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Simulation-Based Tracheal Intubation Training for Medical Students: A Before-and-After Study

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Abstract

Introduction:

Tracheal intubation is a core airway-management procedure, but undergraduate medical students often have limited opportunities to practice on real patients. This study evaluated the effect of a single procedural simulation session on medical students' knowledge, self-assessed technical preparedness, and confidence, while describing a structured in-procedure formative assessment framework.

Methods

This prospective before-and-after study included fourth-year undergraduate medical students with no previous intubation experience at a university simulation center. The intervention consisted of a 60-minute low-fidelity procedural simulation session featuring a theoretical briefing, instructor demonstration, supervised hands-on practice, in-procedure formative assessment using a standardized checklist, and debriefing. Participants completed pre- and post-session questionnaires. Paired comparisons were performed using the paired Student's t-test or Wilcoxon signed-rank test.

Results

Twenty-eight students completed the study. Following the session, significant increases were observed in mean self-assessed technical preparedness (from 2.4 ± 0.8 to 4.4 ± 0.6, $p < 0.001$) and confidence (from 2.3 ± 0.9 to 4.3 ± 0.6, $p < 0.001$). Knowledge of complications improved (2.3 ± 0.9 vs. 4.2 ± 0.7, $p < 0.001$), while perceived difficulty decreased (4.1 ± 0.7 vs. 2.2 ± 0.6, $p < 0.001$). Tube insertion and laryngoscope manipulation were the most common challenges. The simulation was rated as highly realistic (4.7 ± 0.5), with 93% of students finding it very useful and 100% recommending its curriculum integration.

Conclusions

A single structured procedural simulation session was associated with significant short-term improvements in medical students' knowledge, confidence, and preparedness for tracheal intubation. A standardized in-procedure formative assessment checklist may strengthen feedback quality and support competency-based training.

Introduction

Airway management is a cornerstone of anesthesiology, emergency medicine, and critical care. Tracheal intubation remains one of the most important airway procedures because failure or delay may rapidly lead to hypoxemia, aspiration, hemodynamic instability, or cardiac arrest. Learning this procedure

requires more than theoretical knowledge; students must integrate airway anatomy, equipment preparation, patient positioning, laryngoscope handling, tube advancement, confirmation of placement, and situational awareness under stressful conditions.

For undergraduate medical students, opportunities to perform tracheal intubation on real patients are often limited. Clinical exposure depends on patient availability, operating-room schedules, supervisory capacity, and ethical considerations related to patient safety. As a result, many students observe airway management but do not develop sufficient hands-on familiarity before entering internship or residency.

Simulation-based medical education offers a safe, reproducible, and learner-centered environment in which technical skills can be practiced without risk to patients. Previous work has shown that simulation can improve knowledge, procedural performance, and confidence in airway management and other acute-care skills [1]. Furthermore, it allows for deliberate practice, immediate feedback, error correction, and structured debriefing [2–4]. However, the implementation of procedural simulation remains variable in undergraduate curricula, especially in resource-limited settings where simulation centers, instructors, and dedicated curricular time may be constrained.

In addition to training, simulation provides an opportunity for structured formative assessment. During a procedural session, instructors can observe specific steps, identify errors in real time, and provide targeted feedback. Such in-procedure assessment is particularly important for tracheal intubation because seemingly minor technical errors, such as inadequate positioning, poor laryngoscope handling, or failure to confirm tube placement, may have major clinical consequences.

The objective of this study was to evaluate changes in medical students' knowledge, self-assessed technical preparedness, and confidence following a single procedural simulation session on tracheal intubation.

Materials and Methods

Study Design and Setting

This prospective before-and-after study was conducted from January to May 2024 at a university simulation center. The study evaluated the immediate educational outcome of a single procedural simulation session on tracheal intubation. The manuscript was prepared in accordance with the principles of the STROBE statement for observational studies and the reporting recommendations for healthcare simulation research.

Participants

Eligible participants were fourth-year undergraduate medical students who had never performed tracheal intubation in a clinical setting. Participation was voluntary. Students who reported previous formal

airway-management training or previous simulation-based training specifically focused on intubation were excluded. Informed consent was obtained prior to enrollment, and questionnaires were anonymized to preserve confidentiality.

Educational intervention

The intervention consisted of a structured 60-minute procedural simulation session using a low-fidelity airway manikin (Laerdal Airway Management Trainer). Each session was supervised by anesthesiology instructors experienced in simulation-based teaching. Students were trained in small groups of four learners to maximize hands-on practice and feedback.

The session was structured into four distinct phases: (1) a theoretical briefing covering airway anatomy, indications for tracheal intubation, contraindications and risks, required equipment, and the sequence of procedural steps; (2) an instructor-led demonstration of tracheal intubation; (3) supervised hands-on practice by each student; and (4) structured debriefing focused on technical performance, error recognition, complication prevention, and stress management. Students were encouraged to verbalize the steps of the procedure and to ask for clarification during practice.

In-procedure student assessment

To complement the training session, instructors utilized a standardized, in-procedure formative assessment checklist during direct observation of each student. Designed for educational rather than summative purposes, this tool provided a structured approach to identify strengths, detect omissions, and guide real-time feedback.

The checklist evaluated eight key procedural domains:

1. Equipment preparation
2. Patient positioning
3. Preoxygenation and safety checks
4. Laryngoscope insertion and handling
5. Glottic visualization
6. Tube insertion
7. Cuff inflation and tube fixation
8. Confirmation of correct tube placement

Each domain was scored on a three-level scale: 0 (omitted or unsafe), 1 (performed with prompting or partially correct), and 2 (performed correctly and independently). Instructors also documented the primary procedural challenge encountered by each student. Given that this study focused on immediate educational impact without video recording, blinded rating, or inter-rater reliability testing, the checklist served as a tool for formative feedback and error identification rather than a standalone objective

outcome. The complete checklist is available (see Table, Supplemental Digital Content, which outlines the eight-domain standardized formative assessment checklist) to facilitate replication and refinement in future research.

Outcomes and data collection

The primary outcome was the change in self-assessed technical preparedness for tracheal intubation before and after the simulation session. Students rated their self-reported ability to perform key procedural steps, including equipment preparation, patient positioning, laryngoscope handling, tube insertion, and confirmation of tube placement, using a five-point Likert scale ranging from 1 (very low) to 5 (very high).

Secondary outcomes included changes in self-confidence, knowledge of complications, perceived procedural difficulty, simulation realism, satisfaction with the session, and willingness to recommend integration of the session into the undergraduate curriculum. Data on procedural difficulties were collected from student reports and instructor observations during the formative assessment.

Statistical analysis

The sample size was based on feasibility; all eligible students available during the study period were invited to participate. Statistical analyses were performed using IBM SPSS Statistics for Windows, version 25.0 (IBM Corp., Armonk, NY, USA). Continuous variables are expressed as mean ± standard deviation (SD) for normally distributed data or median and range for non-normally distributed data. Categorical variables are expressed as numbers and percentages. Pre- and post-simulation scores were compared using the paired Student's t-test for normally distributed variables and the Wilcoxon signed-rank test for ordinal or non-parametric data. A p value less than 0.05 was considered statistically significant.

Results

Participant characteristics

A total of 28 eligible fourth-year medical students completed the study and were included in the final analysis. The study cohort had a mean age of 23 ± 1 years and was predominantly female (n = 17, 60.7%). Consistent with the selection criteria, none of the participants had prior training or clinical experience in tracheal intubation. A small minority (n = 3, 10.7%) reported previous exposure to simulation-based education in topics unrelated to airway management. Baseline demographic and academic characteristics are presented in Table 1.

Table 1
Demographic characteristics of the study population

Variable	Total (N = 28)
Age, years	23 ± 1
Female sex, n (%)	17 (60.7%)
Previous airway-management training, n (%)	0 (0%)
Previous simulation experience unrelated to airway management, n (%)	3 (10.7%)
Prior exposure to tracheal intubation in a clinical setting, n (%)	0 (0%)
Data are presented as mean +/- SD or number (percentage).	

Educational outcomes

Participation in the single simulation session resulted in statistically significant improvements across all evaluated educational domains (Table 2). Following the training, students reported substantial increases in mean scores for self-assessed technical preparedness (from 2.4 ± 0.8 to 4.4 ± 0.6, $p < 0.001$) and self-confidence (from 2.3 ± 0.9 to 4.3 ± 0.6, $p < 0.001$). Concurrently, scores for knowledge regarding intubation complications significantly improved ($p < 0.001$), whereas the mean score for perceived procedural difficulty dropped by nearly half (from 4.1 ± 0.7 to 2.2 ± 0.6, $p < 0.001$).

Table 2
Comparison of outcomes before and after the simulation session

Outcome	Pre-simulation	Post-simulation	p value
Self-assessed technical preparedness (1–5)	2.4 ± 0.8	4.4 ± 0.6	< 0.001
Self-confidence (1–5)	2.3 ± 0.9	4.3 ± 0.6	< 0.001
Knowledge of complications (1–5)	2.3 ± 0.9	4.2 ± 0.7	< 0.001
Perceived difficulty (1–5)	4.1 ± 0.7	2.2 ± 0.6	< 0.001
Perceived realism of simulation (1–5)	N/A	4.7 ± 0.5	N/A
Session rated as very useful, n (%)	N/A	26 (93%)	N/A
Would recommend curricular integration, n (%)	N/A	28 (100%)	N/A
Values are expressed as mean +/- SD or number (percentage).			

The simulation experience was rated as highly realistic (mean: 4.7 ± 0.5 out of 5). Post-intervention evaluation revealed outstanding learner satisfaction: 93.0% of students (n = 26) found the session highly useful, and 100.0% (n = 28) strongly recommended integrating this simulation module into the undergraduate medical curriculum.

In-procedure formative assessment findings

During hands-on practice, the formative checklist helped instructors identify the steps most frequently requiring prompting or correction. The most common difficulties involved tube insertion (16 students, 57%) and laryngoscope handling (8 students, 29%). Less frequent difficulties involved patient positioning, equipment sequencing, and systematic confirmation of tube placement. These observations were used during debriefing to provide individualized corrective feedback and to emphasize high-risk steps that should be mastered before clinical exposure.

Discussion

In this prospective before-and-after study, a single structured procedural simulation session was associated with significant short-term improvements in medical students' self-assessed technical preparedness, confidence, knowledge of complications, and reduction in perceived procedural difficulty. The intervention achieved high learner satisfaction, and all participants recommended integrating similar sessions into the undergraduate curriculum. These findings support the educational value of simulation-based training for airway-management skills in contexts where direct clinical practice opportunities are limited.

Simulation and procedural skill acquisition

The improvement observed after training is consistent with the principles of deliberate practice, which emphasize focused repetition, clear performance goals, immediate feedback, and progressive correction of errors [3, 5]. Tracheal intubation is a complex psychomotor procedure, and novice learners often struggle to coordinate positioning, laryngoscope handling, glottic visualization, and tube advancement. Simulation allows these steps to be decomposed and practiced in a safe environment before patient exposure.

Previous systematic reviews and meta-analyses have reported that simulation-based airway training improves knowledge, procedural performance, and learner confidence compared with traditional teaching alone [6]. Our results extend these observations to an undergraduate medical student population in a resource-limited educational setting and suggest that even a brief, low-fidelity simulation session can produce measurable immediate educational benefits when it was structured around demonstration, hands-on practice, feedback, and debriefing.

Role of in-procedure formative assessment

A major component of the proposed training model is the use of an in-procedure formative assessment checklist. Such assessment is critical because confidence alone is not equivalent to competence [7]. A learner may feel more confident after simulation while still omitting essential safety steps. Conversely, direct observation during the procedure allows instructors to identify whether the student prepares the correct equipment, optimizes positioning, handles the laryngoscope safely, advances the tube appropriately, and confirms tracheal placement systematically.

The checklist used in this study was not intended as a high-stakes examination. Rather, it functioned as a feedback tool aligned with competency-based education [8]. By assigning each procedural step a simple rating, instructors could transform the simulation from a purely experiential activity into a structured learning encounter. The frequent difficulties observed with tube insertion and laryngoscope handling highlight the value of step-by-step procedural assessment: these are precisely the phases during which suboptimal technique may cause failed intubation, airway trauma, or esophageal intubation in clinical practice [9]

For future implementation, this checklist could be developed into an objective structured assessment of technical skills (OSATS) [10]. This would require assessor training, predefined pass/fail criteria, repeated attempts, video review when feasible, and an evaluation of inter-rater reliability. Such development would allow future studies to move beyond self-reported preparedness and directly measure actual procedural competence.

Knowledge transfer, debriefing, and patient safety

Simulation-based training not only enhances psychomotor familiarity but also supports cognitive integration. During the session, students were required to anticipate complications, verbalize safety checks, and reflect on errors during debriefing. Structured debriefing represents a central component of simulation-based education because it helps learners analyze their reasoning, understand why errors occurred, and develop safer strategies for future clinical encounters [11].

From a patient-safety perspective, procedural simulation is particularly relevant for airway management. Performing initial practice on live patients may expose them to avoidable risks, whereas simulation allows novice learners to make and correct errors before clinical exposure. In educational settings with limited supervised opportunities, simulation can promote equity by ensuring that all students receive a minimum standardized, baseline experience in essential procedures [12].

Educational implications

The present findings support the systematic integration of procedural airway simulation into undergraduate medical training. A pragmatic and scalable model would include a short preparatory theoretical module, instructor demonstration, small-group hands-on practice, in-procedure formative checklist assessment, structured debriefing, and repeat practice for students who require additional support. This model is highly compatible with resource-limited settings because it can be implemented using low-fidelity mannequins and a small number of trained instructors [13].

Curricular integration would also help shift undergraduate education from knowledge-based exposure to competency-oriented preparation. The checklist proposed in Appendix 1 can serve as a practical starting point for departments wishing to standardize feedback and document learner progression over time.

Limitations

This study has several limitations that warrant consideration. First, it was monocentric and included a small convenience sample, which may limit the generalizability of the findings. Additionnaly, outcomes were measured immediately after the intervention meaning that long-term retention was not assessed. Furthermore, the main quantitative outcome was self-assessed technical preparedness rather than independently measured objective performance. Although a formative in-procedure checklist was used to guide feedback, no blinded assessor, video review, or inter-rater reliability testing was performed. Moreover, the before-and-after design did not include a control group, consequently improvements cannot be attributed exclusively to simulation with the same strength as in a randomized trial. Finally, the transfer of skills to clinical practice on live patients was not evaluated.

Conclusion

A single structured procedural simulation session was associated with significant short-term improvements in medical students' knowledge, confidence, and self-assessed preparedness for tracheal intubation. The use of a standardized in-procedure formative assessment checklist provided a structured framework for direct observation and targeted feedback.

Abbreviations

SD
Standard Deviation
SPSS
Statistical Package for the Social Sciences
STROBE
Strengthening the Reporting of Observational Studies in Epidemiology
OSATS
Objective Structured Assessment of Technical Skills

Declarations

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Conflict of Interest Statement: The authors declare that they have no competing or conflicts of interest related to this manuscript.

Ethics approval and consent to participate

This study was an educational, non-interventional study involving voluntary participation of undergraduate medical students during a simulation-based teaching session. Written informed consent

was obtained from all participants, and all questionnaire data were anonymized prior to analysis. As this was a minimal-risk, non-interventional educational study with no clinical intervention, it did not require review by the Ethics Committee of the Faculty of Medicine, University of Tunis El Manar, according to institutional policy. The study was conducted in accordance with the ethical principles of the Declaration of Helsinki.

Consent for publication: Not applicable.

Availability of data and materials

The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

SA conceived and designed the study, collected the data, performed the statistical analysis, and drafted the manuscript. SA, RK, AR, KA, DBA, MT, and SAT contributed to the study design, interpretation of the data, critical revision of the manuscript, and approved the final version. All authors read and approved the final manuscript.

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Supplementary Files

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