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Training Surgical Residents With a Haptic Robotic Central Venous Catheterization Simulator

David F. Pepley, BS,* Adam B. Gordon, BS,* Mary A. Yovanoff, BS,† Katelin A. Mirkin, MD,‡ Scarlett R. Miller, PhD,§ David C. Han, MD,‡ and Jason Z. Moore, PhD*

*Department of Mechanical and Nuclear Engineering, Penn State, University Park, Pennsylvania; †Department of Industrial Engineering, Penn State, University Park, Pennsylvania; ‡Department of Surgery, College of Medicine, The Pennsylvania State University, Hershey, PA; and §Department of Engineering Design and Industrial Engineering, Penn State, University Park, Pennsylvania

OJECTIVE: Ultrasound guided central venous catheterization (CVC) is a common surgical procedure with complication rates ranging from 5 to 21 percent. Training is typically performed using manikins that do not simulate anatomical variations such as obesity and abnormal vessel positioning. The goal of this study was to develop and validate the effectiveness of a new virtual reality and force haptic based simulation platform for CVC of the right internal jugular vein.

DESIGN: A CVC simulation platform was developed using a haptic robotic arm, 3D position tracker, and computer visualization. The haptic robotic arm simulated needle insertion force that was based on cadaver experiments. The 3D position tracker was used as a mock ultrasound device with realistic visualization on a computer screen. Upon completion of a practice simulation, performance feedback is given to the user through a graphical user interface including scoring factors based on good CVC practice. The effectiveness of the system was evaluated by training 13 first year surgical residents using the virtual reality haptic based training system over a 3 month period.

RESULTS: The participants' performance increased from 52% to 96% on the baseline training scenario, approaching the average score of an expert surgeon: 98%. This also resulted in improvement in positive CVC practices including a 61% decrease between final needle tip position and vein center, a decrease in mean insertion attempts from 1.92 to 1.23, and a 12% increase in time spent aspirating the syringe throughout the procedure.

CONCLUSIONS: A virtual reality haptic robotic simulator for CVC was successfully developed. Surgical residents training on the simulation improved to near expert levels after three robotic training sessions. This suggests that this system could act as an effective training device for CVC. (J Surg Ed ■:■■■-■■■. © 2017 Association of Program Directors in Surgery. Published by Elsevier Inc. All rights reserved.)

KEY WORDS: central venous catheterization, computer simulation, haptic feedback, virtual reality, surgical education

COMPETENCIES: Practice-Based Learning and Improvement

INTRODUCTION

Medical professionals place over 5 million central venous catheters (CVC) in the United States each year.[1] CVCs give doctors the ability to provide nutrition, medication, hemodynamic support, and the venous access necessary to perform procedures on a wide variety of patients including those in critical condition. Despite being a common procedure, ultrasound-guided CVC has a reported complications rate ranging from 5.0% to 21%.[1-3] These complications are wide ranging and includes hematoma, hemothorax, pneumothorax, accidental arterial puncture, and infection, all of which can increase the hospitalization time of the patient, medical costs, and the rate of mortality.[4-7] Most complications due to CVC occur during the process of needle insertion.[1,8] These mechanical complications are caused by a variety of factors including clinician inexperience, multiple catheterization attempts, and difficult

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Correspondence: Jason Z. Moore, PhD, 318 Leonhard Building, University Park, PA 16802; e-mail: jzm14@psu.edu

patient anatomy, such as large amounts of adipose neck tissue.[9-11] Therefore, improved training of mechanical needle insertion can help to reduce these needle-insertion complications.

The process of inserting a CVC catheterization needle into the right internal jugular (IJ) vein begins with a surgeon using an ultrasound probe to identify the IJ vein at the apex of the sternal head of the sternocleidomastoid and the clavicle. A catheterization needle is then inserted between a 30° and 45° angle toward the ipsilateral nipple using the ultrasound as guidance. Minimizing the number of insertion attempts, avoiding the carotid artery, and aspirating the needle plunger are just a few of the important aspects of a successful insertion.[12] Catheterization of the right IJ vein at the apex of the sternocleidomastoid and clavicle is performed more often than femoral or subclavian CVC insertion because of its large vessel diameter, lower rate of infection compared with femoral insertion, and more superficial nature than the subclavian vein.[3,13]

Modern CVC training typically takes place using upper torso training manikins, such as the CAE Healthcare (Sarasota, FL) Blue Phantom simulation manikin.[14,15] There is debate, however, over the long-term effectiveness of these manikins. Although one study concluded that simulation training is associated with improved in-hospital performance of CVC insertion,[5] another found that a CVC simulation course improves short-term procedural skills, but these skills quickly degrade over time.[16] These manikin simulators have limited patient anatomy and unnatural tissue properties leaving residents unprepared to work with the wide variety of patients they will encounter in a clinical environment. Furthermore, manikin simulation relies on observation-based qualitative feedback and assessment from an instructor that is vulnerable to bias such as "examiner burnout" due to busy work schedules.[17] More effective training solutions with a quantitative and qualitative feedback need to be developed to fulfill the training needs of surgical residents.

In recent years, haptic feedback and virtual reality (VR) medical simulators have become more sophisticated in their training capabilities.[18] A 2007 study by Morris et al.[19] suggests that haptic feedback training in combination with visual feedback may be an effective training tool for skills where force sensitivity and fine motor skills are a crucial component. A 2016 study by Mohamadipanah et al.[20] indicated that the ability to better understand haptic sensations felt during a procedure could affect CVC performance. To meet these new training recommendations, high- and low-fidelity haptic-based patient simulators are being developed. Research has shown that high-fidelity simulators such as the *LAPSIM* laparoscopic surgical simulator by Surgical Science (Gothenburg; Sweden) and *PalpSim* palpitation simulator by Coles et al. are able to differentiate between expert and novice trainees as well as provide complex haptic feedback to the user.[21,22] This type of high-fidelity haptic simulator has yet to be tested and deployed for use in CVC training.

In light of this, the current article presents the development and training efficacy testing of a novel VR and haptic feedback–based training device for the right IJ vein CVC procedure. The VR haptic robotic CVC simulator shown in Figure 1 uses a unique combination of a navigable virtual ultrasound environment, as well as a haptic needle insertion force characterization developed in previous work.[23] The Material and Methods section of this article gives an overview of the simulator hardware and the development of the haptic syringe, virtual ultrasound, graphical user interface (GUI), and details the experiments conducted to determine the effectiveness of the device. This is followed by the Results and Discussion sections about the experimental outcomes and the future of this training. Lastly, the Conclusions section is presented.

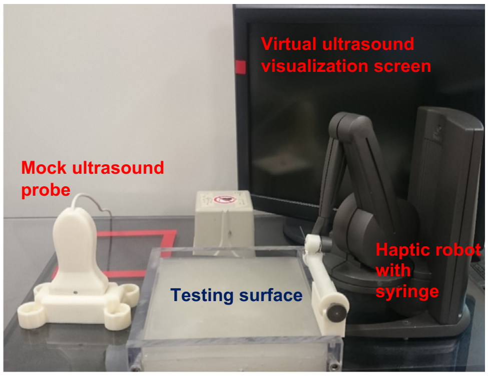

FIGURE 1. Virtual reality haptic robotic central venous catheterization simulator.

MATERIALS AND METHODS

Development of the System Hardware and Software Overview

The simulator is controlled using a custom-built personal computer running MathWorks (Natick, MA) *MATLAB* and *Simulink* software packages. Three degrees of haptic feedback and 6 degrees of freedom in needle position tracking are achieved using a 3D Systems *Geomagic Touch X* (Rock Hill, SC) haptic robotic arm and the Quanser

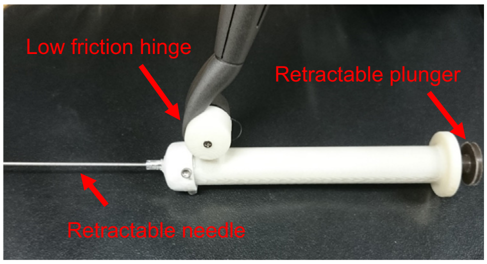

FIGURE 2. Custom built syringe end effector for Geomagic Touch X.