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Evaluating surgical resident needle insertion skill gains in central venous catheterization training

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ABSTRACT

Background: Training for ultrasound-guided central venous catheterization (CVC) is typically conducted on static manikin simulators with real-time feedback from a skilled observer. Dynamic haptic robotic trainers (DHRTs) are an alternative method that simulates various patient anatomies and provides consistent feedback for each insertion. This study evaluates CVC needle insertion efficiency and skill gains of both methods.

Materials and methods: Fifty-two first-year surgical residents were trained by placing internal jugular (IJ) CVC needles in manikins ($n = 26$) or robots ($n = 26$). Manikin-trained participants received verbal feedback from an experienced observer, whereas robotically trained participants received quantitative feedback from the personalized DHRT learning interface. All participants were pretested on a Blue Phantom manikin; participants completed posttesting on a Blue Phantom manikin ($n = 26$) or a novel manikin ($n = 26$) with different vessel depth and position. During pretests and posttests residents were timed, motion-tracked, and scored on an IJ CVC checklist.

Results: (1) All skills on the IJ CVC checklist showed significant ($P < 0.014$) improvements from pretests to posttest; (2) Average angle of insertion, path length, and jerk improved significantly ($P < 0.005$); (3) Average procedural completion time, with standard error (SE) reported, decreased significantly from pretest (M = 3.516 min, SE = 0.277) to posttest (M = 1.997, SE = 0.409).

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Conclusions: No significant group differences were observed in overall skill gains, but residents' average procedural completion time decreased significantly from pretests to posttest. Overall results support DHRT as an effective method for training IJ CVC skills.

Introduction

Ultrasound-guided central venous catheterization (CVC) is a common procedure[1] with a high rate of complications.[2] The likelihood of these complications, however, is significantly lower for surgeons who have inserted a CVC more than 50 times.[3] There is no common standard for evaluating CVC placement competency outside of clinical applications. To determine the effectiveness of particular training methods, many studies use checklists filled out by supervisor,[4] such as the Global Rating Scale Assessment tool (a 9-item Likert scale assessment intended for use generally across multiple skills),[5] and a 24-item binary checklist specific to subclavian CVC skills.[6] The majority of these evaluation methods compare trainee skills to some baseline expectation and evaluate whether they "pass" to be allowed to perform CVC in clinical situations.[7,8] This approach, however, may not rule out incompetency.[9] Although these tools may be effective at evaluating performance on a manikin, it is not clear that these evaluation methods can predict skill transfer from a static simulator to the variation seen in clinical practice.[10] The number of unsuccessful needle insertion attempts significantly predicts cannulation failure,[11] indicating the importance of training and properly evaluating needle insertion skill gains.

Although checklists are useful for standardizing practices, they are imperfect and can encourage "teaching to the test".[12] They are also prone to misuse where observers simply check off boxes rather than providing helpful and targeted feedback to the learner,[13] undercutting a critical part of the learning process.[14] Continuous and qualitative feedback provided during training may help improve skill gains, supporting the need to distinguish between tools for evaluation and those for training.[15] This has led to efforts to develop tools specific for training[16] that rely on motion analysis,[17,18] such as the Imperial College Surgical Assessment device.[17] These assessments use objective measures to evaluate skill performance through metrics such as path length, time to complete, steadiness of motion, velocity, total amount of movement, and overall efficiency of motion.[19-22] The use of electromagnetic sensors to identify motion paths during CVC training show promise as a valid and objective assessment of skills[23] and these metrics can readily be captured using virtual reality simulators.[24]

The development of objective measures of performance can also enhance the quality of feedback that can be provided to novices during training. Research has shown that providing novices with detailed and appropriate feedback is a critical part of the learning process and that the opportunity to incorporate that feedback is crucial to the development of expertise in surgery.[14] A dynamic haptic robotic trainer (DHRT) system was designed to simulate various patient profiles and provides feedback on these metrics.[25,26] The DHRT system includes a personalized learning interface that provides quantitative feedback after each needle insertion on metrics including the angle of insertion, number of attempts, and distance to the center of the vein.[26] It has been suggested that the evaluation of competency of a trainee at a surgical procedure should include a combination of the trainee's self-perception of ability, an evaluator's perception of their ability, and an objective skills-based evaluation of their ability.[27] The purpose of this study was to compare needle insertion skill gains and procedural efficiency of surgical residents before and after training on a manikin with feedback provided by an experienced observer or robot-based training system with personalized learning interface. Results from this study can inform future development of surgical training systems.

Materials and methods

A study was designed to explore the effectiveness of the DHRT system and learning interface as compared to the standard manikin training for increasing CVC needle insertion skills. It first validated the use of a 10-item CVC checklist and qualitative motion tracking metrics to evaluate needle insertion skill gains, and then identified whether the different training modalities impacted resident procedural efficiency when encountering a novel patient scenario. Specifically, the study was developed to answer the following research questions:

RQ1

How do subjective observations of performance change after training and is this dependent on the training method? This question sought to address how a skilled observer's evaluation of first-year surgical residents' performance using a 10-item internal jugular (IJ) CVC skills checklist changed from pretraining to posttraining and if these changes were different between training groups. It was hypothesized that there would be no differences in observed ratings on the IJ CVC skills checklist because prior research has indicated that checklists may not be granular enough to detect changes in performance.[28]

RQ2

How do resident CVC skills quantified through motion analysis change after CVC training and are these dependent on the training method employed? This research question sought to address how the total path length of the needle tip, time to complete the CVC insertion, average angle of insertion of the needle, needle tip velocity, and jerk of the needle tip changed before and after CVC training and if there was a difference between training groups. It was hypothesized that these objective measures of skill gains would increase with training