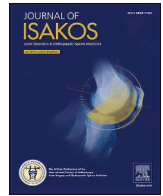




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Original Research

Virtual reality training is associated with high satisfaction and self-perceived surgical confidence in anterior cruciate ligament reconstruction: Experience from an orthopedic residency pilot study

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ABSTRACT

Introduction/objective: Virtual reality (VR) is increasingly used in surgical education by enabling risk-free, immersive, and independent training. As orthopedic surgery residency programs increasingly integrate VR-based simulation, evidence regarding trainee satisfaction and self-perceived confidence remains scarce. This study aims to evaluate orthopedic surgery residents' satisfaction and self-perceived confidence following VR-based simulation training (VRT) in anterior cruciate ligament reconstruction (ACLR). The hypothesis is that VRT would result in high satisfaction and improve confidence in performing the procedure.

Methods: A cross-sectional pilot study was conducted on 12 orthopedic surgery residents (4 per postgraduate year) from a three-year residency program. Residents with prior VR-based ACLR simulation experience were excluded. Each participant completed two VRT sessions using PrecisionOS software on the Oculus Quest 2 headset, practicing the inside-out ACLR technique. Pre- and post-training assessments included a validated five-point Likert scale and the net promoter score (NPS) to measure satisfaction and self-perceived confidence.

Results: Eleven residents (91.7%) completed the study. Overall satisfaction with VRT was high, with most participants rating the experience as "agree" or "strongly agree" across all learning dimensions. The second session showed higher median satisfaction scores in five of six items. Participants valued VR training to improve procedural understanding, facilitate content application, and reinforce skills through immersive, tutor-independent learning. Overall, all sections achieved positive NPS values exceeding 40 (41–73), highlighting that VR training was an engaging way to learn. Third-year residents reported the greatest improvement regarding self-perceived confidence in executing the procedure, particularly to perform as the primary surgeon. First- and second-year residents showed increased confidence in assisting the procedure.

Conclusion: This pilot study suggests that VR-based ACLR training is well accepted by orthopedic surgery residents and provides a highly satisfactory and immersive learning experience. Residents reported improved understanding of procedural steps and increased self-perceived confidence, with senior residents benefiting most in relation to the primary surgeon role and junior residents reporting greater confidence in assisting in the procedure. These findings support the feasibility and acceptability of VR simulation as a self-directed educational tool within orthopedic residency training programs.

Level of evidence: Level IV.

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What are the new findings?

- Virtual reality surgical training was reported as highly satisfactory by orthopedic surgery residents.
- The virtual reality training was valued for improving understanding of procedural steps and reinforcing theoretical knowledge.
- Participants expressed greater confidence in performing and assisting in anterior cruciate ligament reconstruction on real patients.
- Junior and senior residents benefited differently, with senior residents showing the greatest improvement in primary surgeon confidence.

INTRODUCTION

Balancing theoretical and practical training in medical education has been a longstanding challenge [1,2]. In surgical specialties such as orthopedics, hands-on training is essential for acquiring the skills necessary to perform procedures safely and independently [3]. According to a report by Densen, clinicians acquire approximately 80% of medical knowledge through clinical practice; however, medical education remains predominantly theoretical [4].

Traditionally, surgical training follows Halsted's "master-apprentice" model (see one, do one, teach one) [5]. However, in recent decades, this approach has been increasingly questioned due to regulations limiting working hours in residency programs and a growing bioethical awareness that prioritizes patient beneficence and nonmaleficence [6–9]. Additionally, multiple factors influence residents' exposure to diverse pathologies including disease prevalence, rotation site and duration, personal motivation, and the student-instructor relationship [10].

Medical simulation has emerged as a useful alternative to address these limitations. In this context, extended reality (XR), which includes virtual reality (VR) and augmented reality (AR), offers an innovative solution. The XR provides an immersive learning experience in a digital environment using three-dimensional (3D) models, allowing for active, safe, and accessible training that eliminates risks to patients and is considerably more cost-effective than other medical simulation methods [11]. Several studies have demonstrated that these immersive technologies enhance knowledge acquisition, technical skills, and learning speed, showing comparable or superior results to traditional simulation [12–19]. For this reason, some training programs are integrating VR- and AR-based simulation for orthopedic procedures. However, reports indicate that educational innovations often face resistance from users, leading to dissatisfaction and adoption challenges [20].

This pilot study aims to analyze the satisfaction and self-perceived confidence of orthopedic surgery residents following VR-based surgical training (VRT) in anterior cruciate ligament reconstruction (ACLR). The hypothesis is that VRT would result in high satisfaction and improve confidence in performing the procedure.

METHODS

Study design

A descriptive cross-sectional study was conducted from October to December 2023 including residents from a three-year orthopedic surgery training program in Chile, with four residents per year of specialization. Residents with prior VR-based ACLR simulation experience were excluded. This study was a simulation-based educational study involving orthopedic surgery residents only and did not include patients or clinical interventions. The study was evaluated and approved by the authors' institutional ethics committee (approval number 2023-59), data anonymization was assured, and all participants provided informed consent before enrollment. This study followed the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) extensions for healthcare simulation research [21].

The 3-year residency includes progressive surgical participation under supervision, night shifts, and a continuous seminar program including introductory lecture sessions for first-years; simulation is primarily offered through biannual cadaveric labs.

All participants received training on VR-based surgical education, the software, and the device used in the study.

Baseline assessment

Before the simulations, participants completed a multiple-choice question (MCQ) diagnostic assessment covering the theoretical content related to the procedure and a survey collecting demographic information and details about their prior experience with VR systems and the ACLR reconstruction procedure.

VR training

The training consisted of two 90-min practice sessions, spaced one week apart, during which participants performed a complete ACLR procedure using the "inside-out" technique through the "infinity anteromedial" module within the PrecisionOS platform (PrecisionOS Technologies, Vancouver, Canada). The module incorporates the Infinity™ Knee System (CONMED Corporation, Florida, United States) in VR mode. The simulation was delivered using an Oculus Quest 2 headset (Meta Platforms Inc., California, United States) (Fig. 1). A briefing session, held one week prior to training, included cognitive reinforcement and hands-on familiarization with the VR device. Automatic feedback was provided by the software after each session, regardless of whether the procedure was completed. A group debriefing session was conducted with all residents and guided by an orthopedic knee surgeon, following the completion of the second training session.

Assessment of satisfaction and perceived confidence

A customized survey was developed to assess residents' satisfaction with the simulation and their self-perceived confidence in performing the trained procedure (see Supplementary File 1). The instrument included 14 five-point Likert scale items, 4 net promoter score (NPS) questions (rated from 0 to 10), and one open-ended question to gather qualitative feedback. The satisfaction section explored content alignment with theoretical knowledge, support for independent learning, motivation, and engagement. The self-perceived confidence section evaluated residents' impressions of their ability to acquire and master theoretical and practical skills, as well as their confidence in performing the procedure as a primary surgeon or assistant in real clinical settings.

Content validity was evaluated by a multidisciplinary panel of six professionals including experts in medical education, senior surgeons, as well as an orthopedic surgery resident. For the NPS and the self-perceived confidence scale, the item-level content validity indices (I-CVI) ranged from 0.83 to 1.0 in both cases, with a scale-level content validity index (S-CVI) of 0.96 for NPS and 0.91 for the self-perceived confidence scale, which are considered acceptable [22].



Fig. 1. Orthopedic surgery resident practicing ACLR using the PrecisionOS virtual reality simulation platform. The software runs on Oculus Quest 2 hardware and provides a fully immersive virtual arthroscopic operating room environment to guide procedural steps. ACLR = anterior cruciate ligament reconstruction.

Following expert validation, the instrument was applied in an independent sample of 200 participants. Principal component analysis (PCA) and exploratory factor analysis (EFA) identified a stable three-factor structure, explaining 70.7% of the total variance. Confirmatory factor analysis (CFA) demonstrated satisfactory model fit ($\chi^2(74) = 180.405, p < 0.001$) [23]. Items related to experience perception loaded on the first factor, while self-perceived confidence items separated into two distinct factors, which were interpreted as general self-perceived confidence and specific ACLR confidence. Sampling adequacy was excellent (Kaiser-Meyer-Olkin = 0.929) [23], Bartlett's test was statistically significant ($p < 0.001$), and internal consistency for the full 14-item scale was high (Cronbach's alpha = 0.935) [24]. The analysis was performed using open-source statistical software (JASP, Version 0.19.3, University of Amsterdam, Amsterdam, Netherlands).

For the five-point Likert scale responses, favorable answers were defined as those marked “agree” or “strongly agree”, while negative responses included “disagree” or “strongly disagree” selections. Ratings on a 0–10 scale were interpreted globally (combining all responses from both training sessions) using the NPS system, with the following categories [25]:

- -100 to 0: Poor or critical
- 0 to 30: Acceptable
- 30 to 50: Positive
- 50 to 70: Very good
- 70+: Excellent

Given the sample size and the ordinal nature of Likert scale data, these variables were summarized using median values with full ranges. The NPS results were calculated and reported according to standard methodology.

Data collection

Participants completed the self-perceived confidence section of the survey before training, followed by the full survey (satisfaction and self-perceived confidence) after each of the two training sessions. All data were anonymized to minimize response bias and ensure confidentiality. Participation was voluntary, and responses were collected independently to reduce social desirability bias. No identifying information was

linked to the survey data or used during analysis. Only complete responses of all questionnaires were included. Therefore, no imputation for missing data was performed.

RESULTS

Baseline characteristics

Twelve orthopedic surgery residents from a single academic program participated in the study, with four residents representing each training year. The majority of participants were male (10 of 12), with an overall median age of 27.5 years (25–38) (Table 1). At study initiation, none of the residents had performed an ACLR as the primary surgeon, nor had they received prior VR training. Seven participants reported previous

Table 1
Demographic characteristics of participating orthopedic surgery residents.

PGY	Total (n =)	Male (n =)	Female (n =)	Median age (Range)
1	4	4	0	26 (25–34)
2	4	2	2	27.5 (27–32)
3	4	4	0	31 (27–38)
Total	12	10	2	27.5 (25–38)

PGY = postgraduate year.

Table 2
Diagnostic test results by individual and postgraduate year.

Resident	PGY	Score (%)	PGY median score
1	1	46.2%	46.2%
2		53.8%	
3		46.2%	
4		30.8%	
5	2	30.8%	57.7%
6		69.2%	
7		84.6%	
8	3	46.2%	76.9%
9		61.5%	
10		30.8%	
11		100%	
12		92.3%	

PGY = postgraduate year.

experience assisting in real ACLR procedures. Diagnostic test performance increased progressively with advancing residency year, showing greater baseline procedural knowledge among senior residents (Table 2).

Satisfaction and self-perceived confidence in the procedure

The study collected 22 survey responses from 11 participants, achieving a 91.7% response rate. One third-year resident was excluded from the final analysis because the resident completed only a single simulation session.

Satisfaction

High levels of satisfaction were reported regarding VR-based ACLR training using the “inside-out” technique (Fig. 2). All

satisfaction-related questions received positive ratings, with higher median scores in five of the six questions during the second training session, while one item remained unchanged. After the second simulation session, residents predominantly agreed or strongly agreed that the experience effectively enhanced their understanding of procedural steps and the rationale behind key maneuvers and improved their ability to apply relevant theoretical knowledge. Additionally, residents reported that the simulation aligned closely with their formal training curriculum and provided an immersive, self-directed learning experience without the immediate need for clinical supervision.

Overall satisfaction, assessed using the NPS, demonstrated consistently positive evaluations across all domains, with all items exceeding a score of 40. The highest scores were related to the enjoyability of learning ACLR through VR training (Table 3).

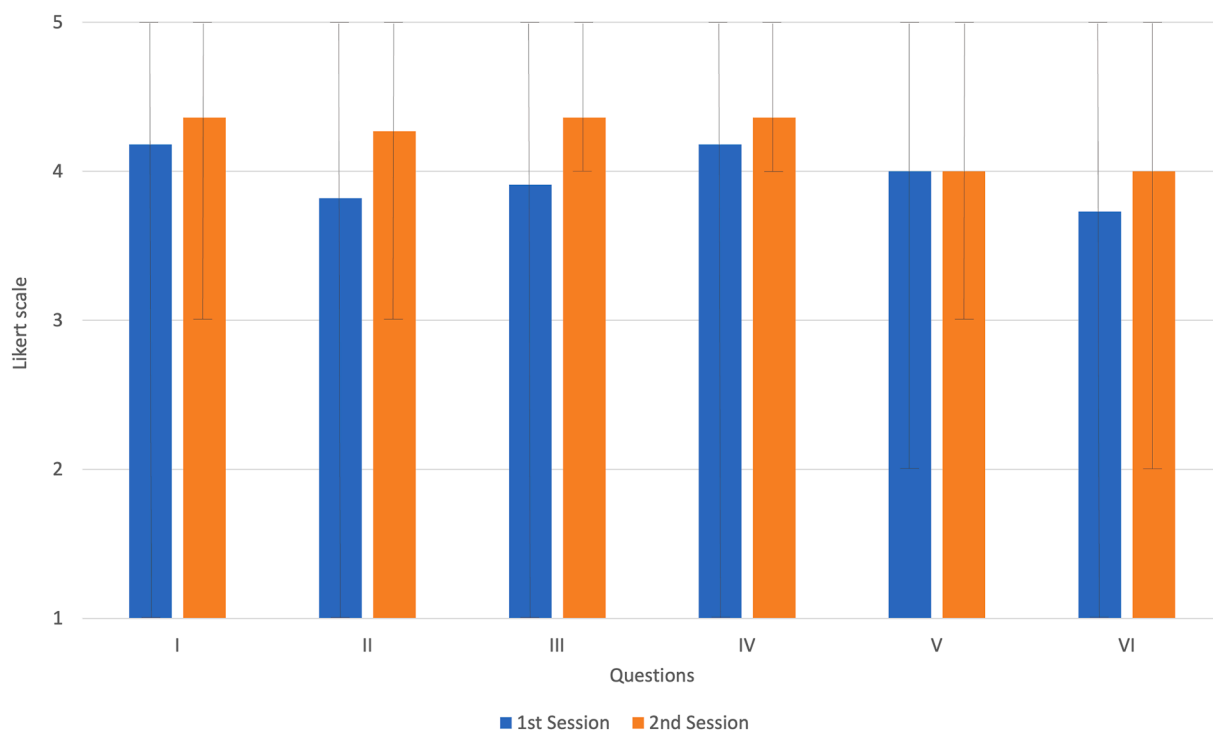


Fig. 2. Progression of satisfaction levels in relation to the use of virtual reality anterior cruciate ligament reconstruction training. Data are presented as median values with full ranges. The y-axis represents a 5-point Likert scale with increasing response options: strongly disagree, disagree, neither agree nor disagree, agree, and strongly agree. The x-axis displays the items used to assess participants' satisfaction with the virtual reality experience, coded sequentially from I to VI

- I: This simulation contributed to understanding how the procedure should be achieved.
- II: This simulation contributed to understanding why the maneuvers performed in the training achieve completion of the procedure.
- III: This simulation contributed to a better application of the content with respect to the trained procedure.
- IV: The maneuvers performed in the simulator relate to the content learned during your training in traumatology and orthopedics.
- V: This scenario provided a realistic and immersive experience.
- VI: This simulator is self-taught and allows me to learn without the need for a clinical tutor.

Table 3
Overall satisfaction following both simulations, measured using the net promoter score.

Evaluation	1–6 Detractors	7–8 Passives	9–10 Promoters	NPS
Question	N (%)			–100 a 100
How likely are you to recommend this experience to a colleague?	2 (9.1)	9 (40.9)	11 (50)	41
How likely are you to review this procedure again using this simulator?	2 (9.1)	7 (31.8)	13 (59.1)	50
Do you feel it was an engaging way to learn?	1 (4.5)	4 (18.2)	17 (77.3)	73
Do you think this type of experience is a recommended learning method for studying medicine?	1 (4.5)	7 (31.8)	14 (63.6)	59

NPS = net promoter score.

Net promoter score values range from –100 to +100, with higher scores indicating greater satisfaction.

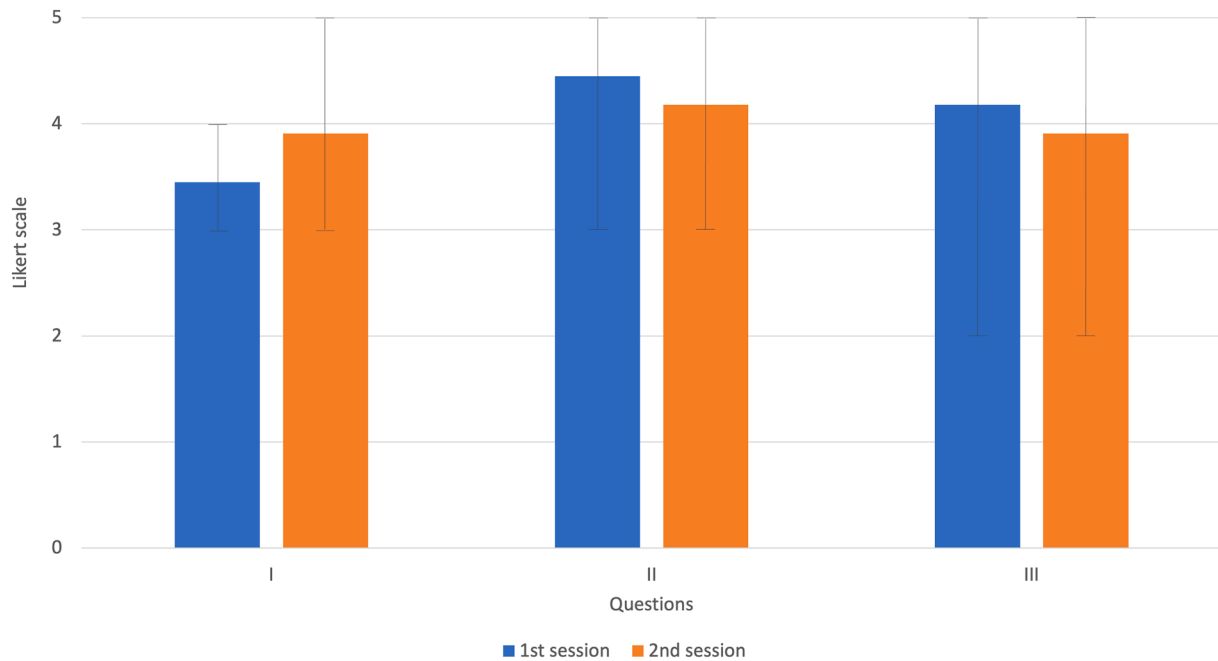


Fig. 3. Progression of self-perceived confidence in learning in relation to the use of virtual reality anterior cruciate ligament reconstruction training. Data are presented as median values with full ranges. The y-axis represents a 5-point Likert scale with response options ranging from strongly disagree to strongly agree. The x-axis shows the items used to assess participants' confidence in learning, coded sequentially from I to III:
 II: I am confident that through this simulation training I am acquiring knowledge that will enable me to function in a real clinical setting.
 III: I am confident that through this simulation training I am developing skills that will enable me to perform in a real clinical scenario

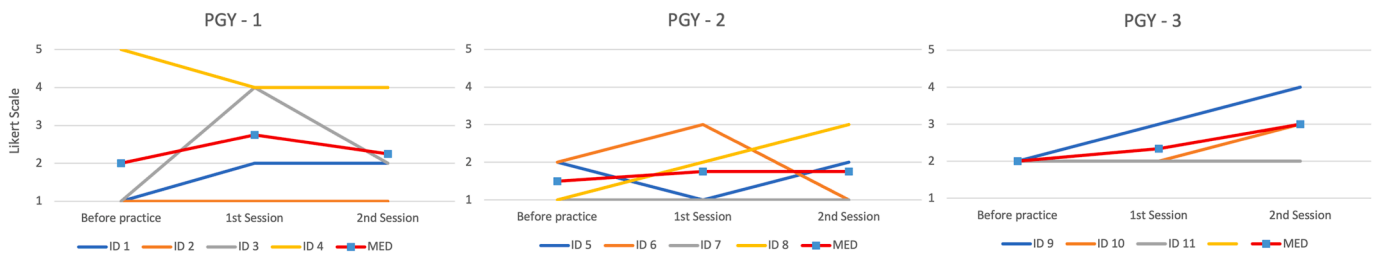


Fig. 4. Progression of self-perceived confidence to perform anterior cruciate ligament reconstruction procedures as primary surgeon by residency year. The graphs illustrate the progression of residents' self-perceived confidence in performing an anterior cruciate ligament reconstruction as the primary surgeon, categorized by postgraduate year (PGY 1, PGY 2, PGY 3). Participants responded to the statement: "I feel confident to perform the trained procedure with real patients as the primary surgeon or in charge of the procedure. The y-axis shows responses on a 5-point Likert scale (1 = strongly disagree, 2 = disagree, 3 = neither agree nor disagree, 4 = agree, 5 = strongly agree). The x-axis indicates the progression of confidence scores from the presimulation stage ("Before practice") to the second training session.
 PGY = postgraduate year; IDx = individual resident participant; Med = postgraduate year median score.

Self-perceived confidence in learning

Residents' self-perceived confidence in learning through VR simulation was generally favorable. Median responses ranged between agreement levels, with most residents reporting that the VR training contributed to mastering the simulation content, acquiring knowledge applicable to real clinical settings, and developing practical skills that could enable performance in real clinical scenarios (Fig. 3).

Self-perceived confidence in performing the procedure

Self-perceived confidence in performing ACLR as primary surgeons increased among third-year residents, with an approximate one-point rise on the Likert scale across training sessions. Among first- and second-year residents, confidence levels were more variable: 37.5% reported increased confidence, 37.5% showed no variability, and 25% reported decreased confidence (Fig. 4).

Confidence in assisting in the procedure either improved or remained consistently high for most residents (72.7%), regardless of residency year (Fig. 5).

Qualitative feedback

Qualitative feedback, gathered through open-ended survey questions and debriefing sessions, identified key areas for improving the VR training experience. Many residents suggested that VR training should be integrated earlier into residency programs, particularly during the first year, to maximize its educational value. Furthermore, limitations in motion fluidity were noted as negatively impacting the realism and effectiveness of the simulation. Residents emphasized the importance of dedicated, protected time for practicing skills to improve training outcomes. Lastly, technical issues such as internet connectivity disruptions were highlighted as factors detracting from the overall user satisfaction.

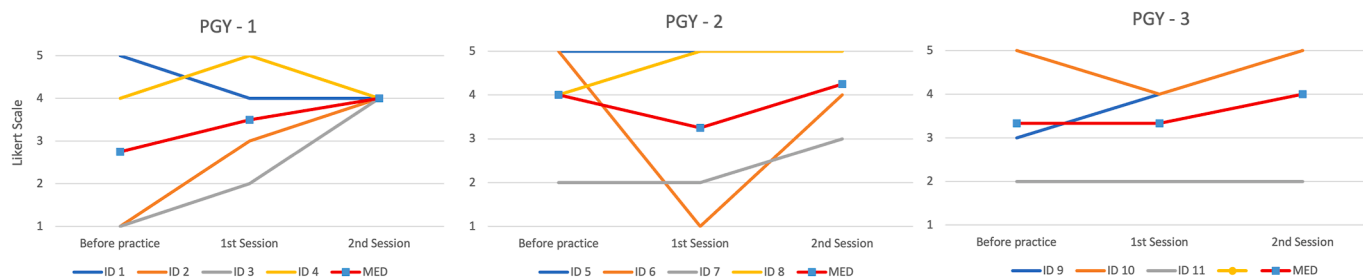


Fig. 5. Progression of self-perceived confidence to assist in anterior cruciate ligament reconstructions procedure by residency year. The graphs illustrate the progression of self-perceived confidence among orthopedic surgery residents, grouped by postgraduate year (PGY 1, PGY 2, PGY 3), in assisting a primary surgeon during an anterior cruciate ligament reconstruction. Participants responded to the statement: "I feel confident to assist a primary surgeon in the trained procedure with real patients." Confidence was rated on a 5-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). The x-axis tracks the progression from the presimulation stage ("Before practice") through the first and second training sessions. PGY = postgraduate year; IDx = individual resident participant; Med = postgraduate year median score.

DISCUSSION

The lack of perceived confidence in surgical skills among residents, and even recent specialists, remains a substantial concern within training programs. Coleman et al. reported that 38% of surgical residents either disagreed or were unsure whether a five-year residency adequately prepared them for independent practice upon graduation [26]. This is reflected in clinical performance: George et al. in a real-world surgical assessment involving almost two thousand senior residents, found that only 77% were considered ready to perform surgeries independently, after evaluation by expert assessors [27].

Residency time constraints, coupled with growing bioethical awareness and patient safety [6–9], raise further questions about the capacity of current surgical training programs to equip residents with the necessary competencies. Within this context, VR simulation has emerged as a promising surgical educational tool and has been reported to demonstrate noninferiority compared to traditional clinical learning and other simulation methods in selected educational context [28–32]. Recent literature suggests that VR offers a safer, accessible, and even cost-effective platform for hands-on practice without compromising patient safety [11,31]. Nevertheless, as an emerging technology, VR requires continuous validation.

The main findings of this study are that VR training for an "inside-out" ACLR technique was highly valued by orthopedic residents in terms of satisfaction and self-perceived confidence in performing and assisting in the procedure.

Regarding satisfaction, residents particularly appreciated the engaging and enjoyable nature of VR training. These findings align with those of Blumstein et al., who found VR more attractive and effective compared to traditional learning methods [15]. This perception is consistent with existing literature on gamification in medical education, demonstrating enhanced motivation and engagement from interactive simulations and peer challenges [33,34]. According to Tung et al. game-based elements in orthopedic training not only boost participation but also facilitate more efficient learning and better knowledge retention [35]. Therefore, integrating VR with gamified strategies may further improve surgical training by offering stimulating, immersive, and reproducible learning environments.

A notable contribution of the present study is the observed increase in self-perceived confidence among third-year residents in performing as primary surgeons, an outcome that remains underexplored in orthopedic and trauma VR literature [16]. Although qualitative feedback from residents and faculty suggested that VR may be especially beneficial for junior residents, the quantitative data from this study show that after two training sessions, self-perceived confidence improved for most residents when acting as assistant surgeons, and for third-year residents when taking the primary surgeon role. A recent systematic review by Hasan et al. proposed that VR-based familiarity and procedural confidence could

improve intraoperative performance [16]. These findings support the idea that VR training can be useful regardless of the learner's academic seniority, promoting residents' autonomy at different stages of the residency program.

Another noteworthy observation is the heterogeneous changes in self-perceived confidence among first- and second-year residents when considering the role of primary surgeon. While some residents gained confidence, others showed no change, and a few even experienced a decline. This could be attributed to the "Dunning-Kruger effect," a cognitive bias in which individuals with limited competence overestimate their abilities [36]. In fact, some junior residents in this study initially rated themselves more confidently than their third-year peers. Although this phenomenon has not yet been explored in VR surgical simulation for orthopedics, a similar pattern in general surgery residents using laparoscopic cholecystectomy simulation in porcine models was observed: lower-performing participants overestimated their skills, while higher-performing residents tended to underrate theirs [36]. In this context, VR training could help recalibrate self-perceptions, promote self-critique, autonomy, and encourage more thorough study, paralleling the impact of traditional high-fidelity simulation.

Effective medical simulation must closely resemble real-life practice [3]. While VR has demonstrated high satisfaction and increased confidence, its realism remains debated [37]. In this study, more than 60% of participants found the VR scenario immersive and realistic. These findings are consistent with a recent literature review where most studies reported favorable realism outcomes [37], although gaps in haptic feedback and ergonomics persist [32], concerns echoed by the present study's residents in their responses to open-ended questions. In response to these limitations, some XR platforms have already incorporated haptic gloves, yielding improved educational outcomes [38,39].

This study is the first in Latin America to incorporate VR-based simulation into orthopedic surgical training and among the earliest globally to assess satisfaction and self-perceived confidence in VRT for ACLR. However, some limitations must be considered before generalizing the results. First, while all residents from the program were included, the sample was small and drawn from a single academic institution. The encouraging results from this pilot study should prompt multicenter research with larger cohorts to enhance generalizability. Second, the primary outcomes were based on self-reported measures including satisfaction and self-perceived confidence, which do not equate to technical competence or objective performance. As described in established educational frameworks, these outcomes correspond to lower-level educational measures focused on learner reaction and attitudes rather than demonstrable behavioral change or performance [40]. Consequently, the findings should be interpreted as reflecting feasibility, learner acceptance, and perceived preparedness rather than true surgical competence. Nevertheless, such early-stage outcomes are commonly used in pilot studies of novel educational interventions and may serve as

prerequisite indicators for the successful implementation of innovative training modalities into orthopedic curricula and for the subsequent evaluation of higher-level outcomes including technical skill acquisition and behavioral transfer [41]. Third, the study relied on self-reported data, which may introduce social desirability and acquiescence biases. For example, residents who experienced technical issues such as system crashes or connectivity problems could have influenced participants' perceptions despite the survey not being designed to assess technical performance. Nonetheless, the survey instrument was validated by a panel of experts and demonstrated excellent adequacy and high internal consistency, and exploratory factor analysis confirmed its dimensionality. Furthermore, as part of the program's commitment to continuous improvement, faculty have begun addressing the issues identified in residents' feedback through targeted technical improvements and structured scheduling adjustments to protect residents' training time. Lastly, the current study assessed perceptions following two simulation sessions. Longitudinal tracking is essential to determine how perceptions evolve and to explore key questions such as the number of sessions needed for optimal training or differences based on residency year. Future research should incorporate objective outcome measures such as knowledge testing, simulator-based performance metrics, or expert-rated technical assessments, as well as follow-up surveys conducted immediately after real-life performance of the trained procedure to better evaluate the impact of VR simulation on surgical performance and skill transfer.

The findings of this pilot study suggest that VR simulation is a promising strategy for improving competence and confidence among junior and senior orthopedic residents performing a technically complex procedure such as "inside-out" ACLR. The tool was well accepted by learners and improved their self-perceived readiness. As technology continues to evolve, it holds the potential to increasingly replicate surgical experience. However, further research is required to validate this emerging modality, particularly regarding skill transfer, cost-effectiveness, implementation of logistics, and barriers within trauma training programs.

CONCLUSION

This pilot study suggests that VR-based ACLR training is well accepted by orthopedic surgery residents and provides a highly satisfactory and immersive learning experience. Residents reported improved understanding of procedural steps and increased self-perceived confidence, with senior residents benefiting most with respect to the primary surgeon role and junior residents reporting greater confidence in assisting in the procedure. These findings support the feasibility and acceptability of VR simulation as a self-directed educational tool within orthopedic residency training programs.

Declaration of generative AI in scientific writing

During the preparation of this work the authors used *ChatGPT* (OpenAI, San Francisco, CA) in order to improve grammar, clarity, and style in English academic writing. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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Declaration of competing interests

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: David Figueroa reports a relationship with International Society of

Arthroscopy Knee Surgery, Orthopaedic Sports Medicine, and the Journal of ISAKOS that includes: board membership. Other authors, declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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