

Integrating Virtual Reality into Surgical Training to Enhance Technical Accuracy and Engagement

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Abstract

The lack of adequate surgical training due to ethical constraints, limited hands-on opportunities, and patient safety concerns contributes to insufficient skill development, low confidence, and restricted growth among trainees. Virtual Reality (VR) offers a promising solution by enabling immersive, risk-free simulation of surgical procedures. This perspective proposes the conceptual development of a VR-based simulation module focused on essential procedural skills such as incisions and suturing. The system includes a 360-degree headset, motion-tracking sensors, and interactive tools to mimic a real operating environment. It will be developed through the collaboration between clinical educators and software designers. The module aims to provide a realistic and engaging experience that supports active learning and improves performance. Although the model has not yet been tested, it has the potential to enable standardized training, personalized learning paths, and increased accessibility. Grounded in current practice gaps, this concept reflects on the transformative role VR can play in modern surgical education, ultimately restoring confidence in early-stage learners.

Keywords: *Virtual reality, surgical training, simulation, medical education innovation, skill development.*

INTRODUCTION

The rapidly advancing field of medical science needs innovations to promote expertise and address ethical limitations, practical administration, and financial barriers in conventional surgical training. Traditionally, cadavers, plastic models, and animals have been used for surgical skills training with all their limitations. As the field evolves, critical questions emerge: How can future surgeons be equipped with real-world skills without incurring real-world risks? The implementation of virtual reality in surgical simulation can be an innovative solution; it can be a valuable training tool in the medical field, creating virtual, live surgical scenarios and a risk-free, immersive environment for skill development. This commentary highlights the potential, challenges, and future integration of VR in surgical simulation, endorsing the integration of clinical skills and modern tools in a way that still values human care and compassion.

VIRTUAL REALITY: A NECESSARY SHIFT IN SURGICAL EDUCATION

Virtual reality comes from two words: ‘virtual’ and ‘reality’. The word ‘virtual’ means near, and ‘reality’ means experience as a human being. So it means it is close to reality, for specific reality emulation. VR creates a simulated environment using computer technology. It allows the user to interact in a 3D virtual world *via* a screen, providing simulated vision, hearing, and touch in the artificial world [1].

Traditional surgical simulation often relies on the use of cadavers or animals, both of which come with significant limitations. The use of cadavers is discouraged primarily for two reasons: first, preserved human corpses are not always readily available in optimal conditions; second, their use is time-limited, as bodies must eventually be returned to families for ceremonial purposes. Similarly, animal-based models present challenges because they need comprehensive infrastructure to house, maintain, and prepare the animals, along with proper disposal procedures. These requirements entail high costs and require the involvement of multiple professionals to ensure appropriate handling [2].

BEYOND CADAVERS AND ANIMALS: OUTDATED MODELS IN A MODERN WORLD

In recent years, plastic models have replaced cadavers and animal-based simulation. This adoption has reduced ethical concerns about patient safety and the potential extinction of animals. However, it still falls short of providing trainees with actual hands-on surgical experience in a real operating theater environment. These models may serve as partial substitutes, but they have not yet proven effective as standalone tools for comprehensive surgical training [3].

The challenges in surgical education include ethical values, limited training opportunities, resource-restricted environments, and patient safety concerns, which have collectively contributed to a lack of skill development and insufficient confidence among trainees.

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VR AS A GAME-CHANGER IN SURGICAL SIMULATION

A randomized study found that using interactive and immersive VR not only improved medical students' knowledge retention but also enhanced their motivation to study and decreased their fear of learning new things [4].

Various studies suggest that integrating a VR-based surgical teaching environment can help trainees reduce psychological pressure and anxiety by providing a risk-free, repeatable, and feedback-rich environment in which they can practice without fear of harming patients, thereby lowering learning pressure and boosting confidence [5].

The significance of implementing virtual reality is to enhance health professionals' skills and help overcome obstacles, including the lack of cadavers, concerns about patient safety, and resource and budget constraints. Furthermore, VR disposition enables impartial and documented evaluations of user skill [3].

The implementation of VR in surgical simulation can enhance self-efficacy [6], support the development of knowledge and technical skills [7], and build learners' confidence in their abilities [8].

BRIDGING THE CONFIDENCE AND COMPETENCY GAP

Furthermore, VR offers diversity in other educational opportunities, such as the development of nontechnical competencies, including awareness and understanding, which are crucial for evolving empathy [3]. Simulation-based training enhances performance, reduces errors, and improves competency [9].

Some platforms, such as Osso VR [10] and Touch Surgery [11], already support surgical trainees by offering immersive environments where they can sharpen their skills and build confidence. These platforms are especially effective for personalized learning, allowing users to progress at their own pace.

Implementing similar VR-based approaches in simulation is urgently needed—not only for beginners but also for experienced surgeons who continue refining their skills throughout their careers. For example, some right-handed surgeons practice using their left hand to improve fine motor control by performing writing or stitching exercises for hours each day [12]. Introducing structured VR-based training modules early in the medical field can help develop this motor precision from the outset, reducing the time required for later correction and enhancing overall surgical performance.

VR can serve as an effective tool for both learning and teaching, especially in resource-limited settings. It can be accessed remotely, allowing students to engage with the material at their own convenience [13]. Moreover, the use of visual representation in VR enhances memory retention by making complex concepts easier to understand and recall [14].

EVIDENCE GAP: WHY A FOCUSED VR SOLUTION IS STILL NEEDED

Many systematic reviews and meta-analyses have emphasized the growing importance of implementing virtual reality (VR) in education. However, much of the existing literature either focuses on general educational settings or fails to distinguish between immersive and non-immersive approaches. One such review reported that the most commonly studied application domains were medicine (78%), social sciences (15%), neuroscience (11%), and psychology (11%) [15].

Several reviews have evaluated the use of head-mounted displays (HMDs) in medical and surgical training. Their findings indicate that current systems often lack education-centered design features, thereby significantly limiting their practical applicability for developing surgical skills [16].

This persistent gap between the needs of surgical training and the limitations of existing VR applications underscores the urgency for a low-cost, remotely accessible, and highly effective VR simulation solution.

LIMITATIONS IN VR ADAPTATION

In 'virtual surgery,' the most common form of medical simulation, the surgeon practices surgical procedures multiple times and enhances their skills in a virtual environment using a virtual patient. Studies have shown that virtual surgery significantly improves surgical performance in the operating room, especially in delicate procedures such as glaucoma and brain surgery [17].

Despite its great importance, several limitations limit its adoption in simulation.

Cost: Various studies have shown that virtual surgery systems are expensive [18] and are not readily adopted in simulations. The software, graphic resolution, display, and other accessories are costly.

Content design: Creating engaging content that makes users feel present in a real surgical environment is a challenge. Designers often lack familiarity with medical terminology and knowledge, which limits their ability to design VR modules that meet actual training needs.

Installation and operation: Due to a lack of knowledge and expertise, educators are unable to introduce and operate the system properly.

CONCEPTUAL INNOVATION: A LOW-COST VR-BASED TRAINING MODULE

VR appears to be a valuable training tool in medical education, enabling safe acquisition of skills. It can be used to train healthcare professionals in anatomy, surgical procedures, and infection control practices. Through virtual simulations, users can rehearse complex procedures using precise visual data, leading to better understanding and performance. This approach promotes skill-building and self-reliance without exposing real patients to risk [19].

This conceptual pilot recommends developing a VR-based surgical simulation module focused on basic procedural skills, including incisions, suturing, and instrument handling. The VR setup will comprise a headset that offers a 360-degree immersive visual experience, motion-tracking sensors to detect hand, head, and body movements, and input devices that allow users to interact with the virtual environment—such as picking up tools, making incisions, suturing, and more. A software system will generate the virtual visuals and control the physical interactions in the simulation. This tool is intended to be a low-cost, effective solution for surgical exercise and will be developed through collaboration between clinical educators and software designers. After development, the module will be pilot-tested with a small group of users to gather feedback on its functionality, realism, and learning value (Table 1).

SCALABILITY, EQUITY, AND REMOTE ACCESS

This module has the ability for further development in the drilling of more complex surgical procedures, such as laparoscopy and robotic surgery. It can also be integrated into remote training programs in underdeveloped regions where access to physical simulation resources is limited [20].

What makes this model unique? The low cost of remote access and its affordability are the distinctive features of this model. As it will be created through the collaborative efforts of software developers and clinical educators, it bridges the gap between technical innovation and clinical training. The purpose is to fill the gap between theoretical knowledge and hands-on surgical practice.

RECOMMENDATIONS FOR MEDICAL EDUCATORS AND POLICYMAKERS

VR has shown strong potential in enhancing spatial memory across a variety of applications. It has been particularly effective in simulating real-world environments to assist individuals with navigation challenges, such as those with neurodegenerative disorders, acquired brain injuries, developmental topographical disorientation, or psychological conditions like spatial anxiety, agoraphobia, and visual impairments, enabling them to move through their surroundings with increased confidence [21].

Furthermore, a recent study showed that using VR to train neurosurgery residents before performing craniotomies on 3D-printed models achieved greater accuracy and efficiency [22]. Similarly, the application of VR in planning intracranial aneurysm surgery has yielded encouraging outcomes [23]. These examples highlight that neurosurgery is a significant direction for expanding VR-based surgical simulation.

These insights highlight the importance of integrating VR into surgical simulation.

For both beginner and experienced doctors, VR can be a promising solution to the problems they face during surgical orientation. Thus, VR can help sharpen skills, build self-confidence, and improve the ability to adapt to the higher-pressure environments of the operating theater. Experienced surgeons can use this to refine their skills and stay up to date with emerging surgical techniques. Furthermore, it will enable trainees to practice rapid decision-making in critical situations without risking real patients.

Table 1: Key features, purpose and importance of innovative surgical headset.

Features	Purpose	Importance
Head set	To provide virtual operation theater environment	Sense of space
Motion sensor	To capture real-time movements and actions of the user	Ensures accurate simulation of surgical gestures and ergonomics
Input devices	To allow users to perform surgical tasks like picking up instruments	Promotes hands-on skills development in a safe environment
Software system	To manage the simulation environment and synchronize user actions	Provides responsive, interactive, and adaptable training scenarios

Significantly, VR will also reduce the dependency of junior surgeons on experienced surgeons for constant supervision during operations, providing a risk-free environment. This will develop individual agency while maintaining the patient's safety.

Due to its dynamism and proven educational value, medical educators and policymakers are advised to include VR models in surgical training programs in early medical education and to continue professional development.

CONCLUSION

With the increasing demand for highly experienced and proficient surgeons, the traditional simulation method alone cannot meet the complex needs of modern surgical simulation. Therefore, integrating virtual reality into simulation is the most powerful way to improve surgical training. It can be an encouraging option to address problems like limited hands-on experience and uneven training, and, most importantly, it can help save the world from animal extinction. VR lets students experience real-life situations virtually, where they can make mistakes and learn without endangering patients' lives. Although its implementation in simulation is limited by factors such as affordability, quality content, and hands-on training on how to use it, creating simple, cost-effective VR can help. Health care workers and policymakers should consider it a valuable and powerful tool for medical education and ongoing training. This will help us to make better surgeons in a safer environment.

CONFLICT OF INTEREST

The author declares no conflict of interest.

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AUTHOR'S CONTRIBUTION

Conceptualized the study, reviewed the literature, and wrote the manuscript.

GENERATIVE AI AND AI-ASSISTED TECHNOLOGIES IN THE WRITING PROCESS

During the preparation of this work the author(s) limitedly used ChatGPT (GPT-4, OpenAI) to get language suggestions and do minor proofreading in some parts of the manuscript. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the published article.

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