ORIGINAL REPORTS

Investigating the Effect of Simulator Functional Fidelity and Personalized Feedback on Central Venous Catheterization Training

Mary A. Yovanoff, MS,[*] Hong-En Chen, MS,[*] David F. Pepley, MS,[†] Katelin A. Mirkin, MD,[‡] David C. Han, MD, MS,[‡] Jason Z. Moore, PhD,[†] and Scarlett R. Miller, PhD[*,§]

[*]Department of Industrial and Manufacturing Engineering, Penn State, University Park, Pennsylvania; [†]Department of Mechanical and Nuclear Engineering, Penn State, University Park, Pennsylvania [‡]Department of Surgery, Penn State Health Milton S. Hershey Medical Center, Hershey, Pennsylvania; and [§]School of Engineering Design, Technology, and Professional Programs, Penn State, University Park, Pennsylvania

OBJECTIVE: To compare the effect of simulator functional fidelity (manikin vs a Dynamic Haptic Robotic Trainer [DHRT]) and personalized feedback on surgical resident self-efficacy and self-ratings of performance during ultrasound-guided internal jugular central venous catheterization (IJ CVC) training. In addition, we seek to explore how self-ratings of performance compare to objective performance scores generated by the DHRT system.

DESIGN: Participants were randomly assigned to either manikin or DHRT IJ CVC training over a 6-month period. Self-efficacy surveys were distributed before and following training. Training consisted of a pretest, 22 practice IJ CVC needle insertion attempts, 2 full-line practice attempts, and a posttest. Participants provided self-ratings of performance for each needle insertion and were presented with feedback from either an upper level resident (manikin) or a personalized learning system (DHRT).

SETTING: A study was conducted from July 2016 to February 2017 through a surgical skills training program at Hershey Medical Center in Hershey, Pennsylvania.

PARTICIPANTS: Twenty-six first-year surgical residents were recruited for the study. Individuals were informed that IJ CVC training procedures would be consistent regardless of participation in the study and that participation was optional. All recruited residents opted to participate in the study.

RESULTS: Residents in both groups significantly improved their self-efficacy scores from pretest to posttest ($p < 0.01$). Residents in the manikin group consistently provided higher self-ratings of performance ($p < 0.001$). Residents in the DHRT group recorded more feedback on errors (228 instances) than the manikin group (144 instances). Self-ratings of performance on the DHRT system were able to significantly predict the objective score of the DHRT system ($R^2 = 0.223$, $p < 0.001$).

CONCLUSION: Simulation training with the DHRT system and the personalized learning feedback can improve resident self-efficacy with IJ CVC procedures and provide sufficient feedback to allow residents to accurately assess their own performance. (J Surg Ed ■:■■■-■■■. © 2018 Published by Elsevier Inc. on behalf of the Association of Program Directors in Surgery)

KEY WORDS: central venous catheterization, virtual reality, simulator fidelity, medical training simulation, self-efficacy, residency training

COMPETENCIES: Practice-Based Learning and Improvement

INTRODUCTION

Central venous catheterization (CVC) is a common procedure used to administer medication, nutrition, and obtain measurements to monitor patients.[1] Although more than 5 million central lines are placed annually in the US each year,[2] up to 39% of patients incur adverse effects[3-5] such as hematoma, pneumothorax, or arterial puncture during

Correspondence: Inquiries to Scarlett R. Miller, Department of Engineering Design and Industrial Engineering, Penn State, 213P Hammond Building, University Park, PA 16803. fax: +(814) 863-7229; e-mail: scarlettmiller@psu.edu

catheter insertion.[3] Importantly, surgeons who have inserted CVCs less than 50 times are twice as likely to incur mechanical complications.[6] Although recent calls in medical research have identified a need for improving and standardizing CVC education in order to reduce these complication rates,[7] advances in medical simulation research have focused primarily on examining the effect of increases in the structural rather than the functional fidelity of simulators. This is problematic because previous research has shown that increases in structural fidelity, or the realism of the environment, does not correspond with increases in educational effectiveness.[8,9] However, increases in functional fidelity, or the match between the system and how a user performs a specific task, has been shown to be a vital component of effective learning and skill transfer.[10] In ultrasound-guided CVC, this functional fidelity includes using the ultrasound and haptic feel to accurately identify the needle location relative to anatomical structures and make corrections to the needle and ultrasound position in real-time to accurately place the needle into the vein.

Current CVC simulation training typically includes a functionally static manikin with an arterial pulse (controlled through a hand-pump) and self-sealing veins.[11] This type of training is limited by the fact that it does not contain realistic force profiles for different tissues (e.g., skin, adipose tissue, and vessel). This is problematic because the high complication rates in CVC procedures have been attributed, in part, to variations in patient anatomy such as body habitus and coagulopathy.[1,12] In addition, this type of manikin training provides only basic feedback on performance, such as blue liquid being aspirated when the introducer needle hits the target vessel. Because of this, manikin training has been criticized as being resource intensive[13,14] because it requires a trained preceptor (e.g., faculty) to be present to provide meaningful, real-time feedback on performance. Thus, in order to efficiently reduce the mechanical complication rates associated with CVC procedures, higher functional-fidelity simulators are needed to objectively evaluate and prepare resident surgeons.

The Dynamic Haptic Robotic Trainer (DHRT)[15] virtual reality system was developed to respond to this gap by teaching CVC needle insertion skills through variations in patient anatomy and by providing objective feedback on performance. This system includes seventeen unique patient cases that vary in the anatomical configurations of the patient. These variations in patient anatomy are simulated in the system through changes in a visual ultrasound image (e.g., size, location, and pulsatility of the vessel) and through haptic feedback provided through the robotic arm of the DHRT system that simulates the force changes of different types of tissues (e.g., skin, adipose tissue, and vessel), see Pepley et al.[15] for details. Validity evidence based on test content was identified by comparing learning and confidence gains in medical students between the DHRT and manikin-based learning systems.[17] Some validity evidence was identified with respect to motion tracked variables, as experts performed better than novices in time to complete and standard deviations of deviations of their needle path.[18] Finally, prior work by the authors has shown that participants improved their performance throughout the course of training on the DHRT system and they approached the level of an expert at the end of their training.[19] An advantage of using functionally high-fidelity simulators like the DHRT for IJ CVC trainings is that they can be designed to automatically present feedback in both textual and graphical forms which can improve information retention.[20] For example, the DHRT system provides users with feedback after each insertion trial on the needle angle, final position of the needle tip, number of insertions, and amount of unnecessary movements, see Yovanoff et al.[21] for discussion. This type of variation in scenario and objective feedback can increase both skill transferability, skill retention, and self-efficacy.[22-25] Self-efficacy is a particularly important construct to explore in surgical residency education because there are links between positive self-efficacy and increased skill performance.[26-28] However, no research to date has explored the effect of simulator functional fidelity or personalized feedback on surgical resident confidence and objective performance and thus it is unclear how the factors affect resident skill gains.

MATERIALS AND METHODS

Based on this prior work, the current study was developed to answer the following research questions (RQ):

RQ1: (A) Do surgical residents improve their CVC self-efficacy over the course of training and (B) is this improvement in confidence dependent on the training environment? Specifically, this research question sought to understand if resident CVC self-efficacy changed from pre-CVC to post-CVC training and if this difference was owing to variations in the CVC training method (manikin or robotic). It was hypothesized that self-efficacy would increase throughout training because prior work has shown that simulator training can increase resident comfort with CVC procedures.[11] However, it was also hypothesized that residents in the robotic group would have larger improvements on CVC self-efficacy because prior research has shown that providing feedback increases self-efficacy[22,23] and help users cognitively engage during the learning process.[29]

RQ2: (A) How do perceived ratings of performance change throughout training and (B) is this change in self-rated performance dependent on the functional fidelity of the training environment? Specifically, this question sought to address how participant self-ratings of performance compared across training groups over the duration of training. The manikin-trained individuals received observational feedback from a higher-level resident, whereas