v. 5, n. 28, 2025

International Journal of Health Science

*Acceptance date: 11/08/2025*

# SURGICAL SIMULATION AND MEDICAL TRAINING: USE OF SIMULATORS AND VIRTUAL MODELS TO IMPROVE THE TRAINING OF SURGEONS

*Igor Moreira Miguez Godoy*

*Jessica Souto Pantoja Moura*

*Alice Costa Ferreira da Silva*

*Gabriel Kisiolar Vaz Ferreira*

*Débora Virgínia Peixoto Montes*

*Arthur Henzo da Silva Santos*

*Renata Michelle Martins Real*

*Adriano Crizel Diehl*

*João Batista Carvalho Penna Sobrinho*

*Mauro Ricardo Souza da Luz*

*Liana Mayra Melo de Andrade*

**Abstract:** Surgical simulation has established itself as one of the most innovative and effective tools in the field of medical training, especially with regard to the training and technical improvement of surgeons. Given this, the present study aims to develop a study on the relevance of surgical simulation and medical training, as well as the use of simulators and virtual models to improve the training of surgeons. The methodology applied was based on a literature review, using books and scientific articles from databases related to the subject, between 2020 and 2025. The results confirm that simulation is effective not only in improving technical skills, but also in developing clinical reasoning, knowledge retention, student motivation, and professional self-confidence. In conclusion, it should be emphasized that surgical simulation represents not only a modern educational tool, but also a transformative milestone in medical training, responding to contemporary demands for greater efficiency, humanization, and safety in healthcare. The future of surgery undeniably lies in the widespread and judicious adoption of these technologies, and educational institutions, regulatory bodies, and health professionals have a fundamental role to play in leading this transition with responsibility, equity, and innovation.
**Keywords:** Surgical simulation. Artificial intelligence. Educational technology.

## INTRODUCTION

Surgical simulation has established itself as one of the most innovative and effective tools in the field of medical training, especially with regard to the training and technical improvement of surgeons. The use of simulators and virtual models represents a paradigm shift in surgical education, breaking with the traditional model of learning focused exclusively on the patient and promoting training based on safety, repetition, and objective assessment of skills (Feeley *et al.*, 2021).

Simulation in the medical context refers to the artificial recreation of real clinical situations in order to train healthcare professionals in a safe and controlled environment. In the case of surgical simulation, this approach involves the use of mannequins, anatomical models, virtual reality (VR) and augmented reality (AR) simulators, allowing the trainee surgeon to practice a wide range of procedures before performing them on real patients (Elessawy *et al.*, 2021).

Historically, surgical training was based on the principle of "see one, do one, teach one," which limited practice and placed the patient in a vulnerable position. Surgical simulation breaks with this model, offering an ethical, effective, and reproducible training field (Meling *et al.*, 2020).

There are several types of simulators used in surgical training, each with distinct characteristics and levels of complexity, as described by Kim *et al.* (2023):

- Low-fidelity simulators: These include anatomical models or mannequins that simulate parts of the human body. They are useful for training basic motor skills, such as suturing or venipuncture.
- Medium Fidelity Simulators: These usually have mechanical or electronic features to simulate physiological responses and are applicable to more complex training, such as laparoscopy or endoscopy.
- High Fidelity and Virtual Reality Simulators: These use advanced virtual and augmented reality software that allow for highly immersive and interactive experiences, with tactile, visual, and auditory feedback. They can be used for robotic, neurological, and cardiac surgeries, among others.

Simulation is not limited to the initial training of medical students, but is also widely used in continuing medical education, skills revalidation, and training in new techniques. Hospitals, universities, and training centers around the world have implemented surgical simulation laboratories to train their professionals and maintain standards of excellence. (Pettinelli *et al.,* 2023). In addition, simulators are used for performance evaluation and are incorporated into certification exams and medical residency selection processes, given their ability to measure practical skills in an objective and standardized manner.

Despite its benefits, the implementation of surgical simulation still faces challenges, such as the high cost of high-fidelity equipment, the need for training qualified instructors, and the effective integration of this methodology into medical curricula. However, technological advances, such as artificial intelligence and computer graphics, promise to make simulators increasingly accessible and realistic (Kim *et al.*, 2023).

Given this, the present study aims to develop a study on the relevance of surgical simulation and medical training, as well as the use of simulators and virtual models to improve the training of surgeons.

## METHODOLOGY

This study was developed through a literature review, with the aim of gathering, analyzing, and synthesizing the main scientific evidence published between 2016 and 2025 on the use of simulators and virtual models in surgical training. The review sought to identify the main technological advances, benefits, limitations, and future prospects of simulation applied to medical training, especially in the surgical context.

The search was conducted in the following databases: PubMed/MEDLINE; SciELO (Scientific Electronic Library Online); Scopus; Web of Science; and Lilacs (Latin American and Caribbean Health Sciences Literature). The following descriptors (DeCS/MeSH) were used, combined with Boolean operators: "Surgical Simulation"; "Medical Education"; "Virtual Reality"; "Simulators"; "Surgical Training"; "Simulation-Based Training"; "Surgeon Training"; and "Educational Technology in Medicine."

The inclusion criteria were full articles published between 2020 and 2025; publications in English, Portuguese, or Spanish; primary studies (clinical trials, cohort studies, qualitative and quantitative studies) or systematic reviews; and works addressing simulation applied to surgical and medical skills training.

The exclusion criteria were theses, dissertations, editorials, and abstracts without access to the full text; studies addressing simulation in non-medical contexts; and works repeated between databases.

Data analysis was performed through interpretive reading and thematic categorization of the main findings, allowing for a comparative discussion between the selected studies, as well as the identification of gaps and trends in the scientific literature.

As this is an exclusively bibliographic research, which does not involve human beings or sensitive data, it was not necessary to submit it to the Research Ethics Committee, in accordance with Resolution No. 510/2016 of the National Health Council.

## RESULTS AND DISCUSSION

Studies such as Li *et al.* (2025) show that the use of simulators allows students and residents to develop fine and complex motor skills, such as hand-eye coordination, instrument control, and movement accuracy. Also according to the meta-analysis conducted by Li *et al.* (2025), participants who trained on virtual reality simulators showed significant improvement in technical performance (SMD = 1.44) compared to traditional teaching.

In this regard, various simulators allow students to make mistakes and learn without compromising patient safety, especially in highly complex procedures such as neurosurgery or cardiovascular surgery. As highlighted by Raison *et al.* (2021), training on simulators contributes to a significant reduction in the number of intraoperative errors in novice residents.

In addition to technical skills, simulators offer cognitive training with surgical steps, three-dimensional anatomy, and clinical reasoning. Applications such as Touch Surgery® have proven effective in reinforcing theoretical knowledge befor ing real procedures, with significant improvements in practical assessments (Aydin *et al*., 2020).

Most modern simulators provide real-time feedback with quantitative data on execution time, accuracy, efficiency, number of errors, and instrument trajectory, allowing students to monitor their progress based on objective metrics, as demonstrated in comparative studies with simulators such as LapSim®, LapMentor®, and RobotiX Mentor® (Biasi *et al.,* 2025).

Unlike traditional methods that depend on the availability of cadavers, patients, or operating rooms, simulation allows for unlimited repetitions. This deliberate practice is essential for consolidating muscle memory and reducing the learning curve, as evidenced by Bickford *et al*. (2025) in robotic surgery training.

Qualitative studies such as Gan *et al.* (2023) indicate that students at a university in China feel more confident and motivated after practicing on simulators. Thus, students who used VR for tendon suturing demonstrated greater self-confidence and superior performance in OSCEs after 1 year (Gan *et al*., 2023).

Despite advances, there are still barriers that hinder the full implementation of simulators in medical education, especially in developing countries or institutions with limited budgets.

High-fidelity simulators and advanced VR/AR systems require a significant investment. In addition to the initial cost, there are expenses for software updates, maintenance, technical support, and instructor training. A robotic simulator such as RobotiX Mentor® can cost over US$ 100,000 per unit, which represents a significant barrier for institutions with limited resources (Bickford *et al.*, 2025).

Some tools require specific laboratories, high-speed internet, powerful computers, and adequate physical space. This limits home use and imposes barriers to implementation in remote locations or hospitals with poor infrastructure (Li *et al.,* 2025).

Sparn *et al.* (2024) cite that because each company develops simulators with their own interfaces and algorithms, there is still little standardization between different systems, which makes it difficult to create common benchmarks for performance evaluation and external validation. Sparn *et al.* (2024) showed that the three most widely used simulators (LaparoS®, LapSim®, LapMentor®) presented similar results, but there was no consensus on which one offers the best correlation with reality.

Many educational institutions still view simulation as something "complementary" rather than an essential part of the curriculum, which makes it difficult to allocate time, budget, and teaching staff. Therefore, for a real impact, simulation must be integrated into the formal curriculum, with a defined workload and mandatory assessment (Sparn *et al.*, 2024).

Although most studies indicate positive effectiveness, many have small samples, are short in duration, and have a high risk of bias. The most recent meta-analyses (Li *et al.,* 2025; Bickford *et al.,* 2025) reinforce the effectiveness but also warn of high heterogeneity of results (high $I^2$), requiring more longitudinally robust studies to confirm the sustainability of benefits over time.

In this context, the medical education landscape is undergoing rapid transformation driven by emerging digital technologies. The use of virtual reality (VR), augmented reality (AR), mixed reality (MR), artificial intelligence (AI), and high-fidelity haptic simulators is shaping a new era in surgeon training. In the coming years, deeper integration of these technologies into medical curricula is expected, with the potential to expand access, reduce risks, and standardize learning on a global scale.

Mixed reality, which combines elements of VR and AR, is being incorporated to allow students to interact simultaneously with the physical world and three-dimensional digital models. A recent study by Wu *et al.* (2025), which highlighted the use of interactive photorealistic 3D visualizations in orthopedic training, demonstrating better spatial understanding and anatomical retention when compared to conventional teaching.

Sadeghnejad *et al.* (2023) describe that the development of more accurate tactile interfaces is a promising frontier, in which state-of-the-art equipment is being designed to more faithfully simulate tissue resistance, textures, and anatomical variations—essential aspects in delicate surgeries such as neurosurgery, minimally invasive cardiac surgery, and otolaryngology.

According to the authors above, they presented a system for nasal endoscopy with haptic feedback and positive validation in practical skills, highlighting the relevance of tactile interfaces (Sadeghnejad *et al.*, 2023).

In this context, artificial intelligence promises to make teaching more adaptable, offering real-time feedback, automatic error identification, performance analysis, and personalized tracks for students, since researchers such as Ma *et al.* (2020) have already demonstrated AI models that analyze videos of simulated surgical procedures and provide intelligent guidance based on expert benchmarks.

For Ma *et al.* (2020), the future points to platforms that "learn with the student," adjusting the level of difficulty of tasks, suggesting specific training based on observed failures, and even predicting surgical risks based on movement and behavior patterns.

It is believed that with the popularization of mobile technologies and accessible devices (such as cheaper VR glasses and cognitive simulation apps), there will be democratization of access to quality surgical education, especially in low- and middle-income countries. Studies such as that by Liu *et al.* (2025) indicate that app-based cognitive simulations are as effective as face-to-face methods for the initial stages of training, allowing for the inclusion of students from remote regions or with limited infrastructure.

According to Liu *et al.* (2025), there is currently a trend toward replacing traditional theoretical tests with objective performance-based assessment systems on simulators. Platforms already allow the recording of metrics such as: Movement accuracy; Execution time; Instrumental trajectories; and Real-time decision making.

Given this, over time, this information could be used to create digital portfolios of surgical skills, valid for professional accreditation, diploma revalidation, and competency certification—aligning with competency-based medical education (CBME) models.

According to Soh et *al.* (2022), with better-trained professionals, surgical errors are expected to decrease, patient safety will improve, hospital costs related to complications will decrease, and the training of specialists will become more agile, especially in underserved regions.

Studies such as Sho *et al.* (2022) describe that physicians trained in simulated environments make faster and more effective decisions in surgical emergencies, demonstrating greater emotional resilience and motor control in high-pressure environments.

Therefore, the future prospects for the use of simulators and virtual models in surgical training are promising and multidimensional. The incorporation of mixed reality, haptic feedback, artificial intelligence, and metaverse environments is poised to redefine the parameters of medical education. Furthermore, it is expected that, in a few years, high-fidelity simulation will be the primary form of practical surgical learning, rather than just an auxiliary tool.

## CONCLUSION

Surgical simulation has established itself as one of the most innovative and promising pillars of contemporary medical education. The use of high-fidelity physical simulators, virtual reality platforms, augmented reality, and mixed reality has transformed the way surgeons in training develop their technical and cognitive skills, allowing for an immersive, safe, and controlled learning experience.

Among the main benefits highlighted in the scientific literature, simulation promotes a risk-free environment where mistakes are a learning opportunity rather than a threat to patient safety. In addition, modern simulators provide real-time feedback, objective performance data, and unlimited repeatability, which are fundamental aspects for the continuous development of surgeons.

However, despite advances, significant challenges remain, including the high costs of acquiring and maintaining simulators, the need for standardization across different platforms, institutional resistance to curriculum change, and ethical and legal issues that arise with the use of intelligent technologies and the collection of sensitive data. Such obstacles require well-structured political, regulatory, and pedagogical strategies to ensure that the benefits of simulation are fully exploited, especially in resource-limited settings.

Therefore, surgical simulation represents not only a modern educational tool, but a transformative milestone in medical training, responding to contemporary demands for greater efficiency, humanization, and safety in healthcare. The future of surgery undeniably lies in the widespread and judicious adoption of these technologies, and educational institutions, regulatory bodies, and healthcare professionals have a fundamental role to play in leading this transition with responsibility, equity, and innovation.

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