

Effectiveness of in-situ room-of-error simulation on anesthesia ventilator preparation among nurse anesthetist students: A quasi-experimental study

Efficacité d'une simulation in situ par chambre des erreurs sur la préparation du ventilateur d'anesthésie chez les étudiants infirmiers anesthésistes: Une étude quasi-expérimentale

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ABSTRACT

Background: Anesthesia ventilator preparation is essential for ensuring patient safety. The "Room of Error" (ROE) is a low-fidelity simulation method designed to improve patient safety skills. This study aimed to evaluate the effectiveness of in-situ ROE simulation training in improving student nurse anesthetists' clinical performance in anesthesia ventilator preparation and to compare its impact with that of didactic lectures.

Methods: A quasi-experimental pilot study was conducted in a public hospital in Morocco. Thirty-nine nurse anesthesia students were randomly assigned to two groups: an experimental group (n = 20) that received in situ ROE simulation training and a control group (n = 19) that received only lecture-based instruction. Performance was assessed using an author-developed scale. Within- and between-group comparisons were performed using McNemar's and Fisher's exact tests (p < 0.05).

Results: The ROE simulation significantly improved the participants' performance in anesthesia ventilator preparation (p < 0.05). The experimental group demonstrated statistically significant differences in only three anesthesia ventilator preparation procedures: oxygen reserve checks (p < 0.001), anti-pollution system verification (p < 0.001), and suction device testing (p = 0.04).

Conclusion: Students' performance improved after the simulation, indicating effective transfer of learning to the clinical setting. Compared to didactic lectures, the ROE method was more effective in developing critical technical skills related to anesthesia ventilator preparation.

Key words: Room of errors, Simulation-based learning, error detection, Anesthesia ventilator, student nurse anesthetists

RÉSUMÉ

Contexte : La simulation par chambre des erreurs (CdE) est une méthode de simulation de basse fidélité visant à renforcer les compétences en sécurité des soins. Cette étude a évalué l'effet d'une formation par CdE sur les performances cliniques des étudiants infirmiers anesthésistes dans la préparation du ventilateur d'anesthésie en comparaison avec la formation traditionnelle par le cours magistral.

Méthodes : Une étude pilote quasi-expérimentale a été menée dans un hôpital public Marocain. Trente-neuf étudiants infirmiers anesthésistes ont été répartis aléatoirement en deux groupes : un groupe expérimental (n = 20) ayant bénéficié d'une formation de simulation in-situ par CdE, et un groupe contrôle (n = 19) ayant suivi seulement le cours magistral. Les performances ont été évaluées à l'aide d'une grille élaborée par les auteurs. Les comparaisons intra- et intergroupes ont été réalisées à l'aide des tests de McNemar et de Fisher (p < 0,05).

Résultats : La formation par CdE a significativement amélioré les performances des participants dans la préparation et la vérification du respirateur (p < 0,05). Des différences significatives entre les deux groupes ont été relevées uniquement sur trois procédures clés sur douze : vérification des réserves d'oxygène (p < 0,001), du système antipollution (p < 0,001) et du dispositif d'aspiration (p = 0,04).

Conclusion : la participation à la formation par Cde a amélioré les performances cliniques des étudiants, confirmant un transfert des apprentissages en contexte réel. Comparée au cours magistral, la CdE s'est révélée plus efficace pour développer des compétences cliniques critiques en préparation du ventilateur d'anesthésie.

Mots-clés : Chambre des erreurs, Apprentissage par simulation, Détection des erreurs, Respirateur d'anesthésie, Étudiant infirmier anesthésiste.

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INTRODUCTION

Medical errors remain a critical concern in healthcare, contributing to an estimated 44,000 to 98,000 deaths annually in the United States (1). In this context, the United States food and drug administration receives over two million reports each year regarding medical devices suspected of causing fatalities, severe injuries, or malfunctions (2). Among these concerns, errors related to equipment failure and human error during anesthesia represent a significant challenge. The anesthesia ventilator plays a pivotal role in surgical procedures; however, its complexity and potential for malfunction contribute to preventable incidents (3). For instance, errors in anesthesia, including breathing circuit disconnects, drug syringe swaps, and gas flow control mistakes, were widely reported, with some leading to adverse patient events (4). Moreover, despite technological advancements in anesthesia equipment, human error remains a leading cause of incidents, often due to insufficient training and usability issues (5).

Consequently, the complexity of anesthesia ventilators necessitates thorough training to ensure proper handling and error management. However, the current clinical training framework has several limitations. Clinical training hours are often limited, preventing students from acquiring adequate practical skills and problem-solving abilities (6). Furthermore, a significant proportion of anesthesia workstation failures and malpractice claims were linked to operating errors, many of which can be prevented through improved training protocols (7). Although checklist-based preoperative systems had successfully reduced equipment-related errors by 48.6% (8), additional educational strategies are required to enhance error recognition and prevention.

To address this gap, simulation-based learning (SBL) has been increasingly integrated into healthcare education as an effective complement to traditional training, such as didactic lectures. SBL provides a controlled environment in which learners can practice skills, recognize errors, and develop problem-solving abilities without putting patients at risk (9). The Institute of Medicine's report "to err is human: building a safer health system" revealed the importance of SBL in fostering a safety culture and improving error management in healthcare (1). SBL has proven particularly effective in anesthesia training, providing hands-on practice through scenarios that replicate real clinical conditions (10). Furthermore, developing errors within a simulated learning environment enhances students' ability to recognize and address mistakes when combined with constructive feedback and supportive learning conditions (11), such as the debriefing simulation phase.

Among the various SBL modalities, the room of errors (ROE) is an innovative pedagogical tool that enhances students' ability to identify and manage errors, promoting patient safety and a positive error culture (12–14). This SBL modality places learners in realistic clinical settings containing intentional, embedded errors. It aims to develop the ability to detect, analyze, and correct safety hazards, foster awareness, and develop critical thinking

skills. This low-fidelity simulation promotes active observation, critical thinking, and teamwork. The ROE is particularly effective for reinforcing patient safety competencies and fostering a culture of vigilance in healthcare practice.

The ROE method has been successfully implemented across various healthcare disciplines, including medicine, nursing, and pharmacy, to help learners develop skills for detecting and preventing medical errors (15,16). Errors in ROE scenarios may involve medication mistakes, improper hand hygiene, malfunctioning medical equipment, or inadequate patient monitoring. Notably, the ROE framework enables participants to engage in experiential learning within a risk-free environment, facilitating skill acquisition and reinforcing the best practices.

In this context, nurse anesthetists play a pivotal role in ensuring patient safety throughout the perioperative anesthesia process. One of their key responsibilities is to ensure the consistent and appropriate implementation of the WHO surgical safety checklist, even in emergency situations. Their active involvement enhances adherence to safety practices, reduces error rates, and fosters a robust safety culture within the surgical team (17). In addition, nurse anesthetists enhance patient safety by preparing and handling the anesthesia ventilator meticulously. This involves verifying that all ventilator parts are attached properly, altering settings based on the current clinical status of the patient, and ensuring that the alarm systems and backup measures are in place in case of equipment malfunction (18). This equipment's preparation and checking procedures are essential for checking that the equipment is functioning properly and anticipating potential respiratory complications (19).

Despite the effectiveness of SBL in healthcare, research on the application of the ROE method in anesthesia ventilator preparation remains scarce. To our knowledge, no studies have specifically investigated the effect of ROE simulation on anesthesia ventilator preparation. Given the critical role of anesthesia ventilators in patient safety, this study aimed to evaluate the effectiveness of in-situ ROE simulation training in improving clinical performance in anesthesia ventilator preparation. In addition, it compared the effectiveness of the ROE simulation to that of didactic lectures in the context of preoperative mechanical ventilation.

METHODS

Study design

The study used a quasi-experimental design with two parallel groups: experimental and control.

Study setting

The study was conducted in a public hospital in Laayoune, Morocco, specializing in otorhinolaryngology, ophthalmology, and neurosurgery. In addition to providing specialized healthcare services, the hospital provides clinical training for healthcare students, including those

enrolled in nursing programs that specialize in anesthesia.

Study duration

The study lasted two months, from April 1 to June 30, 2024.

Participants

We enrolled 39 second-year undergraduate nurse anesthetist students, all of whom had previously completed a 50-hour didactic course on Anesthesia Equipment and Artificial Ventilation. This study represented their first exposure to SBL. Students were allocated to the control group (CG; $n = 19$) and the experimental group (EG; $n = 20$) through simple randomization using Excel's random function and the class list (numbered 1–39). During the simulation, two EG participants were absent, resulting in a final EG sample of 18 students. Consequently, the total number of participants was 37 (Fig. 1).

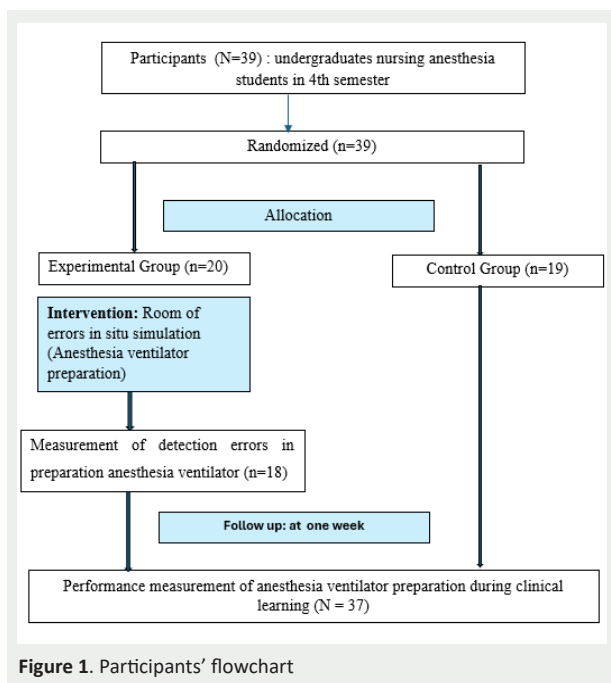


Figure 1. Participants' flowchart

Data collection

The self-developed scale was conceived based on the recommendations of the French society of anesthesia and intensive care entitled "the anesthesia machine and checking before use" (20). It included 12 items that addressed key procedures of the anesthesia ventilator preparation and verification. These included verification of gas and ventilator connections, pressure verification, oxygen reserve, manual ventilation and pollutant gas evacuation systems, and suction device testing. These 12 checklist items were also served as the basis for creating 12 corresponding simulated errors, which were embedded into the scenario for performance assessment. The total performance score for error detection was obtained by summing item scores, where a detected error was scored as one point and missed or unmentioned error as zero point. Participants' performance in the preparation and

verification of the anesthesia ventilator in clinical settings was assessed using this self-developed scale. The internal reliability of this tool among our sample was assessed with a Cronbach alpha of 0.77.

Data analysis

The data analysis was performed using Jamovi software (version 2.3.12). Descriptive statistics were performed to summarize participants' sociodemographic characteristics and errors' detection results. A paired non-parametric McNemar test was used to compare pre-test and post-training outcomes within the EG, while Fisher's exact test was applied to compare proportions between the experimental and control groups. A significance level of $p < 0.05$ was adopted.

Ethical consideration

Participation in this study was voluntary. Before data collection, written consent was obtained from all participants after providing them with a full explanation of the study's objectives and procedures. Furthermore, Approval for the study was obtained from the director of the training institution and the director of the public specialty hospital, the site of the in-situ Room of Errors simulation. In addition, the participants were clearly informed that they could withdraw from the study at any time without any academic or personal consequences. Moreover, it was emphasized that the results of the post-training performance assessments would have no impact on their academic evaluations. All procedures were carried out in accordance with the ethical principles of the Declaration of Helsinki.

Procedures

One week before the training, all students visited the hospital's operating room, the study setting, which was equipped with an anesthesia ventilator and the necessary mechanical ventilation equipment. This visit served as a pre-briefing session to familiarize participants with the environment. Participants were then randomized into an EG ($n=20$) and a CG ($n=19$) using Excel's random function, based on the numbered class list. This study was conducted at a public teaching hospital specializing in otorhinolaryngology, neurosurgery, and ophthalmology in Laayoune, southern Morocco. The simulation training was conducted by two nurse anesthetists and a professor of anesthesia. The team designed the simulation scenario, developed the assessment scale and analyzed the participants' performance.

The training featured a single half-day practical session. Participants were undergraduate students with no pre-simulation practical experience in preparing mechanical ventilation equipment for anesthesia or intensive care contexts. To prevent information exchange between participants, all smartphones and electronic devices were collected prior to the simulation, and each active participant in the ROE scenario waited in a separate location until debriefing. Each participant in the EG was

given six minutes to identify and record errors related to the preparation of the anesthesia ventilator.

The simulated scenario focused on the preparation of the anesthesia ventilator for general anesthesia in a 39-year-old male patient scheduled for tonsillectomy, with no relevant medical or surgical history. The learning objectives targeted technical skills (equipment check and setup according to safety standards) and non-technical skills (situational awareness). The scenario was developed using the cognitive aid template for designing simulation sessions in healthcare, provided by the French society for simulation in healthcare (SoFraSim) (21). Prior implementation, the scenario was reviewed and validated by two medical educators with expertise in SBL. The ROE simulation included three main phases: pre-briefing, simulation scenario: error detection, and debriefing (Fig. 2). The pre-briefing involved an orientation session in the operating room. The briefing was conducted at the entrance of the operating room and lasted 5 minutes. The debriefing was carried out by a single facilitator and lasted 35 minutes. The facilitator reviewed detected and undetected errors, explained the best practices, and discussed appropriate corrective actions. The session concluded with a discussion of measures to prevent adverse events in anesthesia ventilator preparation.

Furthermore, an actual anesthesia workstation was prepared with twelve intentional errors, physically recreated according to the key recommendations from the french society of anesthesia and intensive care (20) regarding the "anesthesia machine and its verification before use". The errors included: anesthesia ventilator not connected to the electrical power supply; gas supply hoses incorrectly connected to the wall outlets; manometer displaying a drop in medical air pressure and complete loss of nitrous oxide supply; empty reserve oxygen cylinder; leak in the main breathing circuit tubing; expired gas sampling line not connected; exhausted soda lime canister; inappropriate manual breathing circuit (pediatric circuit for an adult patient); absence of a waste gas scavenging system; empty halogenated anesthetic vaporizer; insufficient suction pressure; and electric suction unit not connected. The identified errors were recorded on an individual scoring sheet assigned to each participant.

Performance evaluation of error detection in the experimental group was conducted by the study authors. Each participant's score was calculated based on the total number of correctly identified errors during the ROE simulation session (correctly identified = 1; not identified or falsely identified = 0). Post-simulation evaluation for all participants in the clinical setting was performed one week later, on the first day of the clinical internship for the module preparing the operating room for general anesthesia. No intermediate clinical performance assessments were conducted between the simulation day and the post-test evaluation.

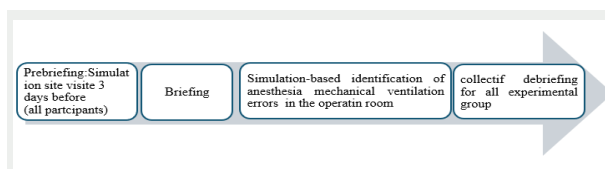


Figure 2. Steps of the in-situ simulation using the Room of Errors for anesthesia ventilator preparation

Data analysis

Statistical analysis was carried out using the computer software Jamovi (version 2.3). Descriptive statistical analysis was conducted on the sociodemographic characteristics of the participants (n=37), including frequency distributions, percentages, and appropriate measures of central tendency. A paired comparison performed in the EG between performance in the ROE simulation and in the clinical setting, with McNemar's test applied due to the dichotomous nature of the variables and the non-normal distribution of the data. Finally, a comparison between the EG and CG groups was carried out using Fisher's exact test, adapted for contingency table analysis with small numbers and for comparison of proportions between two independent groups. The significance level was set at $p < 0.05$.

RESULTS

Participants' characteristics

Table 1 shows the participants' characteristics. A total of 39 students were initially recruited, but two were excluded due to incomplete participation. Consequently, the final sample consisted of 37 students. All participants had no previous experience of SBL. The median age of participants was 21 years [IQR: 20-22]. Most participants were female (n = 26, 70.3%), while males accounted for 29.7% (n = 11). In terms of nationality, Moroccan students were the predominant group (n = 32, 86.5%). The other participants were originally from various African countries, including Zambia (n = 2, 5.4%), São Tomé (n = 1, 2.7%), Burundi (n = 1, 2.7%) and Equatorial Guinea (n = 1, 2.7%).

Table 1. Participants' characteristics

Variables	N=37
Age* (years)	21[20,22]
Gender**:	
• Male	11(29.7)
• Female	26(70.3)
Nationality**:	
• Moroccan	32(86.5)
• São Toméan	1(2.7)
• Zambian	2(5.4)
• Burundian	1(2.7)
• Equatoguinean	1(2.7)

* Median [Q25,Q75] ; ** n(%)

Experimental group performance in anesthesia ventilator preparation: simulation vs. clinical learning

Table 2 presents the results of the comparison between the ROE simulation and clinical anesthesia ventilator preparation performance for the EG. All assessed items showed statistically significant differences, with most items demonstrating improved performance in the clinical setting compared to the simulation ($p < 0.05$). For example, ventilator connection performance increased from 33.4% during simulation to 100% in clinical practice ($p < 0.001$). Medical gas connection improved from 27.78% to 94.45% ($p < 0.001$), and pressure control increased from 38.89% to 66.7% ($p = 0.003$). Other improvements included oxygen cylinder availability (16.7% to 77.78%, $p < 0.001$), ventilator circuit leak test (33.34% to 88.89%, $p < 0.001$), exhaled gas sampling system verification (33.34% to 66.67%, $p = 0.002$), soda lime verification (50% to 83.34%, $p = 0.001$), manual ventilation circuit accessories (27.78% to 72.22%, $p < 0.001$), suction device connection (44.44% to 89.89%, $p < 0.001$), and suction device testing (22.22% to 55.56%, $p = 0.002$). Two items showed a significant decrease in performance in the clinical setting: anti-pollution system (83.34% to 66.7%, $p = 0.031$) and checking anesthetic fluids (77.78% to 61.11%, $p = 0.029$).

Table 2. Performance evaluation of the experimental group in anesthesia ventilator preparation across simulation and clinical learning (n=17)

Items	Simulation training*	Clinical Training*	p**
1. Ventilator Connection	6(33.4)	18 (100)	< 0.001
2. Medical Gas Connection	5(27.78)	17(94.45)	< 0.001
3. Pressure Check	7(38.89)	12 (66.7)	0.003
4. Oxygen Reserve Check	3(16.7)	14(77.78)	< 0.001
5. Pipeline Leak Test	6(33.34)	16 (88.89)	< 0.001
6. exhaled gas sampling system	6 (33.34)	12(66.67)	0.002
7. Soda Lime Check	9(50)	15(83.34)	0.001
8. Manual Ventilation Circuit Accessory	5(27.78)	13(72.22)	< 0.001
9. Anti-Pollution System	15 (83.34)	12(66.7)	0.031
10. Anesthetic Liquid Check	14 (77.78)	11(61.11)	0.029
11. Suction Device Connection	8(44.44)	16(89.89)	< 0.001
12. Suction Device Test	4(22.22)	12(55.56)	0.002

* n(%); p value considered significant at < .05

Comparison between experimental and CG performance on anesthesia ventilator preparation in clinical learning

Table 3 presents the comparison of performance between the experimental group (EG) and the control group (CG) in anesthesia ventilator preparation, assessed in the clinical setting following the ROE intervention. Statistically significant difference was observed between the EG and the CG in the following tasks: "checking oxygen reserves" (EG: 14 [37.84%] vs. CG: 5 [13.5%], $p < 0.001$), "checking the anti-pollution system" (EG: 12 [32.43%] vs. CG: 2 [5.4%], $p < 0.001$) and "testing the suction device" (EG: 12 [32.43%] vs. CG: 18 [48.6%], $p = 0.04$). Furthermore, No

statistically significant differences were observed for the other items, including the ventilator electrical connection ($p = 1.00$), the medical gas connection ($p = 0.34$), pressure control ($p = 0.27$), the duct leak test ($p = 0.23$), the expired gas sampling system ($p = 0.05$), soda lime control ($p = 0.59$), manual ventilation circuit accessory ($p = 0.73$), anesthetic fluid control ($p = 0.06$), and suction device connection ($p = 0.60$).

Table 3. Comparison between experimental and CG performance on anesthesia ventilator preparation in clinical settings

	CG*(n=19)	EG* (n=18)	P**
1. Ventilator electrical connection	18(48.6)	18 (48.6)	1.00
2. Medical Gas Connection	15(40.5)	17(46)	0.34
3. Pressure Check	16(43.2)	12 (32.43)	0.27
4. Oxygen Reserve Check	5(13.5)	14(37.84)	<0.001
5. Pipeline Leak Test	13(35.1)	16 (43.24)	0.23
6. Exhaled Gas Sampling System	6(16.2)	12(32.43)	0.05
7. Soda Lime Check	13(35.1)	15(40.54)	0.45
8. Manual Ventilation Circuit Accessory	12(32.4)	13(35.13)	0.73
9. Anti-Pollution System	2(5.4)	12(32.43)	<0.001
10. Anesthetic Liquid Check	17(45.9)	11(29.73)	0.06
11. Suction Device Connection	18(48.6)	16(43.24)	0.60
12. Suction Device Test	18(48.6)	12(32.43)	0.04

* n(%); ** p value considered significant at <.05 ; n=37

DISCUSSION

The aim of this study was to evaluate the effectiveness of ROE -based teaching approach in improving the learning of anesthesia ventilator preparation and verification procedures and to compare its impact with that of didactic lecture. The results demonstrated that participants in the EG showed significant improvement in overall clinical performance across all procedures related to anesthesia ventilator preparation. When comparing the experimental and control groups, a statistically significant difference in favor of the EG was observed in three out of twelve key procedures: "oxygen reserve checks", "checking the anti-pollution system" and "testing the suction device". No significant differences were found between the two groups for the remaining nine procedures.

Effect of Error Room Simulation on Clinical Performance

The improved clinical performance observed among participants following ROE-based training aligns with previous evidence supporting the effectiveness of error-based simulation in enhancing clinical performance and promoting patient safety practices. Our findings are consistent with those of Park (23), who reported that simulation-based mechanical ventilation scenarios significantly improved the clinical competence of nursing students, particularly in error detection and critical care management. Furthermore, the study of studies focused specifically on Error Room simulation (24) have

demonstrated its positive impact on nursing students' clinical performance, particularly regarding medication error detection, infection control, and management of mechanical ventilation and anesthesia.

Similarly, our positive results may also be attributed to the immersive in situ, high-fidelity simulation, which has been shown to significantly enhance students' clinical knowledge, error detection, and clinical judgment related to mechanical ventilation leading to improved clinical performance during ventilator preparation (25).

The demonstrated positive impact of ROE-based training on clinical performance in anesthesia ventilator preparation should be carefully considered by nurse anesthesia educators, particularly in resource-limited settings. The error room approach is a pedagogical strategy that can be implemented with minimal resources while still fostering awareness and equipping nursing students with essential clinical competencies for early error detection in anesthesia equipment, particularly mechanical ventilation, and promoting a strong culture of patient safety. Drawing on Kolb's experiential learning theory (24) and the principles of deliberate practice (13), the ROE training engages learners actively in risk-focused scenarios, promoting not only procedural memory but also adaptive expertise.

Comparison Between didactic lecture and ROE simulation

While didactic lecture ensures a baseline level of competence in ventilator preparation, our results suggest that ROE simulation provides additional value by acquisition of safety-critical skills. The observed enhanced performance of the ROE group in three key safety-related procedures highlights the potential of this targeted simulation strategy to effectively address documented vulnerabilities in anesthesia practice (26,27). This result aligns with prior evidence suggesting that didactic lecture does not adequately prepare learners for recognizing and managing latent errors in procedural workflows (28). However, no significant differences were observed in nine out of the twelve procedural tasks related to ventilator preparation. This finding may be attributable to limitations commonly observed among novice learners in SBL experience: They had no prior experience with simulation-based learning and are vulnerable to cognitive overload during immersive simulation activities (26). These factors may have impacted their ability to fully transfer learning across all procedure domains within the scope of this study.

In summary, this study demonstrates that ROE simulation is an effective, targeted pedagogical strategy for improving safety-critical skills in anesthesia ventilator preparation. While didactic lecture method ensures baseline competence, ROE uniquely enhances vigilance and error detection in procedures where latent risks are highest, reinforcing its value in health professions education. Furthermore, the decline in performance for certain items could be explained by cognitive overload during the immersive simulation (27) and participants' novice status in simulation (28).

Limitations

There are several limitations in this pilot study. The small sample size and single-center design led us to believe that the results of our study were not generalizable to the entire Moroccan nursing student population. Second, we applied a self-designed checklist made in accordance with the French recommendations on preparation of anesthesia ventilator. However, the instrument lacks validation for a large sample size of Moroccan nursing students' population and needs further psychometric validation. Third, learning outcomes were only evaluated during the immediate post-simulation phase only and at short-term follow-up at one week. Furthermore, all the participating were novices in simulation based learning, and mechanical ventilation preparation in clinical setting, which could have made it more difficult for some participants, because of anxiety or the complexity of the clinical learning environment. Lastly, the learning objectives were limited to recognition of errors, not measuring other key skills like critical thinking, decision-making, and communication.

CONCLUSION

Our study concluded that the ROE simulation training significantly improved anesthesia nursing students' ventilator preparation skills, with effective transfer to clinical practice. Moreover, the study also found that the ROE simulation training was beneficial for improving performance during safety-critical procedures, particularly for anesthesia mechanical ventilation. Furthermore, the identification of specific errors, or the failure to recognize them, is considered a valuable opportunity for nurse educators to lead a discussion that can reinforce learning outcomes during error-based learning. Overall, the findings suggest that the ROE method could promote a positive transfer of skills to the clinical setting, while conferring a selective advantage over didactic lecture for certain verification and preparation tasks. Therefore, future studies with larger samples should explore the long-term effects of the ROE on clinical outcomes, such as error rates and patient safety indicators.

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