

# Virtual Reality-Based Splinting Education to Improve Clinical Competence in Managing Open Mid-Shaft Tibia-Fibula Fractures Gustilo-Anderson Grade Iiib: A Clinical Research Study

Edi Mustamsir<sup>1</sup>, Domy Pradana Putra<sup>1\*</sup>, Christopher Daniel Halomoan<sup>1</sup>, Felix Giovanni Hartono<sup>1</sup>

<sup>1</sup> Department of Orthopaedic & Traumatology, Faculty of Medicine, Universitas Brawijaya – Dr. Saiful Anwar General Hospital, Malang, East Java, Indonesia.

\* Corresponding Author: Domy Pradana Putra, Email: [domy\\_pradana@ub.ac.id](mailto:domy_pradana@ub.ac.id)

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## ABSTRACT

**Introduction:** Open tibia-fibula fractures, especially Gustilo-Anderson grade IIB, present significant challenges in trauma care. Early splinting is crucial for stabilizing the injury, but traditional training methods often fail to replicate the complexity of these cases. This study investigates the effectiveness of Virtual Reality (VR)-based training in improving medical trainees' competence in splinting these fractures. This study aims to evaluate the impact of VR-based training on anatomical understanding, procedural skills, and clinical preparedness for managing complex open tibia-fibula fractures.

**Methods:** A pre-experimental pre-post-test study was conducted with 70 medical students who had completed musculoskeletal and basic splinting modules. Participants underwent a VR-based training session, followed by performing splinting on a manikin. Outcome measures included knowledge, procedural skills, perceived relevance, and satisfaction, assessed using pre- and post-test questionnaires, an observer checklist, and a Likert-scale survey.

**Results:** The mean scores across all outcome measures ranged from 4.49 to 4.70, indicating high levels of engagement and satisfaction. The highest score (4.70) was observed for case relevance, suggesting the simulation closely reflected real-world trauma scenarios. High ratings for VR interactivity (4.69) and overall satisfaction (4.61) further affirmed the effectiveness of the VR module.

**Conclusions:** The VR-based splinting module effectively improved clinical comprehension, technical proficiency, and learner engagement. Its integration into orthopaedic and trauma education may strengthen readiness for real-world emergency fracture management and promote active, risk-free procedural learning.

**Keywords:** bone fractures, medical education, simulation training, splints, virtual reality.

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## INTRODUCTION

Open tibia-fibula fractures are among the most complex and high-risk injuries in orthopaedic trauma care, particularly those classified as Gustilo-Anderson grade IIB.<sup>1</sup> These fractures typically occur due to high-energy trauma mechanisms such as vehicular accidents or falls from significant heights. They are characterized by severe soft-tissue destruction, periosteal stripping, and exposed bone fragments, all of which require urgent and coordinated management to prevent infection, limb loss, and other complications.<sup>2</sup>

Proper early splinting plays a crucial role in stabilizing the injured extremity, reducing pain, and preventing further harm before definitive fixation.<sup>3</sup> Despite being a fundamental skill, splinting in the context of complex open fractures is often challenging for trainees, particularly due to the need for precise alignment, sterile technique, and rapid neurovascular assessment under stressful conditions.<sup>4</sup>

The initial management phase for open fractures extends beyond mechanical stabilization and includes an in-depth understanding of anatomical structures and

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injury mechanisms.<sup>5</sup> The tibia's exposed position and minimal soft-tissue coverage make it particularly susceptible to contamination and delayed healing.<sup>6</sup> As such, the effectiveness of splinting directly influences long-term outcomes, such as infection rates, fracture union time, and functional recovery.<sup>7</sup> Traditional teaching methods—lectures, demonstrations, and limited simulation models—fail to replicate the intricate visual-spatial and procedural demands encountered in actual trauma cases.<sup>8</sup>

In response to these challenges, Virtual Reality (VR) has emerged as a promising tool in medical and surgical education, offering an immersive, three-dimensional environment where learners can explore anatomical relationships, rehearse procedural steps, and practice trauma management without risking patient harm.<sup>9-11</sup> Research has shown that VR can enhance spatial cognition, procedural skills, and confidence among orthopaedic trainees.<sup>12-14</sup> Moreover, VR training fosters active participation and improves long-term retention by engaging both cognitive and motor pathways simultaneously.<sup>15-17</sup>

Despite growing evidence supporting VR in orthopaedic simulation, its application in the splinting phase of open fracture management, particularly for complex Gustilo-Anderson grade IIB fractures, remains underexplored. This study aims to address this gap by evaluating the implementation of a VR-based splinting module for orthopaedic trainees. By simulating accident mechanisms, anatomical damage, and the step-by-step immobilization process, this study seeks to determine whether VR can enhance clinical understanding, procedural competence, and satisfaction in managing these challenging injuries.

## METHODS

### Study Design and Participants

This study was a pre-experimental pre-post-test that was conducted at the Innovation Laboratory of Universitas Brawijaya between August 2025 and January 2026. Participants were medical students currently enrolled in the clinical phase of their education at Universitas Brawijaya, who had completed both the musculoskeletal and basic splinting modules. To participate, students needed to be physically capable of performing the splinting procedure on a manikin and willing to engage in the study by providing informed consent. Only those who met these criteria were included in the study. Participants were excluded from the study if they had prior exposure to Virtual Reality (VR) training related explicitly to splinting or trauma management.

Additionally, individuals with visual impairments that could hinder their ability to fully engage with the VR simulation, such as colour blindness or significant visual acuity deficits, were also excluded. Students with musculoskeletal disorders or injuries that could interfere with splinting were not eligible to participate.

### Sample Size Calculation

The sample size was calculated using a power analysis to detect differences in knowledge and procedural skill before and after VR training. Assuming a standard deviation (SD) of 1.5 for pre-test knowledge scores and a minimal detectable difference of 0.5 points, the required sample size was calculated to be 70 participants to achieve 80% power at a 5% significance level ( $\alpha = 0.05$ ). This sample size ensures sufficient power to detect meaningful changes in both knowledge and procedural performance.

### Sampling Method

A convenience sampling method was employed to select participants from medical students at Universitas Brawijaya. Participants were recruited from those attending the clinical phase who met the inclusion criteria. Invitations to participate were extended via email and in-person announcements. To ensure that the sample represented a broad range of experience, no preference was given to students based on prior clinical experience or self-reported competence in splinting techniques.

### Intervention

All participants attended a standardized VR-based training session, which illustrated an open mid-shaft tibia-fibula fracture classified as Gustilo-Anderson grade IIB. The simulation presented a realistic trauma scene, including injury mechanisms, relevant anatomy, and guided splinting steps. Participants could interact with the virtual environment, rehearse the splinting procedure, and receive immediate feedback via the VR system. After the VR session, each participant performed a splinting procedure on a manikin under the supervision of an experienced orthopaedic observer.

### Outcome Measures

In this study, four primary variables were assessed to evaluate the effectiveness of the VR-based splinting training. First, knowledge was measured using validated pre- and post-test questionnaires that assessed participants' understanding of the injury mechanism, relevant anatomical structures, and appropriate splinting techniques. Second, procedural skill was evaluated by trained observers using a checklist that assessed key aspects of the splinting procedure, including correct splint placement, proper alignment, sterilization procedures, pain management,

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and neurovascular assessment. Third, the perceived relevance of the VR training to real-world clinical practice was assessed using a self-administered questionnaire in which participants rated the VR experience's applicability to managing actual trauma cases. Finally, satisfaction was assessed by having participants rate their overall experience, engagement, perceived usefulness, and ease of learning with the VR-based training module. A five-point Likert scale was used to assess all outcomes. All the instruments used for data collection were validated for content accuracy by three orthopaedic specialists to ensure reliability and clarity.

### Statistical Analysis

Data were analyzed using SPSS version 20.0. Mean and standard deviation were calculated for all variables. The Shapiro–Wilk test was used to assess normality. Results are presented descriptively.

### Ethical Approval

This study has been approved by the Dr. Saiful Anwar General Hospital Ethics Commission with number 107/EC/KEPK/03/2026, which was issued on March 10, 2026

## RESULTS

A total of seventy participants completed the VR-based splinting training module and subsequent evaluation. The overall mean values for the outcome measures ranged from 4.49 to 4.70, with relatively small standard deviations, suggesting that participants responded similarly and that the VR training was both highly satisfying and effective. These results reflect a strong consensus among participants on the quality and relevance of the VR-based training. Table 1 presents the descriptive statistics for the study, including the mean and standard deviation for each assessed variable.

**Table 1.** Descriptive Statistics of The Study

Variable	Mean ± SD
Anatomical Understanding	4.64 ± 0.54
Splinting Skill	4.49 ± 0.76
Case Relevance	4.70 ± 0.49
ATLS Principle Comprehension	4.56 ± 0.58
VR Interactivity	4.69 ± 0.55
Graphical Realism	4.54 ± 0.58
Application Navigation	4.56 ± 0.61
Training Duration	4.57 ± 0.65
Training Suitability	4.69 ± 0.53
Overall VR Satisfaction	4.61 ± 0.57

The highest score,  $4.70 \pm 0.49$ , was for case relevance, indicating that the clinical scenarios presented in the VR simulation closely reflected real trauma cases encountered in practice. This suggests that the participants found the simulation closely aligned with clinical competencies needed for effective emergency management, particularly in trauma settings.

Furthermore, VR interactivity ( $4.69 \pm 0.55$ ) and training suitability ( $4.69 \pm 0.53$ ) received high ratings, underscoring the VR module's engaging and realistic nature. These results indicate that the VR training created an immersive, adaptable learning environment that effectively met the needs of junior doctors in trauma education. Other key parameters, such as anatomical understanding ( $4.64 \pm 0.54$ ), ATLS principles comprehension ( $4.56 \pm 0.58$ ), and application navigation ( $4.56 \pm 0.61$ ), also showed strong performance. These values suggest that participants not only found the platform user-friendly but also that the VR experience effectively enhanced their understanding of anatomical structures, fracture mechanisms, and core trauma management principles. While the scores for splinting skill ( $4.49 \pm 0.76$ ) and graphical realism ( $4.54 \pm 0.58$ ) were slightly more variable than the other variables, they still indicated strong performance. The slight variation might be attributed to differences in participants' prior experience with three-dimensional visualization or varying levels of manual dexterity in procedural simulations. Despite this, these results still point to the overall effectiveness of VR training in improving splinting skills and the virtual environment's visual fidelity. The training duration ( $4.57 \pm 0.65$ ) and overall satisfaction ( $4.61 \pm 0.57$ ) also received high ratings, reinforcing the adequacy of the session length and confirming that the VR module provided a comprehensive, rewarding educational experience for the participants.

Taken together, these findings demonstrate that the VR-based splinting application was not only practical and relevant but also highly effective as an educational tool. The consistently high mean scores across all variables emphasize its potential to significantly enhance anatomical comprehension, procedural skills, and clinical preparedness among medical trainees involved in the early management of fractures.

## DISCUSSION

The results of this study demonstrate that the integration of Virtual Reality (VR) into splinting education significantly enhanced participants' understanding of trauma mechanisms, clinical context,

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and procedural confidence in managing open tibia-fibula fractures classified as Gustilo-Anderson grade IIB. The consistently high mean scores across all parameters, ranging from 4.49 to 4.70, reflect strong engagement and a positive perception of the VR-based learning module. Notably, the high ratings for anatomical understanding, ATLS principle comprehension, and case relevance indicate that VR allowed participants to visualize anatomical relationships, recognize mechanisms of injury, and apply appropriate management principles with greater clarity and realism.<sup>18,19</sup>

The immersive nature of VR provides a unique, interactive environment where learners actively engage with three-dimensional anatomical models and dynamic trauma scenarios, rather than passively observing.<sup>20</sup> This active participation closely mirrors real-world clinical conditions, facilitating the simultaneous development of both cognitive and psychomotor competencies. In the context of splinting education, VR's visualizations help learners accurately understand fracture alignment and effectively apply the principle of immobilizing joints above and below the fracture site.<sup>21</sup>

The highest case-relevance score ( $4.70 \pm 0.49$ ) indicates close alignment between the simulated scenarios and actual clinical situations, an essential feature of practical trauma training. This consistency with real-world practice strengthens the educational value of VR-based simulations. VR-based trauma education enhances clinical readiness and decision-making accuracy compared with traditional methods, underscoring the importance of realistic, scenario-based training.<sup>22</sup> Similarly, immersive VR experiences expose trainees to realistic emergency environments, helping them maintain emotional stability and focus during high-pressure procedures.<sup>23</sup>

Furthermore, the high ratings for VR interactivity ( $4.69 \pm 0.55$ ) and overall satisfaction ( $4.61 \pm 0.57$ ) reinforce that participants valued the realism and engagement provided by the VR training. Increased interactivity in educational technology stimulates deeper cognitive processing, which is essential for maintaining learner motivation and enhancing long-term retention. Participants benefited from a guided procedural flow that mirrored clinical workflows, further enhancing the training's effectiveness.<sup>24</sup>

The results of this study align with findings that VR-assisted preoperative planning for tibial fractures significantly improves spatial accuracy and reduces preparation time compared with traditional CT-based approaches.<sup>25</sup> This supports the notion that VR's

educational value extends beyond technical skill acquisition; it enhances case-based reasoning, situational awareness, and contextual learning—key components of orthopaedic training.<sup>22</sup> Moreover, VR offers the unique advantage of allowing repeated engagement with clinical scenarios without patient risk, making it a highly ethical and practical tool for scalable medical education.<sup>26</sup>

From a pedagogical perspective, VR bridges the gap between theoretical knowledge and psychomotor performance by offering a safe, repeatable, and controlled environment for experiential learning.<sup>27</sup> In this study, participants could revisit trauma scenarios, apply learned principles, and receive immediate feedback, aligning with the principles of competency-based medical education. This approach fosters not only technical skills but also the confidence needed to perform real-world procedures.

Despite the promising results, several limitations must be considered. The cross-sectional design of this study limits our ability to assess long-term knowledge retention or performance. Additionally, since the study involved medical students, rather than residents or practicing clinicians, the findings may not be fully generalizable to more experienced healthcare providers. Future studies should employ randomized controlled trials and longitudinal designs to assess the long-term impact of VR-based training on skill retention and real-world clinical outcomes. Overall, this study reinforces the growing evidence that VR represents a valuable innovation in orthopaedic training. By integrating cognitive, affective, and psychomotor learning domains within a single immersive platform, VR enhances not only theoretical understanding but also procedural accuracy and learner engagement. The findings suggest that VR-based splinting training not only prepares trainees for real-world trauma interventions but also represents a transformative pedagogical medium that supports professional competence and preparedness in managing severe open fractures.

## CONCLUSION

This study demonstrates that Virtual Reality (VR)-based training significantly enhances medical trainees' understanding, skills, and confidence in managing complex open tibia-fibula fractures. The high ratings across key outcome measures, such as anatomical understanding and procedural competence, highlight VR's effectiveness in providing an engaging, realistic learning experience. By offering an immersive, interactive environment, VR bridges the gap between

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theoretical knowledge and practical application, improving clinical preparedness for trauma care. Future research, including larger longitudinal studies, is needed to assess the long-term impact of VR-based training on clinical outcomes in real-world settings.

## CONFLICT OF INTEREST

We declare that no competing financial interests or personal relationships could have appeared to influence the work reported in this manuscript.

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## AUTHOR CONTRIBUTION

Edi Mustamsir: Methodology, Supervision, Validation, Writing — review & editing. Domy Pradana Putra: Conceptualization, Writing — original draft, Validation, Supervision. Christopher Daniel Halomoan: Conceptualization, Project Administration, Writing — original draft. Felix Giovanni Hartono: Formal analysis, Visualization, Writing — review & editing.

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