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ORIGINAL ARTICLE

Observational Study

Enhancing orthopaedic competency through simulation: A student-centered approach to bridge educational gaps

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Abstract

BACKGROUND

Orthopedic training, one of the most useful but under-represented specialties in undergraduate medical curricula, has some difficulties in clinical teaching.

AIM

To determine if simulation-based learning (SBL) was effective in enhancing procedural accuracy, skill confidence, and knowledge recall in final-year medical students.

METHODS

This was a cross-sectional observational study performed in the Department of Orthopaedics in a tertiary care teaching hospital with simulation training facilities. The trial was conducted over 2 months (January 2025-February 2025) and was designed to determine the effect of SBL on procedural skills, knowledge

retention, and self-perceived confidence in a group of final-year medical students. The inclusion criterion was undergraduate medical students in their final year who had clinical postings in orthopedics. Convenience sampling was used to recruit 106 students. The sample size was estimated to achieve a post-training 50% improvement ratio in procedural accuracy, a confidence interval of 95%, and an absolute precision of 10%. The simulation sessions included exercises with synthetic bone models, cast equipment, and procedural packs [orthopedic skills: (1) Closed fracture reduction; (2) Application of plaster; and (3) Traction]. Each session consisted of an instructor-led demonstration, practice under supervision, and immediate feedback.

RESULTS

In our study involving 106 final-year medical students, SBL significantly improved procedural accuracy with scores rising from 62.5% to 84.9% ($P < 0.001$). Knowledge retention also improved markedly with post-test scores increasing from 63.4% to 78.2% ($P < 0.001$). Self-reported confidence levels showed a substantial gain, increasing from 4.6 to 8.2 on a 10-point scale. Prior simulation exposure and academic performance ≥ 75% were significantly associated with higher post-training accuracy. Gender had no significant influence on outcomes.

CONCLUSION

The current study attested to the value of SBL in the enhancement of procedural skills, knowledge retention, and self-confidence of final-year medical students in orthopedics.

Key Words: Simulation-based learning; Orthopedic education; Medical students; Procedural accuracy; Medical education

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Core Tip: Simulation-based learning enhances procedural accuracy, knowledge retention, and self-confidence in final-year medical students training in orthopedics. This study showed significant improvements in accuracy (62.5%-84.9%, $P < 0.001$) and knowledge recall (63.4%-78.2%, $P < 0.001$). Students reported higher confidence levels post-training. Prior simulation exposure and strong academic performance were linked to better outcomes. These findings support the integration of simulation-based teaching in undergraduate medical education for improved skill acquisition.

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INTRODUCTION

Orthopedic training, one of the most useful but under represented specialties in undergraduate medical curricula, has some difficulties in clinical teaching[1,2]. As the musculoskeletal problems account for a high percentage of primary care and emergency medicine, the competent early clinical examination is an essential skill for all medical graduates, independent of their future specialization[3,4]. Traditional models of teaching in orthopedic education, including heavy emphasis on didactics and limited bedside exposure, fail to adequately prepare students to perform fundamental assessments and basic interventions in a manner that is comfortable and competent. The demands for methods of teaching that result in the development of practical skills, critical thought, and procedural dexterity have led the way for the introduction of simulation-based learning (SBL) into orthopedic education[5,6].

SBL, which is the reenactment of clinical situations for the purposes of teaching, provides a safe learning environment for participants to gain and practice critical skills without risk[7-9]. In orthopedics these involve fracture stabilization, joint reduction, arthroscopic navigation, and simple surgical tasks. These include high-fidelity manikins, virtual reality (VR) simulators, synthetic bone models, and computer-assisted procedural modules that enable the practice of skills where it would have been unrealistic to be able to gain sufficient practice in the real classroom environment[10-12]. SBL enables repetitive, self-paced learning, instant feedback, and the ability to make and learn from mistakes, all of which are key to skill acquisition and confidence[7].

Simulation plays an important role in medical education. As the World Health Organization and many academic institutions have stated, simulation enhances not just technical skills and procedural skills but decision-making, communication, teamwork, and patient safety. In operative fields such as orthopedic surgery, simulation may help to decrease the well-recognized void between theoretical teaching and practice. Students participating in simulated orthopedic encounters performed better on objective examinations and experienced increased confidence as they entered the clinical setting[7,13,14]. Furthermore, the modular nature of simulation means educators can customize content according to individual learning needs and proficiency, making it particularly ideal for undergraduate training environments where clinical exposure may be less predictable and ad hoc.

From a student perspective SBL is an ideal fit with adult education theories that focus on experiential learning, reflection, and engagement[15,16]. The medical students increasingly demand education that has a hands-on or practical component to prepare them for the challenges of the working world. Simulators alleviate this by offering an immersive environment in which students learn by working, not simply by watching. It also standardizes resources making them universally available regardless of patient availability or rotation location[17,18]. Beyond that it develops nontechnical skills like time management, situational awareness, and patient-centered communication skills that typically receive less attention in traditional orthopedic education[18,19].

Despite its potential the implementation of simulation in undergraduate orthopedic training is inconsistent between schools and especially in low-resource environments. However, barriers including restricted access to simulation facilities, untrained personnel, and time constraints within the curricula still limit widespread integration. Yet with the advent of cost-effective, portable simulation tools, SBL is becoming more practical on a broader scale. Furthermore, movement toward a model of competency-based medical education heightens the need for outcome-based, systematic models of teaching with simulation as a major one. The present study determined if SBL is effective in enhancing procedural accuracy, skill confidence, and knowledge recall in final-year orthopedic medical students.

MATERIALS AND METHODS

After procuring the Institutional Ethics Clearance, this cross-sectional observational study conducted in the Department of Orthopaedics at a tertiary care teaching hospital equipped with simulation training facilities aimed to evaluate the impact of SBL on medical education. The study was conducted over 2 months (January 2025-February 2025) and was designed to determine the effect of SBL on procedural skills, knowledge retention, and self-perceived confidence in a group of final-year medical students.

The inclusion criterion was undergraduate medical students in their final year who had clinical postings in orthopedics. Convenience sampling was used to recruit 106 students. The sample size was estimated to achieve a post-training 50% improvement ratio in procedural accuracy, confidence interval of 95%, and an absolute precision of 10%. According to the normal formula, sample size was calculated as $n = Z^2 \times P \times (1 - P)/d^2$, we get $n = Z^2 \times 0.5 \times (1 - 0.5)/0.07$, which turns out to be 96. We obtained 106 samples by considering at least a 10% non-response. Students who had finished orthopedic postings and were ready to participate willingly were included in this study. Exclusion criteria were any participant with previous formal orthopedic simulation training and those unavailable during their respective simulation or evaluation sessions. All participants gave written informed consent to participate in the study.

The simulation sessions included exercises with synthetic bone models, cast equipment, and procedural packs [orthopedic skills: (1) Closed fracture reduction; (2) Application of plaster; and (3) Traction]. Each session consisted of instructor-led demonstration, practice under supervision, and immediate feedback. Participants were evaluated based on a pretest that included knowledge-based multiple-choice questions and a procedural checklist evaluation to evaluate learning outcomes. After simulation training the identical assessments were completed, and the self-reported confidence level was logged by the participants (ten-point Likert scale). To promote transparency and reproducibility, a data collection template used in this study has been made available as Supplementary material.

Statistical analysis

Knowledge retention was assessed with a post-test 1 week after the simulation that was identical to the pretest procedure. Procedural accuracy was assessed by faculty observers with standardized checklists, and high accuracy was defined as a score ≥ 85%. Demographic information, previous performance in tests, and previous experience in simulation were also recorded. The information was recorded from each participant on a Microsoft Excel spreadsheet prior to analysis using IBM Statistical Package for the Social Sciences Statistics version 26.0, IBM Corp, Chicago, IL, United States.

Demographic and outcome variables were summarized by descriptive statistics as mean, standard deviation, and frequency percentage. Preintervention and post-intervention mean scores were compared using the paired *t*-test. Associations between dichotomized variables were tested using the χ^2 test. Unadjusted and adjusted odds ratio (AOR) with 95% confidence interval (CI) were computed by logistic regression in order to determine predictors of high procedure accuracy. $P < 0.05$ was considered significant.

RESULTS

A total of 106 final-year undergraduate medical students were included in the study with an average age of 22.6 ± 1.1 years. Gender was equally distributed with 54 males (50.9%) and 52 females (49.1%). In addition 22 students (20.7%) had previously benefited from orthopedic simulation training, and 44 students (41.5%) had obtained ≥ 75% in the last exam (Table 1).

There were significant increases for all areas of interest after SBL. The average procedural success score increased from 62.5% ± 10.3% before the training to 84.9% ± 8.6% after the training, revealing an average gain of 22.4% ($P < 0.001$). Likewise, the mean knowledge score increased from 63.4% ± 11.2% to 78.2% ± 9.4% ($P < 0.001$), demonstrating the efficacy of short-term knowledge retention. Recorded self-reported confidence on a ten-point Likert scale improved similarly from the mean pretraining of 4.6 ± 1.7 to a mean of 8.2 ± 1.1 after the simulation ($P < 0.001$; Table 2).

Table 1 Baseline characteristics of study participants (*n* = 106)

Variable	Category	Frequency (*n*)	Percentage (%)
Age (years)	mean ± SD	22.6 ± 1.1	-
Gender	Male	54	50.9
	Female	52	49.1
Prior simulation exposure	Yes	22	20.7
	No	84	79.3
Academic performance (last exam)	≥ 75%	44	41.5
	< 75%	62	58.5

SD: Standard deviation.

Table 2 Comparison of pre-simulation and post-simulation outcomes (*n* = 106)

Parameter	Presimulation (mean ± SD)	Post-simulation (mean ± SD)	Mean difference	*P* value[1]
Procedural accuracy score (%)	62.5 ± 10.3	84.9 ± 8.6	22.4	< 0.001
Knowledge test score (%)	63.4 ± 11.2	78.2 ± 9.4	14.8	< 0.001
Confidence level (0-10 scale)	4.6 ± 1.7	8.2 ± 1.1	3.6	< 0.001

[1]Paired *t*-test.
SD: Standard deviation.

The proportion of trainees who felt confident (≥ 7 scores) increased from 19.8% preintervention to 61.3% post-simulation-based training ($P < 0.001$; Table 3). The number of previous exposures to simulation significantly correlated with superior procedural accuracy (≥ 85%) ($P = 0.007$; Table 4). High accuracy was obtained by 50.0% of students without previous simulation experience and in 90.9% with previous exposure to case simulation.

In univariate analysis previous experience with simulation was associated with a ten-fold greater likelihood of achieving high technical skill (OR = 10.00, 95%CI: 2.10-47.60, $P = 0.004$). Students with more than 75% in academic examination had higher odds for good procedural accuracy (OR = 2.58, 95%CI: 1.20–5.56, $P = 0.015$; Table 5).

On multivariate logistic regression exposure to previous simulation exposure (AOR = 4.35, 95%CI: 1.26-15.02, $P = 0.020$) and good academic performance (AOR = 2.89, 95%CI: 1.08-7.71, $P = 0.033$) were the only variables independently associated with procedural success after training. In univariate and multivariate analyses, sex did not emerge as a significant predictor in terms of outcomes ($P > 0.9$; Table 6).

DISCUSSION

This study highlighted the valuable role of SBL in improving procedure accuracy, knowledge retention, and self-perceived confidence in orthopedics among final-year medical students. These results are in line with the increasing evidence of the value of SBL in medical education. In the current study we observed a significant improvement in procedural accuracy scores from 62.5% before to 84.9% after complete training. This benefit was consistent with the findings of Butler *et al*[20], who found a combined didactic and simulation course improved interns' and medical students' skills in contagious caprine pleuropneumonia of pediatric supracondylar humeral fractures. Klingebiel *et al*[21] showed that the pelvic ring injury simulator successfully improved trauma surgeons' self-confidence and practical skills in an emergency setting.

Knowledge retention also displayed an impressive improvement from a pretest average of 63.4% to a post-test average of 78.2%. This is in support of the study by Wilson *et al*[22], who concluded that both the VR and physical model simulators had improved immediate and long-term memory retention of key orthopedic principles and knowledge for the undergraduate medical students. Schöbel *et al*[23] showed that immersive VR training resulted in a significantly higher procedural knowledge of steps of the procedure over traditional teaching methods. Self-reported confidence levels increased significantly with students rating their confidence at 8.2/10 post-training *vs* 4.6 pretraining. This increased confidence is in line with what previous research has found about the potential of SBL to promote learners' self-efficacy. Kelly *et al*[24] underscored the value of using a simulated environment to teach musculoskeletal medicine to undergraduates and its role in enhancing the confidence of clinical skills. Table 7 compares the present study with published literature on simulation-based orthopedic education studies[20-24].

Table 3 Confidence levels before and after simulation (*n* = 106)

Confidence level	Pre-simulation	Post-simulation	*P* value[1]
Low (1-3)	34 (32.1)	4 (3.8)	< 0.001
Moderate (4-6)	51 (48.1)	37 (34.9)	
High (7-10)	21 (19.8)	65 (61.3)	

Data are presented as *n* (%).
[1]χ^2 test.

Table 4 Association between prior simulation exposure and post-simulation procedural accuracy (*n* = 106)

Exposure		Accuracy ≥ 85%	Accuracy < 85%	Total	χ^2 value	*P* value
Prior exposure	Yes	20	2	22	7.24	0.007
	No	42	42	84		

Table 5 Predictors of high procedural accuracy (≥ 85%): Unadjusted odds ratio (*n* = 106)

Variable	Odds ratio (95%CI)	*P* value
Male gender	1.02 (0.49–2.15)	0.958
Prior simulation exposure	10.00 (2.10–47.60)	0.004
Academic score ≥ 75%	2.58 (1.20–5.56)	0.015

CI: Confidence interval.

Table 6 Multivariate logistic regression: Adjusted odds ratios for high procedural accuracy (≥ 85%) (*n* = 106)

Variable	Adjusted odds ratio (95%CI)	*P* value
Male gender	0.97 (0.43–2.18)	0.940
Prior simulation exposure	4.35 (1.26–15.02)	0.020
Academic score ≥ 75%	2.89 (1.08–7.71)	0.033

CI: Confidence interval.

The relationship between past exposure to simulation and greater accuracy in skill performance indicates that consistency in the use of simulation tools can result in more skill acquisition. This observation is consistent with the theory of deliberate practice in medical education, suggesting that repeated exposure to clinical situations will improve performance. Kulasegaram *et al*[25] highlighted that the order of sequencing discovery learning before direct instruction was critical to increased transfer performance in the context of skills learning within simulations. Surprisingly, gender did not have a significant effect on the outcomes, showing that SBL offers an opportunity for equitable skills development for all types of learners. This neutral stance is important for the development of inclusive pedagogical approaches. Inclusion of SBL in medical undergraduate curriculum provides a safe learning environment to learn and rehearse acquired practical skills and consequently bridge the gap between theory and practice among students. As health care education continues to develop, the introduction of simulation methods will be a cornerstone for training skilled and confident professionals.

The integration of emerging technologies such as artificial intelligence (AI) and VR presents exciting opportunities to transform the landscape of simulation-based orthopedic education. While this study focused on traditional simulation tools such as synthetic bone models and procedural kits, the rapid evolution of digital platforms offers new avenues for enhancing training fidelity, learner engagement, and personalized feedback mechanisms. VR provides immersive, three-dimensional environments that closely replicate the anatomical complexity and procedural context of orthopedic interventions. Recent advances in VR-based surgical simulation allow students to visualize joint mechanics, manipulate virtual instruments, and perform real-time procedures in risk-free, interactive environments. Studies have shown that VR simulations improved spatial understanding, procedural flow, and learner satisfaction in orthopedic settings. For example, Wilson *et al*[22] demonstrated that VR-based simulations led to greater long-term knowledge retention

Table 7 Comparison of current study with selected simulation-based orthopedic education studies

Ref.	Study design	Participants	Simulation modality	Outcomes measured	Key findings
Kelly *et al*[24], 2017	Mixed-methods study	Medical students	Simulated musculoskeletal environment	Knowledge, confidence, feedback	Improved self-efficacy and musculoskeletal exam skills
Butler *et al* [20], 2017	Pre-post intervention	Interns and students	Supracondylar fracture simulator	Technical skill, self-confidence	Improved skill performance and confidence post-training
Wilson *et al* [22], 2020	Randomized crossover trial	Undergraduate medical students	VR and physical models	Knowledge scores, retention	Both modalities improved scores; VR had slightly higher retention
Klingebiel *et al*[21], 2024	Experimental study	Orthopedic surgeons	Pelvic fracture simulator	Technical confidence, skill acquisition	Simulator enhanced emergency procedure readiness
Schöbel *et al* [23], 2024	Prospective controlled trial	Medical students	Immersive VR for knee arthroscopy	Procedural steps understanding, engagement	VR significantly improved procedural knowledge and engagement
Our study, 2025	Cross-sectional observational	106 final-year MBBS students	Synthetic bone models, plaster kits	Procedural accuracy, knowledge retention, confidence	Significant improvements in all domains; prior exposure and academic scores were predictors of better outcomes

VR: Virtual reality; MBBS: Bachelor of Medicine and Bachelor of Surgery.

compared with conventional physical models in undergraduate orthopedic education. Similarly, Schöbel *et al*[23] reported improved procedural understanding and engagement among students trained using immersive VR modules for knee arthroscopy.

AI further augments the simulation experience by offering real-time, automated performance feedback and adaptive learning pathways. AI-driven simulators can track instrument movements, detect errors, and provide precise metrics such as force applied, trajectory, and completion time. These data-rich platforms enable students to receive individualized feedback, identify areas of weakness, and improve through iterative practice. Moreover, machine learning algorithms can tailor the complexity of simulated cases based on learner performance, promoting mastery-based progression rather than time-based exposure.

The integration of AI also holds promise for standardizing assessment in simulation-based training. Objective, algorithm-driven scoring systems can reduce evaluator bias and improve the reliability of skill evaluation across institutions. When combined with VR environments, AI can simulate a wide range of orthopedic pathologies and procedural variations, preparing learners for real-world clinical diversity. Despite the promise the implementation of AI and VR in undergraduate curricula is still limited due to infrastructure costs, faculty training requirements, and the need for validation studies. Nonetheless, early adoption and pilot programs have shown encouraging results, and further research is warranted to assess their scalability, cost-effectiveness, and educational impact.

Incorporating AI and VR into orthopedic simulation represents a logical next step toward achieving personalized, high-fidelity, and outcome-driven medical education. As technology continues to advance, future orthopedic training may rely not only on physical simulations but also on immersive, intelligent systems that bridge the gap between classroom learning and surgical practice.

While this study provides the important insights into the role of SBL in undergraduate orthopedic education, several limitations must be acknowledged. First, the study was conducted at a single academic institution, potentially limiting the generalizability of the findings across different educational settings with varying resources and curricular structures. Second, although the sample size was adequate for initial statistical analysis, a larger and more diverse participant pool would provide greater external validity. Third, while procedural accuracy and knowledge retention were evaluated objectively, the confidence metric was based on self-reported Likert scores, which are inherently subjective and may be influenced by social desirability bias. Fourth, this study did not include a control group receiving traditional teaching methods alone. As a result while we observed significant improvements in procedural accuracy, knowledge retention, and confidence following the SBL intervention, the absence of a comparator group limits the strength of causal inferences. Future research using randomized controlled trial designs will be essential to directly compare SBL with conventional or blended teaching modalities to better evaluate its relative effectiveness. Another important limitation is the lack of long-term follow-up. This study assessed immediate post-intervention outcomes and short-term knowledge retention only. It remains unclear whether the observed improvements in procedural skills and confidence are sustained over time or translate into superior clinical performance in real-world patient care scenarios. Additionally, we did not include a control group receiving traditional teaching methods alone, which would have strengthened causal inferences regarding the effectiveness of SBL.

For future research we recommend multicenter studies across diverse institutions to evaluate the reproducibility of results in various academic contexts. Incorporating a randomized controlled design comparing simulation-based training with traditional or blended methods would offer more robust evidence of its relative effectiveness. Longitudinal studies assessing skill retention, clinical application during internships, and performance in objective structured clinical examinations would further clarify the impact of simulation on real-life competency. Furthermore, the use of validated performance metrics such as the objective structured assessment of technical skill and blinded faculty assessments would enhance objectivity in skill evaluation. Future work should also explore cost-effectiveness analyses and learner

preferences to guide institutional adoption and resource allocation.

CONCLUSION

The current study attests to the value of SBL in the enhancement of procedural skills, knowledge retention, and self-confidence of final-year medical students in orthopedics. The substantial improvement in post-training performance confirms the importance of incorporating structured simulation modules in undergraduate medical education. Previous exposure to simulation and academic preparedness were found to be independent predictors of higher procedural performance, highlighting the importance of early and course-integrated experience with simulation. Simulation-based education should be an essential part of orthopedic curricula to further enhance the competence of students in readiness to undertake clinical duties due to its applicability, expandability, and learner-focused teaching. Interventional research should be directed to multicentric and long-term follow-up studies to verify these observations and their potential impact on clinical real world routine.

FOOTNOTES

Author contributions: Manohar M, Selvaraj P, Jeyaraman N, and Muthu S contributed to acquiring clinical data and performing the data analysis; Selvaraj P contributed to administration; Selvaraj P and Jeyaraman M contributed to conceptualization; Selvaraj P and Jeyaraman M contributed to manuscript writing; Muthu S and Jeyaraman M contributed to manuscript revision; Jeyaraman M contributed to proofreading; All authors have agreed to the final version to be published and agree to be accountable for all aspects of the work.

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