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Design and Evaluation of Virtual Reality Educational Content for Managing Multiple Trauma Victims in Emergency Medicine Students of Iranshahr

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ABSTRACT

Background: Effective trauma management requires specialized skills, and advanced technologies such as Virtual Reality (VR) can enhance medical education. This study aimed to evaluate the effectiveness of VR-based educational content in training emergency medicine students on managing multiple trauma victims.

Materials and Methods: This educational study involved 40 emergency medicine students who were randomly assigned to two groups. The first group underwent VR-based training in pairs (two students per team) over four sessions, focusing on multiple trauma scenarios. The second group practiced scenario simulations using moulages. Both groups received feedback after each session and had the opportunity to repeat the scenarios.

Results: In this study, the performance of 40 emergency medicine students was evaluated using pre- and post-tests. The results demonstrated that both educational methods—Virtual Reality and live simulation—significantly enhanced student performance. A comparison between the two approaches revealed no significant difference in effectiveness, as both methods led to comparable improvements.

Conclusion: Virtual Reality was recognized as an effective tool for teaching trauma management and could be widely used in clinical education. However, further studies are necessary for a more comprehensive evaluation and to establish the effectiveness of this technology in educational settings.

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Introduction

Trauma refers to severe psychological or physical experiences that individuals encounter when exposed to events such as accidents, violence, war, natural disasters, abuse, or the loss of loved ones (1). These experiences can have profound and long-lasting effects on both mental and physical health. Trauma is generally categorized into psychological and physical types, with severity depending on various factors, including the intensity of the injury and the individual's pre-existing health status (2, 3). Among the different types of trauma, multiple trauma holds particular significance, with accidents being the most common cause (4). In 2018, Iran ranked fifth globally for road accidents, reporting a mortality rate of 20.5 per 100,000 people (5). Despite significant advancements in trauma education and care over the past four

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decades, multiple trauma remains the leading cause of death among individuals under 44 years of age worldwide (6). Multiple trauma victims sustain simultaneous injuries to various body regions due to severe incidents such as motor vehicle accidents (7). A defining characteristic of these injuries is the concurrent damage to multiple organ systems, including the musculoskeletal system, nervous system, and internal organs (8). High-speed traffic accidents are among the most common causes, often resulting in direct collisions, rollovers, or ejection of occupants (9). The severity of injuries in multiple trauma victims depends on the location and extent of the damage. In addition to localized injuries, systemic complications such as internal bleeding, hypotension, impaired oxygenation, brain trauma, and life-threatening conditions—including loss of consciousness and neurological disorders—may occur (10).

Multiple trauma victims require specialized emergency care and initial interventions under the supervision of a multidisciplinary team. This team typically consists of physicians, nurses, paramedics, and other specialists, each playing a critical role in patient assessment and treatment. The expertise of emergency medical personnel in the early stages—such as proper patient handling, accurate injury identification, stabilization, and hemorrhage control—can significantly influence survival outcomes (11). Patient handling and transportation techniques are crucial, as improper movement may exacerbate injuries (12). Targeted training of emergency medical students and developing highly skilled personnel are essential strategies for improving trauma management, reducing mortality, and minimizing complications and long-term disabilities within healthcare systems (13). Traditionally, a significant portion of clinical skills training, particularly trauma management at accident scenes or in emergency departments, has been conducted directly on actual patients. While this method provides valuable hands-on learning, it also poses risks to patients, students, and instructors. Potential adverse consequences include irreparable harm to patients due to errors made during training, as well as heightened stress and anxiety among students, which may hinder learning and reduce confidence (14). In contrast, rapid advancements in medical sciences and the increasing volume of information have created opportunities to reassess educational methods and integrate innovative approaches to enhance medical training (15).

Simulation-based education is increasingly recognized as an innovative approach in medical sciences. This method allows learners to practice practical skills and decision-making in simulated conditions, replicating clinical experiences without exposing actual patients to risk (16). Medical simulation encompasses various modalities, including mannequin-based simulation, scenario-based simulation, virtual reality (VR)-based simulation, game-based simulation, and hybrid simulation, each with unique advantages and challenges (16-19). VR technology immerses users in a virtual environment where they interact by moving their head and body, creating a bridge between the real and cognitive worlds (20). Simulation-based training enables learners to develop technical skills by replicating clinical scenarios without the inherent risks of fundamental patient interactions. The primary goal of VR is to enhance the sense of presence in the virtual environment, making it both immersive and interactive (21). VR also provides sensory feedback, such as visual and auditory cues, which improve situational awareness and teamwork—critical components of medical education (22). The effectiveness of VR-based education in enhancing trauma care has been demonstrated in numerous studies (23-25). However, these studies often face limitations, particularly in addressing the specific educational needs of developing countries. One of the key challenges is the lack of comprehensive needs assessment in the design of VR-based training programs. Therefore, this study aims to design, implement, and evaluate VR-based educational content for teaching trauma management to emergency medicine students responding to accidents.

Materials and Methods

2.1. Study Design

This educational design research aimed to develop, implement, and evaluate virtual reality (VR)-based content for teaching trauma management to multiple trauma victims, from accidents to emergency medical students. The study was conducted at the Clinical Skills Center of Iranshahr University of Medical Sciences. Before enrollment, written informed consent was obtained from all participants.

This educational design research aimed to develop, implement, and evaluate virtual reality (VR)-based content for teaching trauma management to multiple trauma victims, from accidents to emergency medical students. The study used the ADDIE instructional design model (26), which consists of five main phases: Analysis, Design, Development, Implementation, and Evaluation. Each phase is described in detail below.

2.2. Step 1: Analysis

To develop a practical virtual reality (VR)-based teaching method for trauma management, it was essential to identify the root causes of existing challenges and assess the current competence of emergency medical students. Data were collected through a structured survey and an educational needs assessment conducted with senior undergraduate emergency medical students at Iranshahr University of Medical Sciences. The inclusion criteria for the needs assessment phase required students who had completed theoretical courses in trauma management and were in their final year of the emergency medical program. Exclusion criteria included students with prior experience in pre-hospital emergency care or those who had previously participated in similar trauma courses.

For data collection, a questionnaire was designed to identify challenges in teaching methods, opportunities for practice and repetition, educational environment limitations, and training equipment shortages. A practical assessment was conducted at the Clinical Skills Center, where students performed initial trauma management procedures on simulated patients. Trained evaluators assessed student performance using validated checklists.

2.2. Step 2: Design

A specialized committee comprising experts in medical education, emergency medicine, e-learning, and experienced pre-hospital emergency staff was formed to analyze the survey and needs assessment results. Based on the identified gaps, educational scenarios were developed to closely simulate real-world trauma patient management. The expected competencies were derived from the national emergency medical curriculum. Additionally, assessment methods were established to evaluate the educational objectives of each scenario, ensuring alignment with the practical competencies required for trauma management.

2.2. Step 3: Development

Following scenario development, scripts and storyboards were created for VR implementation. These scripts were reviewed for feasibility before being handed over to a VR engineer for development. The initial VR content was tested and iteratively refined based on expert feedback. The final VR simulation provided an interactive, case-based learning experience, enabling students to make clinical decisions using VR controllers while receiving auditory and text-based feedback.

2.2. Step 4: Implementation

A total of 40 undergraduate emergency medical students were recruited for the educational intervention. Participants were selected based on specific inclusion criteria, including completing theoretical courses in trauma management and prerequisite units. Exclusion criteria included prior participation in similar courses or hands-on experience in pre-hospital emergency care.

Participants were randomly assigned to VR-based training (n = 20) and live simulation using mannequins (n = 20). Randomization was conducted using a computerized random sequence generator. In the VR group, students attended sessions at the Clinical Skills Center in pairs, engaging in VR-based trauma management scenarios using head-mounted displays and motion controllers. They were allowed to repeat each scenario thrice and received immediate feedback from faculty facilitators. In the live simulation group, students performed comparable trauma scenarios on high-fidelity mannequins under faculty supervision, with opportunities for scenario repetition and feedback.

2.2. Step 5: Evaluation

Performance assessment was conducted using a workplace-based evaluation before and after the intervention. A simulated accident scene was designed to replicate real-life conditions closely. The evaluation scenario aligned with the training scenarios, requiring students to perform trauma management procedures. Each student's performance was assessed using a validated checklist developed by Falaki et al., with items weighted according to the clinical importance of each step in trauma management. A panel of 10 emergency medicine professors confirmed the checklist's validity and reliability before implementation.

The evaluation included a pre-test and a post-test conducted using mannequins and patient simulators. To enhance realism, the post-test was performed in a simulated accident scene. Performance was assessed based on accuracy, sequence of actions, and adherence to clinical guidelines.

2.3. Statistical Analysis

Data were analyzed using SPSS software version 25. Descriptive statistics, including mean and standard deviation, were calculated for pre-test and post-test scores in both groups. A Paired Sample t-test was conducted to compare pre- and post-test performance within each group, testing the hypothesis that no significant difference existed between pre- and post-intervention scores. An Independent Sample t-test was used to compare post-test scores between the VR and live simulation groups. To control for pre-test score variations and examine adjusted post-test differences, Analysis of Covariance (ANCOVA) was applied. A significance level of 0.05 was set for all statistical tests (27).

Results

Based on the needs assessment results, deficiencies and limitations in emergency medical students' abilities to manage multiple trauma patients were identified. These deficiencies were evaluated as follows:

1. Cervical Immobilization
Identified Deficiency: Students' inability to properly apply cervical immobilization techniques using a cervical collar or other available tools.
Evaluation Process Explanation: In the multiple trauma patient simulation, some students struggled to position the cervical collar correctly and stabilize the neck. Evaluators identified this deficiency using a standardized checklist.

2. Airway Management (if needed)
Identified Deficiency: Weakness in assessing airway obstruction and applying appropriate methods, such as the chin-lift maneuver or insertion of airway devices (e.g., airway guides or endotracheal tubes).
Evaluation Process Explanation: In the simulation, students showed deficiencies in creating and maintaining an open airway, particularly in emergencies, which was identified by assessing initial actions and the time taken to perform them.

3. Oxygen Administration
Identified Deficiency: Lack of awareness or proficiency in selecting and using appropriate oxygen delivery devices (e.g., face mask or cannula) at the correct flow rate.
Evaluation Process Explanation: Evaluators noted that some students failed to select the appropriate oxygen delivery device or set the correct flow rate. This deficiency was identified using the evaluation checklist.

4. Peripheral Venous Access
Identified Deficiency: Weakness in quickly and adequately finding and cannulating peripheral veins.
Evaluation Process Explanation: In the simulation, many students took excessive time to cannulate veins or could not perform the procedure effectively.

5. External Bleeding Control
Identified Deficiency: Inability to apply appropriate techniques for controlling external bleeding, such as direct pressure or a tourniquet.
Evaluation Process Explanation: Some students performed inadequate or incorrect interventions in the simulation of a patient with external bleeding. This deficiency was documented using the evaluation checklist.

6. Spinal Immobilization
Identified Deficiency: Lack of familiarity with correct spinal immobilization methods (e.g., using a backboard or rolling the patient).
Evaluation Process Explanation: In the patient transfer simulation, students lacked coordination within the team and did not use proper techniques, which led to deficiencies.

7. Intravenous Fluid Administration
Identified Deficiency: Weakness in selecting the appropriate type of intravenous fluids, establishing an infusion line, and managing the fluid infusion rate.
Evaluation Process Explanation: Some students struggled to determine the correct infusion rate or select the appropriate intravenous fluid in the simulated patient management.

8. Limb Fracture Immobilization
Identified Deficiency: Inability to use splints or similar devices to immobilize fractures effectively.
Evaluation Process Explanation: Many students had difficulty choosing and applying immobilization tools in the limb fracture simulation.

9. Vital Signs Monitoring
Identified Deficiency: Inaccuracy in recording vital signs such as blood pressure, heart rate, and oxygen saturation.
Evaluation Process Explanation: Some students made errors in using measuring devices or in recording vital sign results.

This study employed two educational methods—virtual reality and mannequin-based simulation—to enhance emergency medical students' skills in managing multiple trauma patients (Table 1). The results demonstrated that both methods positively impacted students' performance.

Table 1. Identified educational goals based on identified needs for educational intervention

No.	Item	Goal
1	Cervical spine immobilization	The student must correctly apply a cervical collar within two minutes under simulated conditions while adhering to cervical spine immobilization principles.
2	Establish an airway	The student must assess airway obstruction under simulated conditions and correctly apply the most appropriate technique or device (e.g., airway guide or endotracheal tube) to establish an open airway within three minutes.
3	Oxygen administration	The student must select the appropriate oxygen delivery device and adjust the oxygen flow rate according to the patient's condition under simulated conditions.
4	Peripheral vein	The student must identify a suitable peripheral vein and successfully cannulate it within three minutes under simulated conditions.
5	Control of external bleeding	Within two minutes, the student must control external bleeding under simulated conditions using direct pressure, sterile gauze, or a tourniquet.
6	Spinal immobilization	The student must immobilize a multiple trauma patient under simulated conditions using the correct rolling technique and a backboard within five minutes.
7	Serum administration	The student must select the appropriate type of intravenous fluid, establish an injection line, and accurately adjust the infusion rate under simulated conditions.
8	Immobilization of a fractured limb	The student must immobilize the patient's injured limb using a splint or appropriate device within four minutes under simulated conditions.
9	Taking vital signs	The student must accurately measure and record the patient's vital signs, including blood pressure, heart rate, and oxygen saturation, within three minutes under simulated conditions.

Below are the detailed explanations and findings of this study:

1. Production of Virtual Reality Content

Virtual reality (VR) content was developed based on identified educational needs. The content featured two patients with different conditions—one critical and one mild—and a highly detailed simulation of a crash scene. A high-quality video was produced using 360-degree equipment and specialized software, demonstrating essential emergency procedures such as cervical immobilization, airway management, bleeding control, and other critical interventions. These videos were provided as VR content, allowing students to interact with the scenes and practice responding to real-life emergencies.

2. Scenario Execution and Evaluation

Accident simulation scenarios and multiple trauma patient management were implemented using educational methods—virtual reality (VR) and mannequin-based simulation. During this phase, pre-test and post-test evaluations were conducted to assess student performance.

Virtual Reality Group: The average pre-test score was 11.67 ± 3.07, while the post-test score increased to 17.20 ± 1.21, demonstrating a significant improvement (P = 0.0034).

Mannequin Group: The average pre-test score was 14.77 ± 0.82, and the post-test score rose to 17.73 ± 0.96, also showing a significant difference (P = 0.0097).

3. Comparison Between the Two Educational Groups

"The independent t-test results comparing post-test scores between the two groups indicated that both educational methods—virtual reality (VR) and mannequin-based simulation—significantly improved student performance. However, no significant difference in post-test performance was observed between the two groups (P = 0.19). Additionally, after controlling for pre-test scores, the ANCOVA test confirmed no significant difference in post-test scores between the two groups (P = 0.211).

The results indicate that both educational methods—virtual reality (VR) and mannequin-based simulation—effectively enhanced students' practical skills in managing multiple trauma patients (Figure 1). However, no significant difference was found between the two methods, suggesting that both can serve as practical educational tools in emergency medical training.

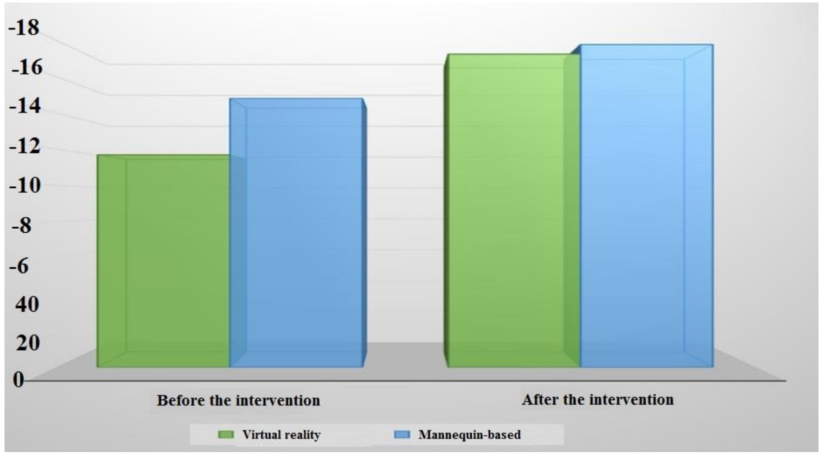

Figure 1: Mean pre-test and post-test scores in the virtual reality group and the mannequin-based group

Discussion

This study is the first to evaluate the impact of two educational methods—virtual reality (VR) and simulation with moulages—on the performance of emergency medical students in managing multiple trauma victims. The results demonstrated a significant increase in average pre-test and post-test scores in both groups ($P < 0.01$), confirming the effectiveness of both methods. However, independent t-tests and ANCOVA revealed no significant difference between the post-test scores of the two groups ($P > 0.05$), suggesting that both educational methods were equally effective in enhancing students' performance.

This study found that both virtual reality (VR) and moulage simulation significantly improved students' performance scores, with no statistically significant difference between the two methods. These findings align with Bahmidi et al. (2022), who compared VR-based training to traditional lectures and observed improved student scores, though the difference was insignificant. However, Bahmidi et al. also assessed student satisfaction and reported that VR increased learner satisfaction—an aspect not explored in the present study (28). While both studies support the effectiveness of VR in medical education, the absence of a significant difference between the two methods underscores the need for further research. Future studies should explore additional factors, such as student satisfaction, motivation, and learning retention, to comprehensively evaluate these educational approaches in clinical settings (28).

The findings of this study contrast with those of Mansouri et al. (2021), who reported that virtual reality (VR)-based serious games were significantly more effective than traditional lectures. A key distinction between the two studies is the use of serious games in Mansouri's research, which incorporated a more interactive approach to engage students, potentially explaining the greater effectiveness observed (29). Furthermore, Mansouri et al. evaluated additional aspects of the learning experience, including usability and students' enthusiasm for learning through VR, whereas our study focused solely on performance outcomes. Incorporating qualitative assessments—such as motivation, enthusiasm, and overall learner experience—could provide a more comprehensive understanding of the effectiveness of these educational methods. Comparing the results of these studies underscores the importance of instructional design features, such as interactivity and motivational elements, in determining the success of modern educational approaches. Future research could incorporate standardized tools, such as the Game Usability Scale, to offer a more thorough evaluation of VR-based learning methods (29).

Both this study and the research by Moradpour et al. (2022) examined the effectiveness of virtual reality (VR) technology in educational settings, yet their findings differed (30). In this study, although both VR and moulage simulation significantly improved student performance, no significant difference was observed between the two methods. In contrast, Moradpour et al. found that VR was significantly more effective in enhancing dental students' scores than traditional methods (30). The two studies' key distinctions are the educational context and intervention design. In Moradpour's study, VR was used to teach specific practical skills (tooth arrangement), which may have effectively leveraged the technology's interactive and 3D visualization capabilities. Conversely, our study focused on multiple trauma management, which may not benefit as much from VR's visual and interactive features as skill-based fields like dentistry (30). Furthermore, Moradpour et al. explored additional factors, such as student satisfaction and faculty approval of VR, which could positively influence its acceptance and effectiveness. Qualitative assessments in future studies—such as satisfaction, engagement, and faculty perspectives—could provide a more comprehensive understanding of VR's role in medical education (30). These findings suggest that the impact of VR technology depends on multiple factors, including instructional design, educational context, and the type of skills being taught. Future research should account for these variables to optimize the implementation and evaluation of VR-based learning methods.

Both this study and the research by Pittel et al. (2020) explored the use of virtual reality (VR) technology in teaching trauma management skills (24). While our study compared the effectiveness of VR and moulage simulation in improving student performance, Pittel's study focused on designing and developing a 360-degree VR training program. This difference in study objectives highlights the diverse applications of VR technology in medical education, ranging from comparative assessments of different training methods to the creation of new educational content (24). Additionally, Pittel's study emphasized interactive and team-based skills, such as teamwork and anticipating the next steps in care planning, adopting an approach that extends beyond individual performance improvement. This focus on collaborative learning could be particularly valuable in designing future training interventions, especially for medical and emergency medicine students preparing to work in team-based clinical settings (24).

This study demonstrated that both educational methods—virtual reality (VR) and moulage simulation—significantly improved students' performance. However, no significant difference was found between the effectiveness of the two methods. These findings align with the study by Harrington et al. (2018), which utilized VR simulation to teach decision-making in trauma management (31). Harrington et al. reported that VR not only reduced medical errors and improved decision-making but was also perceived by participants as an enjoyable and effective learning method (31). The differences in results may stem from variations in intervention objectives and study design. While our study compared the effectiveness of two educational methods, Harrington et al.. focused on validating and evaluating the learning experience with VR. These differences suggest that VR can serve various educational purposes, from teaching technical skills and decision-making to enhancing learner engagement (31). Additionally, Harrington et al. emphasized the reduction of medical errors, a factor directly related to patient safety—an aspect not assessed in the present study. Future research should explore the impact of VR on performance errors and clinical safety by incorporating similar evaluation metrics (31).

This study and Colonna's research explored the application of virtual reality (VR) technology in teaching trauma management skills. However, the objectives and approaches of the two studies differed. While our study compared the effectiveness of VR and moulage simulation in improving student performance, Colonna's study focused on designing and evaluating a new simulator (TVRSim) and assessing its impact on decision-making and practical skills (32). Despite these differences, both studies highlight the potential of VR technology to enhance learning and skill development. In Colonna's study, the TVRSim simulator improved ATLS skills, and participants expressed high satisfaction with its convenience and effectiveness for learning. These findings align with the relatively high satisfaction levels reported in our study regarding VR-based training (32). However, there were notable differences in the evaluation approaches. Colonna's study specifically assessed ten critical decision points and compared performance between experienced surgeons and novice trainees—an analysis not conducted in our study but one that could be considered for future research (32). Furthermore, Colonna's findings suggested that VR technology reduced clinical errors and enhanced decision-making, underscoring the need for further studies examining the impact of VR on reducing performance errors and improving patient safety (32).

This study and the research by Haynesworth both evaluated the effectiveness of virtual reality (VR) in trauma management training, but their objectives and study populations differed. While our study focused on emergency medicine students and compared the effectiveness of VR and moulage simulation in improving performance, Haynesworth's study examined the impact of VR on skill development and anxiety reduction among essential science physicians managing trauma

(33). Despite these differences, both studies demonstrated the benefits of VR in enhancing learner performance. In our study, both the VR and moulage simulation groups significantly improved student performance. Similarly, Haynesworth's study found that physicians in the VR FIIT group completed their tasks more quickly and accurately (33). A notable aspect of Haynesworth's study was the positive impact of VR on reducing learner anxiety, an outcome not evaluated in our research. Since anxiety reduction can contribute to better performance in high-stress situations, future research should explore the psychological effects of VR-based training to provide a more comprehensive understanding of its benefits in trauma education.

This study has several strengths, including directly comparing two educational methods—virtual reality (VR) and moulage simulation—in trauma management training, providing valuable insights into their relative effectiveness. Additionally, using a well-defined cohort of emergency medicine students ensures that the findings directly apply to the target population. However, some limitations should be considered. One limitation is the absence of a longitudinal assessment of learning retention, which would help determine the long-term effectiveness of the interventions. Another limitation is the lack of qualitative data, such as student satisfaction or motivation, which could provide a more comprehensive understanding of the learning experience. Additionally, the study primarily focused on performance outcomes; future research could incorporate other metrics, such as anxiety reduction or clinical error rates, to assess the broader impact of these training methods on clinical safety. Despite these limitations, this study contributes valuable insights into applying VR and moulage simulation in medical education, highlighting their potential as practical training tools.

Strength and limitations

This study has several strengths. One of its main advantages is the direct comparison of two advanced educational methods—virtual reality and moulage simulation—offering valuable insights into their relative effectiveness in trauma management training. Additionally, including emergency medicine students as the study population ensures that the findings directly apply to clinical education. Another notable strength is using a standardized assessment approach to evaluate students' performance before and after the interventions, thereby enhancing the reliability of the results. However, this study also has some limitations. First, it did not assess long-term knowledge retention, leaving uncertainty about whether the observed improvements persist over time. Second, qualitative factors such as student satisfaction, engagement, and motivation were not evaluated, which could provide a more comprehensive understanding of the learning experience. Furthermore, the study focused solely on performance outcomes without considering other critical aspects, such as the impact of these educational methods on reducing medical errors or improving decision-making in real-world clinical settings. Future research should address these limitations by incorporating longitudinal follow-ups, qualitative assessments, and clinical error reduction metrics. This approach would enable a more comprehensive evaluation of the role of virtual reality and moulage simulation in medical education.

Conclusion

The findings of this study indicate that both virtual reality and moulage simulation are practical educational methods for enhancing emergency medicine students' performance in trauma management. The absence of a significant difference between the two methods suggests that virtual reality can be a viable alternative to moulage-based training, offering greater flexibility and an immersive learning experience. While virtual reality has demonstrated potential benefits, such as increased engagement and enhanced realism, its broader impact on clinical competency, decision-making, and patient outcomes warrants further investigation. Future research should prioritize large-scale studies with diverse populations, longitudinal assessments of knowledge retention, and the integration of qualitative measures, including student satisfaction, motivation, and psychological responses. Additionally, evaluating the cost-effectiveness and feasibility of implementing virtual reality in different educational settings will be crucial in determining its practical application in medical training.

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Conflict of interest

There is no conflict of interest.

Author's contribution

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