

ORIGINAL ARTICLE

High-Fidelity Simulation for Emergency and Difficult Airway Management Training in Novice Learners

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Introduction: Emergency airway management presents a significant challenge for medical students, demanding critical skills with limited opportunities for real-world practice on live patients. Simulation-based medical education offers a valuable platform for acquiring knowledge, skills, and appropriate attitudes across all healthcare professions. This study aimed to evaluate the efficacy of a high-fidelity simulator-based training program in enhancing knowledge acquisition and learners' perceptions regarding emergency and difficult airway management among novice learners.

Methods: A quasi-experimental, single-group pretest-posttest design was employed. Twenty-nine fifth-year medical students enrolled in an anesthesiology course participated in this study. All students were novices in high-fidelity simulation-based learning (SBL) and had no prior experience with intubation in real-life emergency airway situations. Prior to SBL, students received lectures and basic intubation training with part-task simulation under instructor guidance. A pre-test was administered one day before the SBL session. Two scenarios were designed: emergency airway management and difficult airway management. All students were divided into 16 leaders and 13 observers. Upon completion of the SBL program, all students underwent a post-test to assess their knowledge improvement and completed a survey to evaluate their perception of the SBL experience.

Results: The results demonstrated a statistically significant increase in the overall knowledge scores post-intervention compared to the pre-test ($p < 0.05$). Both Leaders and Observers showed comparable improvements in knowledge acquisition. Furthermore, the participants reported high levels of satisfaction and increased self-confidence in managing emergency airways.

Conclusion: The integration of SBL significantly improved the learners' knowledge and perceived confidence in handling emergency and difficult airway scenarios. Knowledge improvement and learners' perceptions were comparable between leaders and observers.

Introduction

Emergency airway management is a critical, life-saving intervention in clinical practice. Failure to secure an airway promptly can lead to severe and catastrophic complications, including profound hypoxia, permanent neurological damage, and death¹⁻². For novice learners, such as medical students, acquiring these essential skills through the traditional "see one, do one" model on live patients is increasingly limited by ethical concerns and patient safety priorities³. Consequently, there is an urgent need for effective educational strategies that provide a safe yet realistic environment for training in high-stakes airway scenarios. Simulation-based medical education (SBME) offers a valuable platform to bridge this gap, providing a safe environment for fostering multidisciplinary communication and structured feedback without compromising patient safety⁴.

Simulation-based medical education (SBME) has emerged as a cornerstone in medical training, bridging the gap between theoretical knowledge and clinical practice⁵. A systematic review and meta-analysis have demonstrated that technology-enhanced simulation is consistently associated with significant improvements in knowledge and skill acquisition compared to no intervention⁶. Specifically, high-fidelity simulators (HFS) provide a realistic physiological response to inter-

ventions, allowing learners to experience the stress and complexity of emergency and difficult airway management without risking patient harm⁷⁻⁸.

In the context of Thailand, the national competency standards for medical graduates (B.E. 2566/2023) strictly mandate proficiency in basic and emergency life-saving procedures prior to entering clinical internship⁹. However, integrating high-fidelity simulation into the undergraduate curriculum presents significant logistical challenges, particularly for regional medical education centers. High-fidelity simulators are resource-intensive and expensive, often resulting in high student-to-simulator ratios⁸. To maximize the utility of these limited resources, simulation sessions are frequently designed as group activities where a few students act as active participants or "Leaders," while the rest act as "Observers."

While the general efficacy of simulation is well-documented, prior research has largely focused on experienced residents or specialized practitioners, leaving a paucity of evidence regarding its immediate impact on novice learners facing emergency intubation for the first time. Furthermore, the practical necessity of utilizing observer roles raises a critical gap in knowledge: Does the role of a directed observer provide equivalent knowledge acquisition and perceived learning value compared to the active leader role in high-

fidelity airway scenarios?¹⁰⁻¹¹.

Understanding this "role equivalence" is vital for optimizing medical curricula and resource management in resource-limited settings. Consequently, this study sought to address the existing knowledge gaps through a structured simulation intervention. The primary objective of this study was to evaluate the effectiveness of a high-fidelity simulation program in enhancing knowledge acquisition and learners' perceptions regarding emergency and difficult airway management among fifth-year medical students. The secondary objective was to compare these educational outcomes—specifically knowledge improvements and satisfaction levels—between students acting in active participant roles (Leaders) and those in directed observation roles (Observers).

Methods

Study Design

This cross-sectional, quasi-experimental study utilized a single-group pretest-posttest design to assess knowledge acquisition and learner perceptions among novice medical students.

Study Population

The study population consisted of fifth-year medical students from a six-year MD program during their anesthesiology clerkship. Since the simulation was conducted as part of the mandatory, routine educational curri-

culum, all students actively participated, and no explicit informed consent was required for the educational activity itself.

The inclusion criteria required that all students were from the same academic year, shared an identical curriculum during their anesthesiology rotation, and were novices in high-fidelity simulation-based learning (SBL) without prior experience in real-life emergency endotracheal intubation. This selection process ensured a homogeneous baseline across all learners.

The exclusion criteria were defined as: (1) absence from the simulation session, (2) incomplete attendance from the briefing to the debriefing phase, and (3) failure to complete either the pre-test or the post-test and survey. No participants met the exclusion criteria.

Simulation Intervention and Role Allocation

One week prior to the session, students were provided with self-study materials, foundational lectures, and basic intubation training using low-fidelity part-task trainers. The primary SBL intervention utilized the CAE Apollo high-fidelity patient simulator (CAE Healthcare, Sarasota, FL, USA). The simulation was conducted in a dedicated laboratory equipped to mimic a standard general ward and an Intensive Care Unit (ICU) environment.

Participants were organized into small groups of 3–4 members. Role allocation

within each group was determined through voluntary self-selection. To ensure a comprehensive learning experience, a role rotation strategy was implemented between different scenarios so that no participant performed the same role twice. For comparative analysis, participants were categorized based on their primary active role during the assessed scenarios into a "Leader" group (responsible for decision-making and interventions) and an "Observer" group (responsible for observing the scenario participants, recording key points to provide constructive feedback, and contributing to the shared reflection during the debriefing).

Two core scenarios were designed based on ASA 2022 guidelines: emergency airway and unanticipated difficult airway management. To enhance psychological fidelity, a failure to secure the airway within two minutes triggered physiological deterioration, including a SpO₂ drop to 70% and bradycardia. Each SBL session followed a standardized structure: a 5-minute pre-briefing, a 10–15 minute scenario, and a 15–20 minute debriefing using the Gather-Analyze-Summarize model.

Outcome Measurements and Data Collection

The educational outcomes were evaluated using two primary instruments designed to assess knowledge acquisition and learners' perceptions.

1. **Knowledge Assessment:** A 10-item multiple-choice questionnaire (MCQ) was administered to evaluate cognitive knowledge. The questions covered critical areas such as indications for intubation, rapid airway assessment, confirmation of endotracheal tube placement, alternative airway devices, and team communication. The tool demonstrated excellent content validity (Index of Item Objective Congruence [IOC] = 0.67–1.0). Each correct answer was awarded 1 point. This assessment was conducted as a pre-test one day prior to the session and as a post-test immediately following completion.

2. **Learners' Perception Survey:** Following the training, a self-reported survey was administered to evaluate perceptions using a 5-point Likert scale (Cronbach's alpha = 0.85). The survey captured perceptions across the briefing, scenario, and debriefing phases, and evaluated the overall impact of the high-fidelity manikin on learning stimulation, enjoyment, and critical thinking.

Regarding skill evaluation, direct observation of clinical and non-technical skills was conducted by instructors during the scenarios. However, this was utilized exclusively for formative feedback during the debriefing phase and was not recorded for summative quantitative analysis.

Statistical Analysis

Statistical analysis was performed using SPSS. The normality of data distribution for continuous variables was initially assessed using the Shapiro-Wilk test. For normally distributed data, such as participants' age, descriptive statistics were reported as mean $\pm$ standard deviation (SD), and comparisons between the Leader and Observer groups were conducted using an independent t-test. Categorical data, such as gender distribution, were analyzed using the Chi-square test.

Given the non-normal distribution of the knowledge scores, nonparametric statistics were utilized for these outcomes. Knowledge scores and Likert-scale perception ratings were reported as median and interquartile range (IQR). Within-group differences between pre-test and post-test knowledge scores were analyzed using the Wilcoxon signed-rank test. Between-group comparisons (Leader vs. Observer) for both knowledge gains and perception ratings were evaluated using the Mann-Whitney U test. In addition,

the magnitude of the change from pre-test to post-test was quantified as the mean difference with its corresponding 95% confidence interval (95% CI). A p-value of < 0.05 was considered statistically significant.

Ethical Considerations

Ethical approval was granted by the Institutional Review Board of Sawanpracharak Hospital (COE No. 32/2568).

Results

A total of 29 fifth-year medical students (Leader group, $n=16$; Observer group, $n=13$) completed the simulation session and all associated assessments. Table 1 presents the baseline characteristics of the participants. The mean age of the cohort was 22.24 ± 0.5 years. There were no statistically significant differences between the Leader and Observer groups regarding age, gender distribution, or baseline knowledge scores (all $p > 0.05$), indicating that the groups were well-matched prior to the intervention.

Table 1 Baseline characteristics and initial knowledge scores of the participants (N=29)

Characteristics	Total (n=29)	Leader (n=16)	Observer (n=13)	p-value
Age (years), Mean $\pm$ SD	22.24 $\pm$ 0.5	22.31 $\pm$ 0.6	22.15 $\pm$ 0.5	0.471
Gender, n (%)				
Male	13 (44.8)	6 (46.20)	7 (53.8)	0.379
Female	16 (55.2)	10 (62.5)	6 (37.5)	
Pre-test Score (Max 10), Median (IQR)	10 (9-10)	10 (9-10)	10 (9-10)	0.918
Pre-test Score (Max 10), Mean $\pm$ SD	9.28 $\pm$ 0.9	9.31 $\pm$ 0.9	9.23 $\pm$ 1	0.831

Knowledge Acquisition Overall knowledge scores significantly increased from a pre-test median of 10 (IQR 9–10) to a post-test median of 10 (IQR 10–10) (mean difference 0.586, 95% CI 0.227–0.946; $p = 0.003$). When comparing the two roles, both the Leader and Observer groups demonstrated significant and nearly identical improvements in knowledge.

There was no statistically significant difference in the post-test scores between Leaders (Median 10, IQR 9–10) and Observers (Median 10, IQR 9–10) ($p = 0.83$). These findings suggest equivalent knowledge acquisition regardless of whether the student assumed an active or observational role (Table 2)

Table 2 Comparison of Mean Knowledge Scores by Role (n=29)

Roles	Statistic	Pre-Test	Post-Test	Mean difference (95% CI)	p-value
Leader (n=16)	Mean $\pm$ SD	9.31 $\pm$ 0.94	9.88 $\pm$ 0.34	0.562 (0.049–	0.034
	Median (IQR)	10 (9-10)	10 (10-10)	1.076)	0.034
Observer (n=13)	Mean $\pm$ SD	9.23 $\pm$ 1.09	9.85 $\pm$ 0.37	0.615 (0.035–	0.040
	Median (IQR)	10 (9-10)	10 (10-10)	1.196)	0.039
Total (n=29)	Mean $\pm$ SD	9.28 $\pm$ 0.99	9.86 $\pm$ 0.35	0.586 (0.227–	0.002
	Median (IQR)	10 (9-10)	10 (10-10)	0.946)	0.003

Learners' Perceptions and Attitudes
The simulation program received consistently high ratings across all perception domains. As shown in Table 3, the mean scores for the briefing, scenario participation, and debriefing phases were uniformly high for both groups. Notably, students in the Observer role

reported substantial levels of satisfaction, particularly regarding the simulation's ability to stimulate learning and enhance critical thinking through directed observation. Comparisons between roles revealed no significant differences in any perception category (all $p > 0.05$).

Table 3 Comparative Learner Perceptions of Simulation-Based Learning Phases (Leader vs. Observer)

Issues	Leader (Mean $\pm$ SD)	Observer (Mean $\pm$ SD)	p-value
Pre-Simulation (Preparation)			
Difficulty of pre-test	3.69 $\pm$ 0.946	3.92 $\pm$ 0.862	0.494
Assigned self-study materials	3.88 $\pm$ 1.258	4.00 $\pm$ 0.707	0.752
Scenario Execution			
Realism, excitement, participation	4.56 $\pm$ 0.512	4.31 $\pm$ 0.480	0.182
Scenario difficulty	4.19 $\pm$ 0.981	4.00 $\pm$ 0.577	0.548
Debriefing (Reflection)			
Suitable atmosphere (no stress)	4.13 $\pm$ 1.310	4.38 $\pm$ 0.650	0.521
Debriefing covered subject matter	4.31 $\pm$ 0.793	4.54 $\pm$ 0.519	0.385

Strategic Sentiment Toward Simulation-Based Learning When evaluating the strategic sentiment regarding simulation as a teaching tool, a distinct "perception gap" was observed, although it did not reach statistical significance (Figure 1). While 100% of Observers strongly agreed or agreed that SBL stimulates learning and promotes comprehensive thinking, a slightly lower proportion of Leaders

(87.5%) shared this sentiment. Most notably, 92.3% of Observers advocated for the expansion of SBL to other clinical subjects, compared to only 62.5% of Leaders ($p = 0.141$). Furthermore, a substantial majority of the overall cohort (89.7%) indicated that simulation training should be introduced earlier in the medical curriculum.

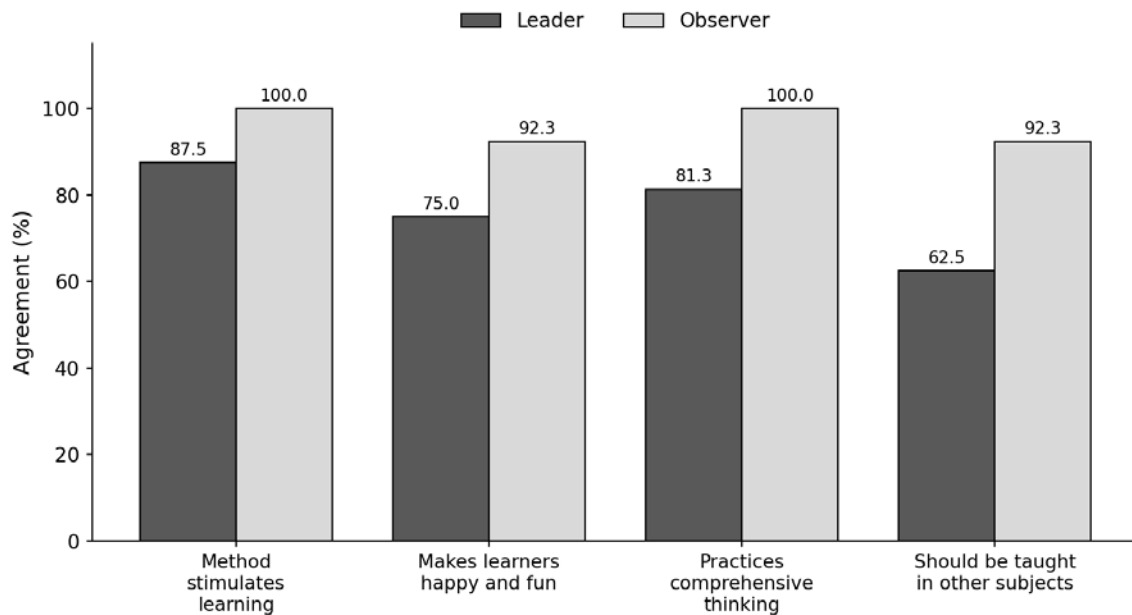


Figure 1 Learner Agreement on Educational Benefits of High-Fidelity Simulation-Based Learning (Leader vs. Observer)

Discussion

The primary findings of this study underscore the effectiveness of high-fidelity simulation in accelerating the cognitive preparedness of novice medical students for high-stakes airway crises. The significant improvement in knowledge scores and the notable reduction in score variance suggest that simulation-based learning (SBL) effectively standardizes knowledge levels toward near-mastery across a diverse student cohort. These findings align with current evidence suggesting that technology-enhanced simulation consistently yields superior knowledge acquisition compared to traditional didactic methods^{6,12}.

Role Equivalence and Learning Theories

A critical observation of this research is the parity in knowledge acquisition between students in the Leader role and those in the Observer role. This "Role Equivalence" suggests that learners can acquire complex behaviors and knowledge vicariously through directed observation, a concept deeply rooted in Social Learning Theory¹³⁻¹⁴. In our study, Observers were not passive; they were cognitively engaged through the pre-briefing and the shared debriefing phase. This engagement facilitates the reflective observation and abstract conceptualization stages of the experiential learning cycle¹⁵, which has been shown

to provide significant educational value in medical school settings¹⁶. Our results are consistent with recent literature suggesting that structured observation is a potent pedagogical tool that allows students to learn without the immediate performance anxiety often experienced by active participants^{10-11,17}.

The "Perception Gap" and Psychological Fidelity

Interestingly, our data revealed a "Perception Gap" regarding the strategic value of simulation. While both groups were highly satisfied, Observers were significantly more likely than Leaders to advocate for the expansion of SBL to other clinical subjects. This may be attributed to the lower cognitive load experienced by Observers, allowing them to step back from the technical pressures of intubation and view the broader pedagogical framework¹¹. Conversely, Leaders likely focused more intensely on technical mastery under stress, which may narrow their immediate perspective on curriculum-wide benefits. However, educators must ensure that such high satisfaction does not lead to overconfidence, which can occasionally occur in high-fidelity simulation environments¹⁸.

The utilization of high-fidelity simulators played a cornerstone role in providing psychological fidelity. By simulating physiological triggers such as rapid desaturation and bradycardia, students were forced to navigate

difficult airway algorithms under realistic pressure¹⁹. This immersion is critical for developing non-technical skills, including situational awareness and team communication²⁰⁻²¹. Furthermore, the use of a structured debriefing model successfully facilitated the transition from individual experience to shared mental models, as emphasized in modern reflective learning frameworks²²⁻²⁴.

Clinical Implications and Limitations

In the context of Thailand, this study demonstrates a successful implementation of a simulation curriculum that aligns with national competency standards for medical graduates⁹ and supports digital literacy initiatives in higher education²⁵. Despite these positive educational outcomes, this study has several limitations that should be acknowledged.

First, the primary limitation is the relatively small sample size (n=29) drawn from a single institution. Although this number reflects the total enrollment of a single academic year cohort at our center—thereby minimizing sampling bias—it may limit the statistical power to detect subtle differences between the leader and observer groups, as well as the overall generalizability of the findings. Second, the pre-test and post-test scores exhibited a skewed distribution, reflecting the high baseline knowledge of the participants and a potential ceiling effect. To address this, non-parametric statistical methods were strictly employed to

ensure the robustness of the data analysis.

Third, a structured instrument for quantitative clinical skill assessment was not utilized. Because this research was integrated into a time-constrained SBL curriculum, instructors focused on formative feedback across multiple holistic competencies beyond just technical skills, including teamwork, decision-making, and crisis resource management. In our setting, detailed technical proficiency is typically evaluated later through formal Objective Structured Clinical Examinations (OSCE).

Finally, this study assessed immediate knowledge gain but did not evaluate long-term retention or the direct transfer of these skills to live patients. Future multicenter, longitudinal research over multiple academic years is recommended to assess skill decay over time²⁶ and to formally incorporate OSCEs for quantitative skill measurement.

Conclusion

High-fidelity simulation-based training significantly improved knowledge of emergency and difficult airway management among novice fifth-year medical students, and learners reported high levels of satisfaction and self-confidence across the briefing, scenario, and debriefing phases. Knowledge improvement and learners' perceptions did not differ between students who took the active Leader role and those in the directed Observer role,

indicating that the two roles produced comparable educational outcomes in this setting.

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