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Augmented and virtual reality in surgical training and planning

Realidade aumentada e virtual no treinamento e planejamento cirúrgico

Realidad aumentada y virtual en la formación y planificación quirúrgica

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Miguel Lucas Silva Valente
Medical Student
Institution: Universidade Federal do Acre (UFAC)
Address: Rio Branco – Acre, Brazil
E-mail: miguelvalente001@gmail.com

Donizete Junior Dalto
General Surgery Resident
Institution: Fundação Hospital Estadual do Acre (FUNDHACRE)
Address: Rio Branco – Acre, Brazil
E-mail: juniordalto.ro@gmail.com

Francisca Alessandra Lima de Souza
Medical Student
Institution: Universidade Federal do Acre (UFAC)
Address: Rio Branco – Acre, Brazil
E-mail: falessandra32@gmail.com

Ana Cristina Ferreira
Medical Student
Institution: Universidade Federal de Roraima (UFRR)
Address: Boa Vista – Roraima, Brazil
E-mail: anacristinacf22@gmail.com

Roque Júnior Diniz Legramanti
General Surgery Resident
Institution: Fundação Hospital Estadual do Acre (FUNDHACRE)
Address: Rio Branco – Acre, Brazil
E-mail: bandac2008@gmail.com

Natália dos Anjos Tenório
Institution: Universidade Federal de Alagoas (UFAL)
Address: Maceió – Alagoas, Brazil
E-mail: anjosnatalia2@gmail.com

Sthefanie da Silva Bessa
MD
Institution: Centro Universitário São Lucas (UNISL)
Address: Porto Velho – Rondônia, Brazil
E-mail: bessasthefanie@gmail.com

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Bernardo Furtado Cruzeiro
General Surgery Resident
Institution: Fundação Hospital Estadual do Acre (FUNDHACRE)
Address: Rio Branco – Acre, Brazil
E-mail: becruzeiro@hotmail.com

Rafael Felipe Gonçalves Batista
General Surgery Resident
Institution: Fundação Hospital Estadual do Acre (FUNDHACRE)
Address: Rio Branco – Acre, Brazil
E-mail: raphaellmed2685@gmail.com

Ary Rodrigues Turcheto
General Surgery Resident
Institution: Fundação Hospital Estadual do Acre (FUNDHACRE)
Address: Rio Branco – Acre, Brazil
E-mail: aryturcheto@gmail.com

ABSTRACT

This literature review examines the impact of Augmented and Virtual Reality on surgical training and procedural planning. These technologies improve surgical accuracy, reduce intraoperative errors, and offer a safe training environment. While challenges such as implementation costs and training standardization remain, the benefits make AR and VR promising tools for future surgical education and practice.

Keywords: Augmented Reality, Virtual Reality, Surgical Training, Surgical Planning, Medical Simulation.

RESUMO

Esta revisão de literatura examina o impacto da Realidade Aumentada e Virtual no treinamento cirúrgico e no planejamento de procedimentos. Essas tecnologias melhoram a precisão cirúrgica, reduzem erros intraoperatórios e oferecem um ambiente seguro para treinamento. Embora desafios como custos de implementação e padronização do treinamento ainda existam, os benefícios tornam a Realidade Aumentada e a Realidade Virtual ferramentas promissoras para a educação e a prática cirúrgica no futuro.

Palavras-chave: Realidade Aumentada, Realidade Virtual, Treinamento Cirúrgico, Planejamento Cirúrgico, Simulação Médica.

RESUMEN

Esta revisión de literatura examina el impacto de la Realidad Aumentada y Virtual en la formación quirúrgica y en la planificación de procedimientos. Estas tecnologías mejoran la precisión quirúrgica, reducen los errores intraoperatorios y ofrecen un entorno seguro para la formación. Aunque persisten desafíos como los costos de implementación y la estandarización de la formación, los beneficios hacen que la Realidad Aumentada y la Realidad Virtual sean herramientas prometedoras para la educación y la práctica quirúrgica en el futuro.

Palabras clave: Realidad Aumentada, Realidad Virtual, Formación Quirúrgica, Planificación Quirúrgica, Simulación Médica.

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1. INTRODUCTION

Technological advancements have significantly impacted medical practice, particularly in the field of surgery. Among emerging innovations, Augmented Reality (AR) and Virtual Reality (VR) have been widely explored to enhance surgical training and procedural planning. These technologies allow professionals to immerse themselves in high-fidelity simulated environments, reducing risks for patients and providing a more interactive and effective learning experience (SANG et al., 2024; KAWASHIMA et al., 2024).

Augmented Reality integrates digital elements into the physical environment, allowing the overlay of three-dimensional images in real-time during surgical procedures. In contrast, Virtual Reality creates a fully digital environment where surgeons can practice technical skills without direct interaction with real patients or tissues (TONI et al., 2024). These approaches have been extensively adopted to train motor and cognitive skills, improving the learning curve and knowledge retention among healthcare professionals (XIONG et al., 2025).

Traditional surgical training, based on real patient practice and training on animal or cadaveric models, faces challenges related to resource availability and patient safety. The introduction of AR and VR offers an innovative solution by enabling surgeons to simulate complex scenarios, refine their skills, and minimize intraoperative errors (DU et al., 2025). Moreover, these technologies are applied in surgical planning, allowing for a better visualization of patient anatomy and greater precision in procedure execution (QI et al., 2024).

Given the growing interest and implementation of these technologies, this review aims to analyze the impact of Augmented and Virtual Reality in surgical training and procedural planning, identifying their benefits, limitations, and future perspectives.

2. METHODS

This literature review followed the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) protocol guidelines. A systematic search was conducted in the PubMed, Embase, Scopus, Cochrane Library, and Web of Science databases, covering studies published between 2013 and 2025. The following descriptors were used, combined with Boolean operators (AND, OR): "Augmented Reality", "Virtual Reality", "Surgical Training", "Surgical Planning", "Simulation", "Medical Education". The inclusion criteria adopted were: (1) studies evaluating the use of AR and VR in surgical training and planning, (2) original articles published in English or Portuguese, (3) studies employing robust

methodologies to assess the effectiveness of these technologies. Reviews without original data, studies with small or irrelevant samples, and articles without full-text access were excluded.

The study selection was performed in three stages: (1) screening of titles and abstracts, (2) full-text reading of potentially relevant articles, and (3) critical evaluation of the methodological quality of the included studies. Two independent reviewers conducted the selection process, and disagreements were resolved by a third reviewer.

For the critical quality assessment of the studies, tools such as the Medical Education Research Study Quality Instrument (MERSQI) and the Newcastle-Ottawa Scale (NOS) were used. The synthesis of the results was performed qualitatively, identifying usage patterns, advantages, limitations, and gaps in the existing literature.

The extracted data were organized into tables that included information on authors, year of publication, study type, evaluated interventions, and key findings. This approach ensured a comprehensive analysis of the impact of Augmented and Virtual Reality on surgical training and procedural planning.

3. RESULTS

The analysis of selected studies revealed that the application of Augmented and Virtual Reality in surgical training and planning has a significant impact on surgeon education and procedural accuracy. Several studies demonstrated that using these technologies improves execution accuracy, reduces intraoperative errors, and provides a safe environment for practical learning (RAHIMI et al., 2023; COLOMBO et al., 2023).

Virtual Reality has been widely employed in teaching motor skills and simulating complex surgeries. Studies indicated that trainees subjected to VR training exhibited higher knowledge retention and better technical performance compared to traditional methods (STEVANIE et al., 2024). Additionally, VR has been applied in surgical planning, allowing surgeons to perform detailed and personalized preoperative simulations, resulting in better predictability of outcomes (LAN et al., 2023).

Augmented Reality has primarily been used to guide intraoperative procedures, improving surgeons' spatial perception and reducing dependence on conventional monitors for medical image visualization. Recent studies indicate that integrating AR with surgical navigation systems increases anatomical localization accuracy and enhances clinical outcomes (BEGAGIĆ et al., 2024).

Furthermore, the combination of AR and VR with artificial intelligence has been explored to enhance the personalization of surgical training, providing immediate feedback and performance-based improvement suggestions (MOFATTEH et al., 2022).

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The use of these technologies has also demonstrated a reduction in surgical time, as VR allows for procedural rehearsals and AR enables real-time assistance, optimizing decision-making (SUN et al., 2023). Some studies reported that AR-assisted surgeries improved ergonomics and reduced surgeon fatigue, contributing to better efficiency in the operating room (TONI et al., 2024).

Another notable finding is the impact of AR and VR in telemedicine and remote surgery training, allowing experts to assist procedures in real-time, which has been particularly beneficial in underserved regions with limited access to experienced surgeons.

4. DISCUSSION

The findings of this review support the growing acceptance of Augmented and Virtual Reality as effective tools in medical education and surgical practice. The main advantage of these technologies is their ability to provide a safe learning environment where errors can be corrected without compromising patient safety (MOFATTEH et al., 2022). Moreover, the accessibility of VR-based simulators allows for standardized training, reducing disparities in surgical education.

However, challenges still need to be addressed for the widespread adoption of these technologies. The high costs of implementation, the need for specialized infrastructure, and the learning curve associated with these tools are significant barriers (SUN et al., 2023). Additionally, issues related to visual fatigue, adaptation of professionals to continuous use, and the lack of standardization in training protocols require further research.

Future studies should focus on evaluating the long-term effects of AR and VR on clinical outcomes, as current data is still limited. The integration of these technologies into medical curricula may be a solution to increase their accessibility and acceptance, ensuring that students and professionals have early and continuous exposure to these advancements (TONI et al., 2024).

5. CONCLUSION

Augmented and Virtual Reality represent a significant advancement in surgical training and procedural planning, providing greater precision, safety, and efficiency in procedures. Despite the challenges, the benefits outweigh the limitations, making these technologies promising for the future of surgery. Future research should focus on optimizing accessibility, developing standardized guidelines, and integrating these tools into routine clinical practice, ensuring that more professionals can benefit from these innovations.

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