Medicine Meets Virtual Reality 22
J.D. Westwood et al. (Eds.)
IOS Press, 2016

doi:10.3233/978-1-61499-625-5-175

Junctional and Inguinal Hemorrhage Simulation: Tourniquet Master Training

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Abstract. Hemorrhages are the leading cause of potentially survivable combat mortalities when patients are unable to reach a treatment facility in time. New tourniquet devices have been developed to combat hemorrhages in the field. However, there is a lack in training systems to properly teach and assess users on tourniquet device application. We have developed an objective feedback system applicable to various full body manikins. We tested the system with expert users and received improvement feedback and verified the system's usefulness in instructing and assessing correct tourniquet device use.

Keywords. Hemorrhage, Tourniquet, Simulation

1. Introduction

Battlefield medical treatment has advanced in recent years for post-combat casualty cases after reaching a military medical treatment facility (MTF). However, the majority of casualties occur before arriving at a MTF, up to 90% of potentially survivable mortalities are caused by hemorrhages (1,2,3). To contest potentially survivable hemorrhage deaths, new types of hemorrhage tourniquet devices have been developed, specifically the Abdominal Aortic Junctional Tourniquet (AAJT), Combat Ready Clamp (CRoC), and SAM Junctional Tourniquet. New tourniquet devices are applied in difficult cases where traditional tourniquets would be inadequate; specifically for non-compressible hemorrhages at junctional and inguinal locations. Although the FDA has approved the devices, the tourniquets lack training and assessment systems to teach skills and ensure appropriate tourniquet application.

Current tourniquet training is performed through application on either bleeding simulators or live training partners. However, neither option provides objective means of feedback to learners or instructors. Key feedback for correct application include

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identifying important anatomical landmarks, applying sufficient pressure to occlude blood flow, and correctly complete all tourniquet application steps within 1 minute.

The aims of the Tourniquet Master Training project are to develop a scenario-based training system that will meet key training requirements, and teach the cognitive and motor skills necessary for safe placement of non-compressible hemorrhage control devices. To achieve this, we developed a sensor-enabled physical simulation, using sets of pressure sensors and simulated anatomy to teach and assess tourniquet application performance. In this study, we design and improve a sensor-enabled system for objective performance measurement with novice and expert users.

2. Methods & Materials

2.1. First Design

For the first design of the sensor-enabled manikin, we identified the location of the neurovascular bundle on our Simulaids STAT manikin, the major anatomical structure to be occluded during inguinal hemorrhage control. Seven reconfigurable Interlink FSR 406 Force Sensing Resistors were placed around key inguinal locations on the manikin. We collected correct and incorrect tourniquet applications with a test user, sampling sensor data at 15Hz with an NI USB 6210 and a custom voltage divider connected to an HP Pavilion dv6t-7000 laptop. Unique sensor recording patterns were observed for correct and incorrect tourniquet applications, demonstrating that our system can provide objective information on performance assessment and feedback via correct applied pressure, position, application steps, and completion time (4).

2.2. Second Design

The second design was aimed at developing a training protocol, testing ease of use with users, and resolving anatomical realism and durability concerns from the first design. We selected the Rescue Randy manikin for use in this design. Relative to other manikin choices, Rescue Randy is more ideal for traveling to data collections due to its cost effectiveness and transportability. To protect the manikin from potential tourniquet-based damage, 2 layers of 4 inch wide 3M Scotchcast Plus fiberglass casting tape was wrapped across the abdominal and inguinal regions of the manikin.

To correctly apply the tourniquet devices, combat medics identify important anatomical landmarks to locate the neurovascular bundle, including the anterior superior iliac spine (ASIS), pelvic bone, and belly button. Modular representations of these landmarks were developed to enable any full body manikin for tourniquet application assessment. A ½ inch thick belly fat layer was fabricated from 1:1:1 ratio of Smooth-On's EcoFlex® 00-30 A, EcoFlex® 00-30 B, and Slacker®. A ¼ inch radial circle cut on the fat layer represented the belly button. We molded a Human Pelvis Teaching Model to mimic the ASIS protrusions using Mold Star® 30. Smooth-Cast® 300 was cured in the mold to produce the ASIS bones, shaving off excess and smoothing the product using a file. The manikin's protective cast provided a hard surface at the end of the pelvis; this section represented the pubic tubercle.

A stretch-to-fit singlet was modified with sewn-in Lycra pockets at the abdominal, inguinal and ASIS regions to provide adjustable anatomy and sensor configurations for different manikin sizes. We expanded the system to allow abdominal region force capture by increasing the total FSR amount to 10. We developed a pulse feedback system using Precision Microdrives 10mm Shaftless Vibrational Motors. Motor vibration was powered and controlled by the digital inputs of the NI USB 6210 and NIMAX software, producing physical feedback for pulse at 2Hz and 5% duty cycle. Sensor data was collected using Charles River Analytic's custom software with a sampling frequency of 50 Hz. The software records and feeds sensor activity to a display, providing users with a live feed of tourniquet location, pressure applied, successful completion of steps, and completion time. The hardware for measuring sensor data was similar to first design.

We presented the second design for user testing with 5 novices and 8 experts. Novices were defined as participants without previous experience with tourniquets and were recruited from University of Wisconsin-Madison. Experts were defined as experienced users in applying tourniquet devices or instruct others on tourniquet usage. Experts were recruited from the 2015 Military Health System Research Symposium (MHSRS). Participants of the study were provided short instructional videos for AAJT and CRoC tourniquet devices, visual aids for tourniquet operation and placement, and 2 minutes of free play to acquaint users with the device prior to applying the tourniquets on the manikin. Participants were provided a live feedback display, reporting on tourniquet pressure, location, completed steps, and overall time (Figure 1).

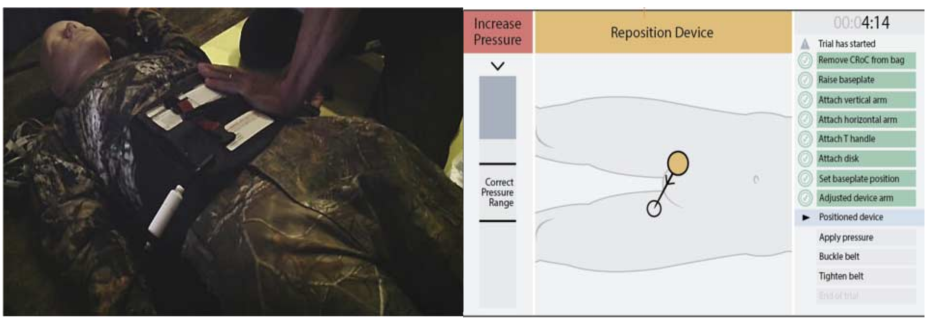

Figure 1. Expert applying AAJT to sensor enabled manikin (Left) with a sample of live feedback (Right).

3. Results

Participants evaluated the system and provided feedback on the issues and usefulness of the physical simulation and software display designs. Table 1 outlines feedback received from novice and expert participants. Common responses concerned difficulty in locating and feeling the belly button, tourniquet device failure, and improving the software's display of tourniquet steps and positional feedback. Experts and novices agreed that our objective performance system would be useful in teaching and assessing tourniquet application skills.

Table 1. Summary of expert and novice feedback with the second tourniquet training system design.

Feedback Topic	User Responses	Common Issue
Tourniquet Device	4	Tourniquet Device Failure
Software and Visual Display	4	Improve live feedback's location display
Anatomy Concerns	3	Unable to locate belly button
Blood flow/Bleeding Feedback	3	Lack of bleeding/blood flow feedback
Manikin Selection	2	Request proof of concept on other manikins
Training Methods	1	Adhere to current training scenarios and conditions

4. Discussion

The goal of this study was to develop a sensor-enabled physical simulation to teach and assess tourniquet device application performance. We developed and updated our designs for use with novice and expert users. User feedback from experts at MHSRS helped assess the usefulness of the design as a teaching and assessment tool.

Experts visually checked for bleeding during tourniquet placement. Our physical pulse system provided bleeding feedback, but was not the natural technique experts used to confirm hemorrhage control. Future work for our designs includes adapting our system for use with current combat medic training scenarios and conditions, develop a durable wireless system, and determine the suitability of the physical pulse system. Overall, experts agreed this system was useful for teaching and assessing tourniquet placement. Experts were passionate about our system providing an objective assessment of performance.

Acknowledgments

This work is supported by the US Army Medical Research and Material Command under Contract No. W81XWH-13-C-0021. The views, opinions and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy or decision unless so designated by other documentation. In the conduct of research where humans are the subjects, the investigator(s) adhered to the policies regarding the protection of human subjects as prescribed by Code of Federal Regulations (CFR) Title 45, Volume 1, Part 46; Title 32, Chapter 1, Part 219; and Title 21, Chapter 1, Part 50 (Protection of Human Subjects).

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