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Featured Article

Tracheostomy Overlay System: An Effective Learning Device Using Standardized Patients

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Tracheostomy Overlay System;
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Abstract: A team of students and faculty from engineering and nursing developed a wearable Tracheostomy Overlay System (TOS) for use with standardized patients. This device was designed to improve education of health professions students while learning assessment and care of a patient with a tracheostomy in clinical practice. The initial study of the TOS included nursing student participants (N = 57) who were tested on tracheostomy care and suctioning using either the traditional teaching method (a manikin) or the new TOS on a standardized patient to determine effectiveness of the TOS as a teaching method. Self-efficacy surveys were collected and identified clinical behavior was observed and quantified by two trained, independent observers. Survey results indicated significantly more positive clinical interaction (19.7 ± 8.34 TOS vs. 4.0 ± 4.80 manikin, $p < .05$) and self-correction (3.04 ± 1.95 TOS vs. 0.43 ± 0.73 manikin, $p < .05$) when the participants used the TOS. The TOS has the potential to improve simulated nursing education in both academia and clinical practice settings for patients with a tracheotomy.

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The Tracheostomy Overlay System (TOS) is a wearable chest plate for standardized patients (SPs) that can be used in skills and simulation education. The current use of SPs in simulation is proven to be an effective way to increase fidelity; however, there are many limitations on the type of injury or illness that can be assigned to SP cases. When using SPs, complex cases that require invasive lines and tubes, such as a tracheostomy tube, are not currently feasible, and although high-fidelity (HF) manikins have this capability, they lack the necessary human interaction and feedback that SPs offer to simulation. The TOS has been developed and evaluated by an interdisciplinary team of faculty and students from three departments (engineering, nursing, and theatre) to address the limitations of the SPs in simulation. The device sits over the actor's torso,

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aesthetically representing a chest and throat with an inserted tracheostomy tube. Nursing students can now perform tracheostomy care and suctioning on a live patient and perform an assessment, tracheostomy care, and suctioning while the actor reacts appropriately to deep suctioning or too much faceplate pressure/manipulation using cues built into the device. Additionally, this device can be used for scenario-based simulations that are designed for patients with a tracheostomy.

Key Points

- SPs are an effective healthcare education tool but are limited to non-invasive procedures.
- Tracheostomy care and suctioning is important to healthcare training, but requires an invasive procedure, preventing the use of SPs in training.
- The TOS allows SPs to be used in tracheostomy care and suctioning training.

Background

A tracheostomy is a surgically created artificial airway that enters through the anterior aspect of the neck into the trachea to bypass the upper airway and provides a safe airway to a patient whose airway is otherwise obstructed (Dawson, 2014). This procedure is one of the oldest and most common medical procedures for life-threatening airway obstructions (Rajesh & Meher, 2005). The most common reason for a tracheostomy is for long-term mechanical ventilation; however, the procedure is also used when there is severe upper airway obstruction due to trauma, anaphylactic reaction, and infection (Dawson, 2014).

Tracheostomy care consists of sustaining the surgically inserted tracheostomy tube and stoma to reduce bacterial growth and preventing infection, as well as preventing skin breakdown and contain secretions so they do not block the tube (Craven & Hirnle, 2000; Nance-Floyd, 2011). Nurses are primarily responsible for tracheostomy care, including the cleaning, replacing, or changing the inner cannula, changing the dressing, and cleaning the area around the stoma (Craven & Hirnle, 2000). All these procedures require minor disturbances of the face plate (Dawson, 2014). For tracheostomy care and suctioning, nursing students are learning their psychomotor skills during practice simulations (Lasater, 2007); therefore, it is important to reinforce the need to stabilize the face plate when the inner cannula is removed.

Another important factor in tracheostomy care is the comfort of the patient. Patients report discomfort when more pressure is placed on their trachea. Verbal communication of the patient is impaired during the tracheostomy cleaning procedure; therefore, nursing students must use alternative methods to determine when they are causing discomfort to the patient (Dawson, 2014; Serra, 2000). Improper patient care can result in trauma to the trachea, impaired oxygenation, decannulation, infection, and airway occlusion (Mitchell et al., 2012; Nance-Floyd, 2011).

Patients with tracheostomy tubes often require tracheal suctioning to maintain a clear airway or improve ventilation by removing excess secretions (Dawson, 2014; Martin, 2008; Mitchell et al., 2012). There is great variation on the suctioning technique used among clinicians (Mitchell et al., 2012; Nance-Floyd, 2011). Although suctioning is a skill that can be lifesaving, it also poses a threat to the patient through complications, including hypoxemia, mucosal trauma, increased intracranial pressure, infection, atelectasis, and cardiac arrhythmias (Martin, 2008). These threats are exacerbated with poor technique and uninformed care providers. The use of deep suctioning has been discouraged in the literature secondary to mucosal trauma at the carina (Bailey, Kattwinkel, Teja, & Buckley, 1988; Nagaraj, Fellows, Shott, & Yacoub, 1980). Bailey et al. (1988) reported that significant necrosis or tracheal inflammation can be the result of the suction catheter impacting the patient's carina. Nagaraj et al. (1980) reported that repeated impact caused by deep suctioning also leads to formation of granulation tissue and bronchial stenosis. Patients with tracheostomy tubes already lack the body's natural filtration of the upper airway which makes them more susceptible to infection (Dawson, 2014). Respiratory infections can be deadly to patients who are already medically fragile, making it imperative for nurses to have the proper training before practicing these skills in a clinical setting.

Teaching methods for nursing students may involve practice on static or HF manikins. The static manikin is anatomically correct and gives the ability to physically practice tracheostomy care and suctioning (Lasater, 2007; McCaughey & Traynor, 2010). HF manikins offer scenario-based simulations and can be standardized as well as easily modified to simulate any number of clinical scenarios (Lasater, 2007; Triola et al., 2006). Training with HF manikins has been found to enhance patient safety, as well as improve fidelity to hospital settings according to participants (McCaughey & Traynor, 2010).

However, there are limitations with manikins. The static manikins are unable to provide realistic patient reactions or real-time feedback (Berragan, 2011; Luctkar-Flude, Wilson-Keates, & Larocque, 2012; McCaughey & Traynor, 2010). Although the HF manikins are equipped with speakers that can be used during a simulation to answer participant questions, there is no ability for the health care participants to use nonverbal cues from the patient to improve their communication and react to a realistic physical response (Lasater, 2007). Additionally, the cost of HF manikins as well as the staff to maintain them is often unaffordable for many colleges and universities (Lasater, 2007). The difficulty in creating a realistic environment in current simulations may lead to difficulties when translating patient care in practice (Berragan, 2011). The lack of realistic experience can lead to procedural errors, create distrust in patients, and impede the nurse–patient relationship.

Use of SPs is an effective alternative to HF manikins in health care education, particularly for improving communication skills and self-confidence (Cowperthwait, Saylor, & Schell, 2013). The types of scenarios that can be simulated with SPs are currently limited to noninvasive therapies to protect the actor from harm or discomfort. The ideal educational tool would facilitate realistic patient interaction, both verbal and nonverbal, between the SP and trainee. This would allow the trainee to participate in simulations involving medically complex patients they would likely encounter in a hospital environment, while not harming the SP in any way. The TOS was born from this concept.

The TOS provides a clinically accurate response from the patient by providing sensory cues to the SP enabling them to respond appropriately to the quality of care provided. The objective of this study was to evaluate the effectiveness of the TOS as a training tool for nursing students compared with the current educational tools, namely static and HF manikins. The results of this study could potentially shift educational standards of practice for training in tracheostomy care and, in doing so, improve health care provider competence in the field.

Methods

The Tracheostomy Overlay System

The TOS is a vest that provides the appearance of a lifelike male torso, worn anteriorly on a live actor. The vest contains an integrated sensor system to detect improper tracheostomy care and/or suctioning technique by a trainee. The vest opens in a fashion similar to a clamshell design, with the tracheostomy tube and its sensors sandwiched between a foam-padded back plate that rests against the actor and a silicone-covered front plate that is molded to resemble a human male torso and neck (see Figure 1A). The tracheostomy faceplate, which is visible on the front plate, is instrumented with two force sensors that detect axial (anterior-posterior) and torsional manipulations of the faceplate (SR-F2R-R5, Electronic Experimental Solutions, Minden, NV, USA). Preliminary studies with clinically active nurses were conducted to establish the threshold values for "excessive force" on the faceplate; these were determined to be 9.34 N axially and a 4.09° (2.37 mm) rotation. When faceplate forces exceed these thresholds (too much movement or pressure applied to the faceplate), a small, vibrating motor in the left shoulder strap of the TOS is activated (see Figure 1B), and the actor is cued to respond. The instruction for the "level" of response or type of response is determined by the nursing or simulation faculty, that is, coughing, tearing up, becoming dyspnic, showing discomfort, and/or becoming anxious. A second set of sensors (SR-F2R-R5, Electronic Experimental Solutions) detects impact of the suction catheter on the carina, triggering a vibrating motor in the TOS right shoulder strap. The actor is taught by nursing or simulation faculty how to respond after being cued by the device (violent coughing, dyspnea, pain, eyes watering). The force sensors and vibrating motors are integrated using a microcontroller (Arduino Uno R3, Sparkfun, Niwot, Colorado, USA) embedded in the vest.

Additionally, the TOS has the capability to output anterior lung sounds from four different locations, corresponding to the upper and lower lobes of each lung (the right middle lobe will be incorporated into future prototypes). Each location is able to produce four different sounds: vesicular (normal), coarse crackles, fine crackles, and wheezing independent of the other. The audio is output from two microprocessors (Raspberry Pi, Revision B, model VILX3, UK), which are single-board computers that store the audio files and are connected to two speakers each. Each speaker is situated under the top layer of the TOS to best replicate realistic lung sound auscultation (see Figure 1B). The microprocessors can be operated using a personal computer or tablet via a Wi-Fi connection; therefore, a nursing instructor can wirelessly manipulate the lung sounds through a computer at the bedside for skills learning or from the control room for scenario-based simulations.

Educational Study Design

To evaluate the effectiveness of the TOS as a clinical training tool, junior-level nursing students (trainees) were

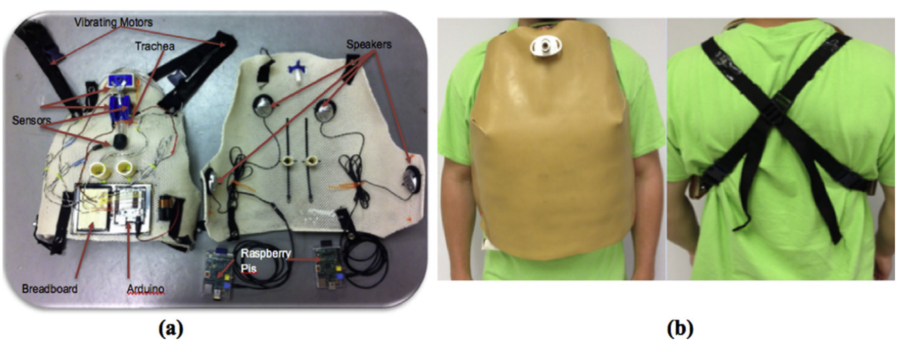


Figure 1 The Tracheostomy Care Overlay System, showing (A) Interior components and (B) anterior and posterior views of the device being worn by a live actor.

invited to participate in a prospective, randomized control trial approved by the Institutional Review Board of University of Delaware (University of Delaware, Newark, DE). Trainees were recruited from an adult health medical surgical course at the University of Delaware. None of the nursing students had prior instructional or clinical practice providing tracheostomy care or suctioning. Trainees were randomly assigned to tracheostomy care and suctioning instructional modules involving either static manikin training (Manikin) or simulated patients wearing the TOS system. All trainees regardless of educational module first participated in the traditional course required skills practice laboratory for tracheostomy care and suctioning on a static manikin while being coached by teaching assistants and simulation instructors. One week after the practice session, participants were randomly assigned (N = 57) to their educational module (Manikin [n = 30]vs. TOS [n = 27]). Both the practice and final return demonstration sessions were overseen by a simulation instructor. For the TOS final return demonstration, five (5) undergraduate theatre students (actors) were recruited to serve as SPs. Actors were well trained in medical simulation as part of a broader curriculum (University of Delaware Healthcare Theatre Program) and were given specific training by clinical faculty as how a patient would react to the different sensors from the TOS.

Outcome Measures

Outcome measures for this study included validated survey instruments to measure changes in self-perceived competency as well as quantifiable observations of clinical behavior during simulation sessions. Two validated surveys were administered to the participants: (a) Nursing Anxiety and Self-Confidence with Clinical Decision Making Scale (NASC-CDM; self-confidence $\alpha = 0.97$, anxiety $\alpha = 0.96$; White, 2014) and (b) Self-Assessment of Self-Efficacy (SE) ($\alpha = 0.96$; Alavi-Majed, 2014). Each survey was administered to every participant immediately before and after both the practice and the final return demonstration. During the final return demonstration, clinical behavior was observed and quantified by two trained, independent observers. The total number of positive clinical behaviors was tallied, with positive clinical behavior defined as the following events: explanation of the procedure to the patient, offering reassurance to the patient, asking the patient for feedback using yes or no questions, and self-correction of bad technique. Examples of bad technique include breaking sterility, causing undesirable manipulations of the faceplate, deep suctioning that impacted the patient's carina, and causing the patient general discomfort. Interrater and intrarater reliabilities of the observations from the two independent observers were determined by repeated evaluation (three trials) of two recorded clinical simulations of tracheostomy care and suctioning. These two simulations were only used to establish intrarater and interrater reliabilities and were not included in the final data set for TOS evaluation. For the final data set, survey and observational results were compared pretraining versus posttraining across instructional modalities (Manikin vs. TOS) using repeat measures two-way analysis of variance (ANOVA) with $p < .05$ as assumed level of significance.

Results

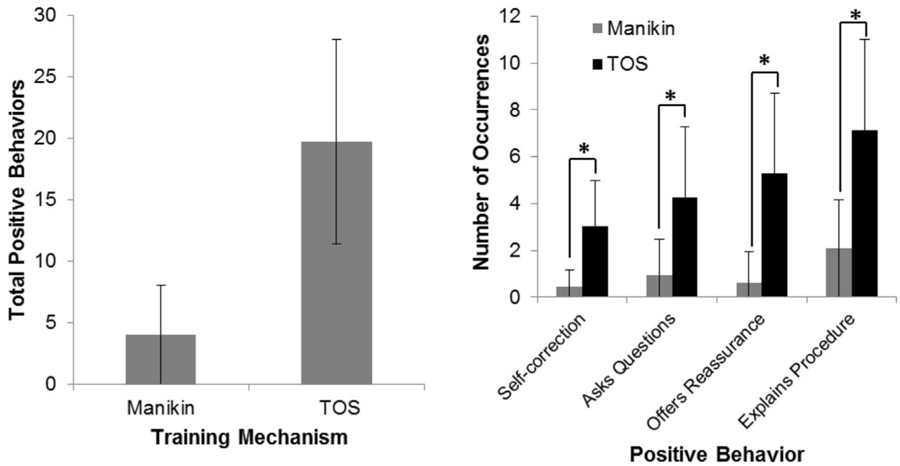
There were no differences between trainee groups in terms of demographics (100% female; 92% white, 4% Asian, 4% Hispanic) or year-in-training (88% third-year undergraduate nursing students, 12% undergraduates in accelerated nursing program). Survey response rates were 100% for prepractice session and 74% for both prefinal and postfinal training sessions. Interrater reliability of the two independent observers of clinical behavior was high (Cohen κ, 0.80 ± 0.05), and intrarater reliability was nearly perfect (ICC, 0.98 ± 0.02).

Survey results indicated no significant difference in either self-efficacy or self-confidence and anxiety with training modality. Posttraining, NASC-CDM scores were 2.99 ± 0.28 for Manikin versus 2.75 ± 0.44 for TOS ($p > .05$, ANOVA); and SE were 3.44 ± 0.14 for Manikin versus 3.39 ± 0.36 for TOS ($p > .05$, ANOVA). Neither training modality demonstrated significant improvement in NASC-CDM or SE scores for prefinal versus postfinal training session ($p > .05$).

Training modality did affect clinical behavior, as observed during the final training session with both TOS and Manikin groups. TOS trainees demonstrated significantly more positive clinical interactions than Manikin (19.7 ± 8.34 vs. 4.0 ± 4.80, $p < .05$; see Figure 2A). In addition to an increased amount of positive patient interactions, students who trained with the TOS self-corrected their behavior considerably more than those who trained with the Manikin (3.04 ± 1.95 vs. 0.43 ± 0.73, $p < .05$; see Figure 2B).

Discussion

These results strongly suggest that the new TOS is an effective tool to improve technique, fidelity, communication, and preparedness for clinical practice. Observational data show that nursing students interact with the standardized patient much more readily when training with the TOS as opposed to the manikin. The participants were found to correct their own mistakes, ask questions, offer reassurance, and explain the procedure to their patient more often when training with the TOS. This indicates that when training with the TOS, nursing students demonstrate real-time recognition of error and are able to correct their technique, resulting in greater attention to patient safety. The survey results suggest that there is no difference between training devices in nursing students' perceived self-efficacy, self-confidence, and anxiety. Therefore, it can be said that the



(a) **(b)**

Figure 2 Mean number of positive behavior observed comparing (A) total positive behaviors observed for each simulation and (B) positive interactions broken down by behavior type. A statistical difference was observed for each case ($p < 0.05$, ANOVA). Whiskers represent ±1 standard deviation from the mean. *Note.* TOS, Tracheostomy Care Overlay System; ANOVA, analysis of variance. *$p < 0.05$, ANOVA.

benefits of training with the manikin are preserved with the TOS.

Findings in previous studies of HF medical training simulations have shown a significant improvement in students' confidence and self-efficacy after completing the simulation (Berragan, 2011; Paige et al., 2014). The findings of this study are inconsistent with this prior work in that no improvement in self-efficacy or self-confidence was shown with repeated training with either training modality. The length of training may explain this, which, in our study was very short (two training periods over 1 week). Previous studies considered the effect of repeated training over a 10-month period and showed improvement in self-assessed outcomes (Tofil et al., 2014). Our results are significant, however, in that participants clearly demonstrate positive changes in behavior and patient safety when using the TOS, regardless of the brevity of the study.

Overall, there were several strengths for this study. First, the TOS technology was compared with the current tracheostomy teaching technique by first-time learners of tracheostomy care and suctioning, eliminating the contamination of data by nursing students' previous knowledge. The participants understood the didactic content related to tracheostomy care and suctioning but had no clinical experience or opportunity to perform it before the practice laboratory, creating an ideal group for comparing which method of training is more effective. Because the procedures performed are identical, regardless of the training device, the differences in results arise strictly due to the student's experience during the return demonstration. Furthermore, the device itself creates a situation in which unbiased quantitative observation can be made which offered validity to the results.

A follow-up simulation experience would be beneficial to determine the overall learning and performance of the nursing students carrying out tracheostomy care and suctioning on either the TOS device or the manikin as part of a simulated scenario along with other types of care. This follow-up study would benefit from a new validated tool to compare learning objectives as the current surveys used for comparing learning objectives were burdensome. The follow-up study would ideally utilize scenarios that incorporate a patient with a tracheostomy to assess effectiveness within a scenario-based simulation experience. This addition would give insight into the student's ability to react to challenges that arise and demonstrate critical thinking based on assessment findings. They will also receive patient centered feedback regarding their procedural explanations and therapeutic communication skills during an event that required quick thinking, strong teamwork, and confidence with the required skills. The researchers plan to incorporate a simulation experience into the study design with the second generation prototype of the TOS.

The results of this study demonstrate that the TOS has the potential to substantially improve simulated nursing education in both academia and clinical practice settings in tracheotomy care and suctioning. This device offers simulation centers an educational tool that closely mimics clinical practice and provides educators with an opportunity to assess their students' ability to recognize and correct errors in patient care before they ever provide care in a clinical setting. The TOS system enhances the fidelity of tracheostomy care and suctioning while contributing to the development of therapeutic communication skills of the healthcare professional. Nursing students are able to recognize mistakes before they have built muscle memory, which would contribute to improved patient outcomes. This novel method of training is in its first phase of prototypes and clinical testing but the outcomes of this study provide researchers with the knowledge that the TOS will greatly benefit skills and simulation education.

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