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A hierarchical task analysis of cricothyroidotomy procedure for a virtual airway skills trainer simulator

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Abstract

BACKGROUND: Despite the critical importance of cricothyroidotomy (CCT) for patient in extremis, clinical experience with CCT is infrequent, and current training tools are inadequate. The long-term goal is to develop a virtual airway skills trainer that requires a thorough task analysis to determine the critical procedural steps, learning metrics, and parameters for assessment.

METHODS: Hierarchical task analysis is performed to describe major tasks and subtasks for CCT. A rubric for performance scoring for each task was derived, and possible operative errors were identified.

RESULTS: Time series analyses for 7 CCT videos were performed with 3 different observers. According to Pearson's correlation tests, 3 of the 7 major tasks had a strong correlation between their task times and performance scores.

CONCLUSIONS: The task analysis forms the core of a proposed virtual CCT simulator, and highlights links between performance time and accuracy when teaching individual surgical steps of the procedure.

The first priority in the management of critically ill patients is establishment of a secure airway to ensure oxygenation and ventilation. Airway compromise represents a leading cause of preventable death in trauma patients, affects all populations, and delivers devastating consequences when not immediately rectified.[1] When challenging anatomy precludes intubation by conventional

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means, an emergency surgical cricothyroidotomy (CCT) is a life-saving maneuver, and often the only viable option.[2,3]

Despite the life-saving role of this procedure, only 1% of all critical airways require CCT, limiting trainee experience. The Accreditation Council for Graduate Medical Education recommends that critical care fellows perform at least 3 CCT procedures during their training years to develop proficiency[4]; however, emergency medicine physicians have a sufficiently high success rate for intubation (97% on fewer than 2 attempts) that opportunities to fulfill this quota are few.[5] This infrequency creates a dilemma, as the vital role of CCT in life-threatening scenarios mandates a strict knowledge of anatomic landmarks and a high level of surgical dexterity. Indeed, CCT can incur a high complication rate, varying from 6% to 40%.[2,6] Complications include laceration to nearby structures, vocal cord damage, vascular injury, and creation of a false lumen, all which compromise the airway and increase mortality.[6]

Proficiency in CCT requires training supplemental to clinical experience, to equip practitioners with the skills to safely manage these high-stakes situations. The American College of Surgeons has attempted to bridge this training gap through *Advanced Trauma Life Support*[7]; however, this course offers practice on a sporadic basis, without a graded continuum of training. Moreover, low-fidelity simulators used in courses such as *Advanced Trauma Life Support* are costly and plastic mannequins lack of the realistic tactile feedback optimal for mastering this surgical procedure.[4,8,9] Concurrently, porcine and human cadavers, although more realistic, are impractical, as the CCT membrane becomes damaged with only one use.[10] Few models offer practice with procedural complications or anatomic variants.

In contrast to the aforementioned simulators, virtual reality (VR) simulators offer a risk-free training and assessment platform at various difficulty levels. VR simulators allow the trainers to repeatedly perform tasks and to receive quantitative feedback on their performance.[9,11] These qualities allow for improved operating room and emergency room performances.[12–15]

The long-term aim of our study is the development of a VR simulator for emergency CCT, with an emphasis on replication of tactile sensation and a realistic sense of proprioception using haptics technology. We seek to incorporate the multiple complex variables–cognitive and mechanical–involved in the successful performance of this life-saving procedure, to create a high-fidelity simulator ideal for systematic training. Our ultimate goal is to integrate clinical practice with technology into an elegant teaching tool, and to equip trainees with the proficiency and confidence that their patients require in the direst of circumstances. Toward this end, we performed a hierarchical task analysis (HTA) of the CCT procedure, to identify key metrics of performance and assessment for use in the CCT simulator.

Methods

Procedure analysis

A HTA is a structured and objective approach to identify and describe the procedural steps taken to achieve goals. HTA decomposes the procedure into a hierarchy of tasks and subtasks and expresses the relations among these tasks. The goal of this hierarchical expression is to objectively detail each and every step to formulate necessary or optional actions and decisions performed during the surgery. The derivation of HTA is necessary for the development of performance metrics and subsequently in depth time and performance analysis. In HTA for CCT, a total of 7 videos of experts performing procedure were recorded. One CCT was performed on a hospitalized patient in an emergent setting, and 6 CCT procedures were performed on cadavers in the Advanced Surgical Skills for Exposure in Trauma course. Each cadaver-based procedure was recorded with 3 Go Pro cameras from different angles. Two of the 3 cameras were situated for capturing observer views (as seen in Fig. 1), and 1 camera was attached to the surgeon's head to capture a first person view. All recorded videos were deidentified to remove any cadaver or surgeon-specific data before analysis. For completeness of the video analysis, the procedure and the tasks analysis are discussed in the following.

Five distinct steps comprised the task analysis: (1) initiation of procedure, (2) creating incision, (3) securing airway, (4) verification, and (5) suturing. Each main task had several subtasks. The list of the main tasks with their start and end time events for video analysis is listed in Table 1. The hierarchy of these tasks, their order of execution, and their relation are shown in Fig. 2.

In all cases, the preparation of instruments task was already completed before the recording of the video. Furthermore, although verification of the endotracheal tube (ETT) is always a required step to identify the successful oxygenation of the patient, we could not include this task in our measurements as all except 1 procedure were performed on cadavers. For these reasons, the verification and preparation tasks were removed

Figure 1 Observer camera view.