accounted for another

78% of the wounds. The conclusions from this study were that the wounding patterns from the Iraq and Afghanistan conflict are similar to previous conflicts, except that there is a much greater frequency of head and neck wounds. Additionally, with 78% of the injuries originating from an explosive mechanism, blast injuries account for the highest proportion of all injuries in any large-scale conflict to date.

Research and Development Focused on Severe Trauma Simulations

Acknowledging the need for better simulated severe trauma, from 2007-2010, the U.S. Army Research Laboratory Human Research and Engineering Directorate Simulation and Training Technology Center led a joint Army Technology Objective (ATO) with the U.S. Army Medical Research and Materiel Command (USAMRMC), titled Severe Trauma Simulations. The initial purpose of the ATO was to research and develop innovative technologies to realistically simulate the look, feel, and smell of severe trauma to prepare medics, combat lifesavers, and Soldiers to deal with the injuries encountered on the battlefield. The results of this effort produced:

- Simulator worn gunshot wounds, amputations, and flail chest created with new silicon techniques;
- Static (non-bleeding) and dynamic (bleeding) kits for creating customized silicon wounds;
- Poly trauma scenarios composed of facial/airway trauma, flail chest and multiple gunshot wounds to the leg;
- Reusable injury creation kits and prosthetics for use over multiple training sessions;
- Improved realism in skin, flesh, bone and blood; and
- Robotic amputations introducing movement to indicate agony and provide a visible sign of life.

Many of these efforts resulted in an instantaneous perceived training program benefit and were transitioned to field use almost immediately.

Medical Training Using Patient Actors, Mannequins, Cadavers and Live Tissue

Many of the medical training and skill assessment classes have historically been conducted using dimensional moulage and well trained patient actors (Collicott & Hughes, 1980) (Trauma, 1997) (Tostaine & Fareed, 2010). A moulaged patient actor may look and act like an actual trauma patient; however, a typical healthy patient actor cannot depict the same physiology (heart rate, pulse, etc.) of an injured or sick patient; thus a moderator or instructor is still needed to provide information regarding changes in vital signs. A computerized patient simulator may create a more realistic training scenario because it can provide accurate and real-time changes to trainee interventions.

Patient simulators exist with varying fidelity. Non-electronic mannequins represent the low end of patient simulator capabilities and are still used today (see Figure 4) (*Adult Life Suppport ALS*, 2015). Since the 1990's, sophisticated patient simulators, originally developed for anesthesia training, have been used in medical training (Kapur & Steadman, 1998). These simulators physically mimic the human form and often have complex mathematical models to represent different injuries, illnesses and treatments. They are used for everything from training basic lifesaving skills through surgical interventions. Moulage and limbs representing a variety of trauma can be added to these simulators to match particular training objectives (see Figure 5).

Figure 4: Low Fidelity Mannequin

Figure 5: High Fidelity Mannequins with Silicon Wounds

Several studies have compared the increase in the trauma management skills of medical students trained on a patient simulator with students taught only with a traditional lecture. In one study (Gilbart, Hutchison, Cusimano, & Regehr, 2000) both training groups performed better than the control group of students receiving no instruction; however no significant difference in trauma assessment test scores was shown in the two trained groups. In another study (Marshall et al., 2001), a patient simulator was successfully used to train military emergency personnel in trauma assessment skills. In this study trauma management skill scores increased 23% in critical treatment decisions, 25% in potential for adverse outcomes, and 47% in team behavior after the course using a high fidelity patient simulator.

Many other studies have been conducted validating the use of patient simulators to train and test trauma assessment. Simulators have been used in trauma scenario tests with surgery interns after a standard Advanced Trauma Life Support (ATLS) course (Ali, Gana, & Howard, 2000) (Marshall et al., 2001). After ATLS training, the ratings in critical treatment decisions improved. Similarly, in a study (Holcomb et al., 2002) on trauma team performance using an advanced patient simulator, it was shown that the patient simulator could be effectively used for testing trauma assessment. None of these studies, however, compared training or testing methods with a patient simulator to conventional methods involving moulaged patients.

In 2003 the first randomized comparison of trauma assessment training methods using a mannequin-based patient simulator versus a moulaged patient (Lee et al., 2003) was conducted. Using a test population of 60, this study showed that interns who trained with a simulator demonstrated a small but statistically significant improvement on individual trauma assessment tests. Specifically, simulator training resulted in higher scores in the identification and management of the injury. These higher scores suggest that there may be advantages to trauma assessment training in a scenario where physiologic changes are observed and hospital type monitors provide constant information regarding patient vital signs; therefore eliminating or minimizing the need for a moderator. Additionally, the computer-controlled capabilities of a patient simulator provided reproducible trauma scenarios, compared with the potential variability from a verbal moderator and patient actor.

In 2010 a study was published that compared 2D traditional classroom training with 3D moulage on patient actors for a dermatology teaching course (Garg, Haley, & Hatem, 2010). The objective of this course was to teach students to identify common skin problems. With a sample size of 90 trainees, results showed a definite advantage to the three dimensional moulage on patient actors over the two dimensional text book style instruction. This study, although important, cannot be directly compared with the 2D trauma tattoos for several reasons. Typical text book learning does not involve any exposure to a patient actor or to a simulator which provides an extra level of immersion and increases the perceived importance of a correct diagnosis. Additionally, this study was based on skin abnormalities, not on trauma.

Cadavers and live tissue (animals) have also been used for trauma training (Kaufmann & Liu, 2001). Traditional moulage is not used on either cadavers or animals, as the tissue itself can depict the trauma. During cadaver training, fresh cadavers are used to minimize tissue degradation. Even so, there is little to no repeatability since once a cadaver is used for a particular training scenario tissues are damaged or destroyed making it unlikely that it can be used again. Additionally, cadaver tissue and vessel texture as well as appearance are very different from living tissue and vessels.

Other training events have more recently been done with perfused cadavers (Aboud et al., 2011). In this training fresh cadavers were hooked to pumps, fluids, and ventilators to simulate body fluids, breathing, and a heartbeat. Traumatic wounds were inflicted on the tissues, allowing trauma teams to rapidly assess and treat the wounds. Overall, the training received very high scores for realism, but trainees still noted that the cadaver tissue did not look, feel, behave and sometimes smell like living human or animal tissue.

Trauma training with live tissue (typically goats or pigs) has been done for many years (Porter, 1999). The use of animals for medical training has also been highly criticized and questioned (English, 1989) and yet there still seems to be an almost unquantifiable value in the use of live tissue training. A typical military trauma training course reports the use of live tissue as a culminating event to a multi-day course (Sohn et al., 2007). During the study period, 327 soldiers participated and completed the entire course. Based on data collected with surveys, pre- and post-tests, and after-action comments, 97% of the trainees indicated that their confidence and ability to treat combat casualties had improved. Other studies have shown a definite pathophysiologic benefit to live tissue training because the trainees are treating a living creature (Reeds, 2010). Even with current and emerging technologies, the sense of immersion and urgency generated from treating a living creature appears challenging to recreate with any type of simulation system. However there are several notable negative training issues with live tissue. The anatomy of a goat or pig is obviously very different from that of a human, especially when it comes to managing the airway or when treating trauma on the extremities. The neck and throat of the animals is very different from human anatomy; the leg structures of the animals tend to be smaller and leaner than human arms and legs. Also, the presence of fur, horns and hoofs can be distracting. Additionally, the physiology of these animals is very different from humans, for example, pigs absorb drugs much quicker than humans, and so they require a closer monitoring and re-administering of medicine. Observing that there are still issues with many of the current methods for exhibiting trauma for training providers at the point of injury, other creative and innovative solutions are still desired.

Children's Tattoo Technology

The art of decorating the body with ink and paint has existed since ancient Egyptian times (Chaudhri & Jain, 2009). The use of cheap, temporary tattoos to quickly decorate the body is a much more recent phenomena (Kosut, 2006). As shown in Figure 6, these tattoos have most often been used to easily apply pretty and fun decorations to children ("How to Apply the Perfect Temporary Tattoo,"). Tattoos depicting trauma (Simetri, 2014) have recently been introduced as a trauma training option. These tattoos are based on the exact same technology as decorative children's tattoos. This makes these trauma tattoos an inexpensive and potentially desirable training tool.

Figure 6: Application of a Decorative Tattoo

INITIAL TESTING

Silicon-based wounds have already completed usability testing. Additionally, basic testing has been done with the tattoo moulage. These efforts are described below.

Silicon Moulage Testing

Research has already been done on the usability and training utility of these high fidelity dimensional silicon wounds (Figure 7) (Sotomayor & Salva, 2009; Wiederhold, Salva, Sotomayor, Coiro, & Wiederhold, 2009). Observational studies on durability as well as timed studies on applying high fidelity wounds to actors were completed in 2008 and

2009. These efforts indicated a definite training benefit in using high fidelity silicon-based wounds over the previous method of hand crafted, one time use wax wounds. Data showed total application/removal times for silicon wounds ranged from approximately 24-28 minutes (see Tables 1 and 2). The silicon-based wounds needed little to no rework during an eight hour military training day with 80 degree and higher air temperatures.

Figure 7: Silicon Moulage

Table 1: Time Data with Human Actors

Step	Time
Application	10 Minutes
Set Up Kit	10 Minutes
Removal	3 Minutes
Clean Up Kit	5 Minutes

Table 2: Time Data with Patient Simulators

Step	Time
Glue Application	2.6 Minutes
Glue Dry Time	6.3 Minutes
Make Up Time	9.4 Minutes
Clean Up Kit	4.8 Minutes

Although the silicon wounds have proven effective, there is still a need to create less expensive synthetic wounds that would be quick and easy to apply. The idea of using children's temporary tattoo technology to create these type of synthetic wounds (Figure 8) appears to be relatively new, possibly originating with a creative use of Halloween tattoos and makeup in 2011 (Zachary, 2011). Additionally, a small company has recently experimented with creating realistic trauma tattoos based on actual wounds (Simetri, 2014). An initial self-application of the trauma tattoos indicates a maximum 2-3 minute application time and a 12 + hour durability on clean, smooth skin. One of the obvious differences between the silicon and tattoo wound technologies is that the trauma tattoos have little depth or texture; they are close to totally flat. Dimensional silicon moulage provides a tactile presence that can be detected in the dark or in other areas of the body where vision may be obstructed, such as under clothes. Dimensional silicon moulage also provide a three-dimensional cavity that can be packed with gauze. The trauma tattoos provide only a slight difference in texture when applied to a surface. The question is whether or not wound depth and tactile sensation are required for training tasks at the point of injury. Is assessment at this level of care more about visual inspection or sense of touch?

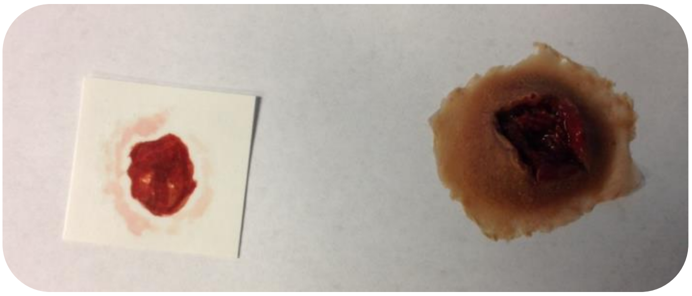

Figure 8: Tattoo (left) vs Dimensional Silicon (right) Wound

Anecdotal Use Data on Trauma Tattoos

A first responder training exercise was conducted July 16th, 2014 in Orlando, Florida (see Figure 9), where preliminary durability and application time data was collected on the tattoos. Over the course of the morning, seven separate groups were sequentially exposed to the moulage tattoo wounds as depicted in Table 3. Three groups of law enforcement officers and another four groups combining law enforcement officers with fire and rescue groups found the casualties and assessed the patients at the point of injury. The synthetic wounds were not bandaged, as treatment was not the goal of this training exercise. No touch-ups were required between scenarios. From casual observations these two-dimensional wounds appeared to provide the necessary queues for the first responders to follow the appropriate procedures.

Figure 9: First Responder Exercise Using Trauma Tattoos

Table 3: Initial Trauma Tattoo Use

Time Start	Time End	Total Time	Activity
8:20am	8:55am	35 minutes	Apply 2-3 wounds to each of 4 human actors
8:55am	9:10am	15 minutes	Apply 1-2 wounds each and coagulated blood to 3 mannequins
9:10am	9:25am	15 minutes	Add coagulated blood to wounds on 4 human actors
9:30am	12:00pm	150 minutes	Exercise with 7 different training groups

Initial Cost Analysis

The cost of the individual trauma tattoo pieces ranges from 50 cents to $3.00. Additional costs to apply these wounds might include alcohol pads to clean the area prior to application. The silicon moulage is available as a commercial kit. A standard kit contains 25 wounds with adhesive, blending wax, simulated blood, etc. and is available for approximately $3000 ("Simulaids," 2014). This averages to $120 for each individual silicon wound. The price comparison between tattoo and silicon moulage however is not as simple as comparing $120 to $3, because the silicon dimensional wounds can be reused for additional training sessions whereas each trauma tattoo can only be reused over the course of a day. Also, some of the silicon wounds have an embedded tube which allows the extra feature of active bleeding. The tattoo wounds can only give the appearance of bleeding by applying simulated blood on top of the tattoo attached to the patient actor or mannequin.

EXPERIMENT PLAN

Building on the research and usability studies already discussed, several large data collection activities are planned over the next year to explore the technology effectiveness of the tattoo wounds compared to three-dimensional silicon wounds. The same wound will be used for both types of moulage. Three different types of wounds will be assessed with a group of trainees large enough to provide statistical significance. The simulated wounds will be based on injuries typically trained in military exercises, as well as providing an appropriate variety of medical conditions. The simulated wounds under consideration are a bullet entry wound with no simulated bleeding (as shown in Figure 8), bruising with no abrasion or broken skin, possibly including swelling, and a large laceration through the fatty tissue with active bleeding (Figure 10).

Figure 10: Large Laceration Tattoo (left) and Silicon (right) Wound

The basic hypothesis for this effort is that at the point of injury, a tattoo wound provides the same immersion, sense of urgency, and visual cues as a three-dimensional silicon wound of the same injury. The study design will attempt to control the variables that may affect the overall outcome such as active bleeding at the injury site, environmental conditions such as lighting, noise and temperature, previous training, and prior exposure to actual wounds. To minimize variability in the test subjects, only combat medic trained or equivalent will be used in this study. Survey questions will include information regarding the years of experience and/or training to further clarify experience levels. To examine the hypothesis and variables a series of activities, pre-tests, and experiments will be conducted. These will include:

- Durability testing on the silicon wounds to determine how many times they can be removed and re-applied before they begin to fail;
- Longevity testing on both the silicon and tattoo wounds – how long will they stay on a patient actor before they begin to fail?;
- Technology effectiveness evaluations including objective measures of time on task and subjective measures with pre and post surveys; and
- Convening of an expert panel to evaluate the merit of the new tattoo moulage.

The research will conclude with a complete analysis of all data collected to determine the overall effectiveness and utility of tattoo moulage.

CONCLUSIONS

Because the trauma tattoos are easy, quick and inexpensive to apply and remove from human actors, mannequins and partial task trainers, they may provide training utility in many areas. Consideration of other uses and requirements of the tattoo technology, suggests tattoos have potential for visually indicating several medical conditions including:

- Bruises and scrapes in a clinical setting;
- Phases of healing, both proper and inadequate;
- Cyanosis (bluing around the lips) in a clinical setting; and
- A transparent overlay on patient actors or mannequins to show the location and orientation of underlying vessels and organs.

The coloring of bruises and scrapes is an important diagnostic indicator and is not easily depicted in training exercises. In addition to bruises and scrapes, and the ability to indicate hidden anatomical information beneath the surface of the skin, phases of healing can also be indicated by the changing colors of bruises, etc. Mastering how to realistically indicate changes in skin color with these temporary tattoos could also lead to a more accurate depiction of cyanosis (visual indicator around the mouth of a lack of oxygen). Realistically indicating cyanosis in training scenarios has been an unmet challenge for many years. Additionally, understanding the three-dimensional anatomy underneath the skin has always been a challenge for medical providers. Tattoos may offer an affective visual training aid to allow the trainee to virtually see through the skin. It is possible that a simple tattoo could offer an inexpensive and easy to use solution for these and many other medical conditions where a change of skin tone or a deeper understanding of anatomy is important.

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