v. 4, n. 11, 2024

International Journal of Health Science

IMMERSIVE TECHNOLOGIES IN NEUROSURGERY: A COMPREHENSIVE REVIEW OF VIRTUAL AND AUGMENTED REALITY APPLICATIONS

Lucas de Freitas Sommer
Faculdade Ciências Médicas de Minas Gerais (FCMMG)
Belo Horizonte - MG
https://orcid.org/0009-0006-8093-3792

Rafaela Goulart Cruz de Magalhães
Faculdade Ciências Médicas de Minas Gerais (FCMMG)
Belo Horizonte - MG
https://orcid.org/0009-0009-0050-4632

Isabella Vitória Sousa Soares Tomiazzi
Centro Universitário Maurício de Nassau de Cacoal (UNINASSAU de Cacoal)
Cacoal - RO
https://orcid.org/0009-0005-3261-4490

Laysa de Souza Maia
Faculdade de Educação de Jaru (FIMCA)
Jaru - RO
https://orcid.org/0009-0008-6702-8688

Maria Thereza Morosini Golin
Universidade do Oeste de Santa Catarina (UNOESC)
Joaçaba - SC
https://orcid.org/0009-0000-5907-9305

Jessica Rauta Balbino
Faculdade Brasileira de Cachoeiro (MULTIVIX)
Cachoeiro de Itapemirim - ES
https://orcid.org/0009-0002-8969-8523

João Vitor Noronha Capanema
Faculdade de Ciências Médicas de Minas Gerais (FCMMG)
Belo Horizonte - MG
https://orcid.org/0009-0009-0349-7415

Maria Luísa Ribeiro de Paiva Hubner
Centro Universitário Redentor - Afya (UniRedentor)
Itaperuna - RJ
https://orcid.org/0000-0001-8058-6109

Italo Kauan Ribeiro de Carvalho Martins
Universidade Federal do Maranhão (UFMA)
São Luís - MA
https://orcid.org/0009-0000-5689-9236

Rafaela Fornazier Martinelli
Faculdade Brasileira de Cachoeiro (MULTIVIX)
Cachoeiro de Itapemirim - ES
https://orcid.org/0009-0009-7013-1587

Ana Beatriz Landim Ribeiro
Universidade Nove de Julho (UNINOVE Vergueiro)
São Paulo - SP
https://orcid.org/0009-0008-4552-8059

Neidejany de Assunção do Sacramento
Universidad Nacional de Rosario (UNR)
Rosario - Argentina
https://orcid.org/0000-0001-7050-6697.

Abstract: Objective: Evaluate and synthesize current and potential applications of immersive technologies, specifically virtual reality and augmented reality, in neurosurgery, with a focus on surgical training and preoperative planning. **Method:** Narrative Bibliographic Review through the Pubmed database, using the search strategy "Virtual reality", "Augmented reality", "Neurosurgery", in association with the Boolean operators "OR" and "AND", resulting in 651 initial articles. After applying the inclusion and exclusion criteria, only 17 became official sources for the study. **Discussion:** Studies highlight the importance of virtual (VR) and augmented reality (AR) in neurosurgical training, improving skills in complex procedures. VR positively impacts students' accuracy and attitude, although haptic feedback needs to evolve. Implementing VR in resource-limited areas requires high standards. For neurosurgeons in training, VR reduces operative stress, but there is no significant evidence of immediate clinical improvement. AR, VR and mixed reality promise to transform neurosurgery globally. **Final considerations:** The integration of VR and AR in neurosurgery has transformed preoperative training and planning, highlighting advances in accuracy and effectiveness. Despite this, challenges such as simulation fidelity and long-term correlation require further investigation. Future studies are crucial to the successful application of mixed reality, ensuring the continued effectiveness of these technologies in contemporary neurosurgery.

Keywords: Neurosurgery, Virtual Reality, Augmented Reality, Immersive Technologies.

INTRODUCTION

Immersive technologies have shaped considerable innovations in various spheres of human life, providing a redefinition of individuals' interaction with reality. These technologies, including virtual reality (VR), augmented reality (AR) and mixed reality (MR), have historical roots dating back to the 18th century, evolving over time, particularly in the cinematic and flight simulation areas, until the terminology "virtual reality" was formalized by Jaron Lanier in 1967 (JEAN W. C. et al., 2021; KAZEMZADEH et al., 2023).

Currently, the combination of immersive technologies with artificial intelligence (AI) has played a crucial role in improving medicine, facilitating diagnoses, prognoses, planning, training and surgical procedures (DURRANI S. et al., 2022). The introduction of VR, AR and MRI has shown particular relevance in neurosurgery, where enhanced visualization and simulation can be vital to the success of surgical procedures, particularly in complex operations such as the removal of metastatic brain tumors (PELARGOS P. et al, 2017; KAZEMZADEH et al., 2023).

The use of these technologies can facilitate preoperative testing, the development of neurosurgical skills, and the execution of surgical procedures with greater precision. VR, for example, allows the simulation of surgical procedures in a cyber environment, providing neurosurgeons with the opportunity to practice and improve before a real procedure. On the other hand, AR offers the superimposition of virtual objects to reality, assisting in the intraoperative visualization of critical structures, thus reducing associated risks and potentially improving surgical results (PELARGOS P. et al., 2017; KAZEMZADEH et al., 2023).

The purpose of this review was to evaluate and synthesize contemporary and future applications of immersive technologies, in particular virtual reality and augmented reality, in neurosurgery. The focus was on surgical training and pre-operative planning, exploring how these innovations can contribute to improving the training of neurosurgeons and the effectiveness and safety of neurosurgical procedures.

METHODOLOGY

This is a narrative review developed according to the criteria of the PVO strategy, an acronym that represents: population or research problem, variables and outcome. Used to develop the research through its guiding question: "How are immersive technologies, specifically virtual reality and augmented reality, impacting surgical training and preoperative planning in neurosurgery?" In this sense, according to the parameters mentioned above, the population or problem of this research refers to patients who require neurosurgical approaches and who could benefit from the use of immersive technologies for more precise and effective surgical planning, and has the objective to evaluate and synthesize current and potential applications of immersive technologies, specifically virtual reality and augmented reality, in neurosurgery, with a focus on surgical training and preoperative planning.

The searches were carried out by searching the PubMed Central (PMC) database. The search terms were used in combination with the Boolean terms "AND and "OR" through the search strategy: ((Virtual reality) OR (Augmented Reality)) AND (Neurosurgery). From this search, 651 articles were found, subsequently submitted to the selection criteria. The inclusion criteria were: articles in English and Portuguese, published between 2022 and 2023 and which addressed the themes proposed for this research, studies such as clinical trial, systematic review, literature review, systematic review and meta-

analysis, experience reports, case series, original studies, observational studies and made available in full. The exclusion criteria were: duplicate articles, available in abstract form, which did not directly address the proposal studied and which did not meet the other inclusion criteria. A total of 17 articles were selected to compose the present study.

DISCUSSION

The training of neurosurgery residents, historically anchored in William Halsted's 'see one, do one, teach one' model, faces the challenge of evolving within a context of workload restrictions and increasing demands for quality. Innovations such as virtual reality (VR) and augmented reality (AR) have been recognized as valuable tools, capable of complementing practical learning through advanced simulations that offer safe and effective training (PELARGOS P. et al., 2017). Virtual reality and augmented reality technologies offer neurosurgery residents the opportunity to practice complex surgical procedures in a safe and controlled context. With advanced simulators, they can repeat surgical techniques under the guidance of qualified instructors, fostering effective collaboration and providing immediate feedback on their actions (GONZALEZ-ROMO et al., 2023). While augmented reality allows for enhanced visualization of anatomical structures, virtual reality offers an immersive simulation of neurosurgical scenarios, improving practical skills in an environment that simulates the complexity of surgical practice (KAZEMZADEH et al., 2023; DURRANI S. et al., 2022). VR is also innovating in the area of tissue physics and deformation rendering, which can be crucial for understanding how real tissues may react during surgical procedures, thus improving simulations for training (DURRANI S. et al., 2022).

Rossitto C. P. et al. (2023) highlights the positive impact of VR training on the accuracy and understanding of neurosurgical procedures among medical students. Participants in this study demonstrated a significant increase in the accuracy of external ventricular drain (EVD) placement as well as an improvement in attitude toward VR use following training. However, although VR simulation was valued for its realism in terms of procedure planning and execution, haptic feedback was considered insufficient. This point highlights a potential area of development to increase simulation fidelity. These results support the integration of VR into surgical training and preoperative planning in neurosurgery, indicating that such immersive technologies can not only improve the skills of future surgeons but also patient safety, despite the need for continued technological evolution to maximize effectiveness. of training.

Virtual reality simulators can be programmed to replicate a diverse range of surgical interventions, facilitating comprehensive and accessible training, essential in regions with limited resources (ROSSITTO C. P. et al., 2023). It is crucial, however, that the implementation of virtual reality simulators in educational programs encompasses high standards of technical quality, including sound, high-resolution graphics and haptic feedback, to ensure an authentic experience and training reliability (KAZEMZADEH et al., 2023). For the continued advancement of neurosurgical education, it is imperative to invest in advanced simulators that provide immersive experiences covering a wide range of pathologies. This will ensure equitable access to high-quality training resources across diverse socioeconomic settings (FARAH G.J. et al., 2023).

Gonzalez-Romo. et al. (2023) evaluated the perception of participants in their study

about virtual models in a cloud-based VR environment, focusing on neurosurgery, categorizing the evaluations into realism, usefulness, practicality, satisfaction and recommendation. Most participants agreed or strongly agreed that the models are realistic and practical, and that this system must be part of neurosurgery residency training. Furthermore, they believe that virtual cadaver courses through this platform could be effective for education. Internal and external validation responses were positive in 94% and 91.4%, respectively. The conclusion of the study proposes that cloud-based VR interfaces are an innovative resource for neurosurgery education, enabling interactive and remote collaboration between instructors and trainees using volumetric models created with photogrammetry. The authors suggest that this technology could be integrated into a hybrid anatomy curriculum for neurosurgery education and recommend further studies to evaluate the educational value of this type of innovative resource. The potential applicability of virtual reality in training and preoperative planning in neurosurgery is highlighted, suggesting a promising integration of these technologies into the educational curriculum, although further investigation is needed for a comprehensive assessment of its value.

VR training has been associated with decreased operative stress and cognitive load for neurosurgeons in training (KAZEMZADEH. et al., 2023). On the other hand, there is no evidence of significant improvements in short-term clinical results when compared to conventional planning (LAN L. et al., 2023). Still, VR is a promising tool for preoperative planning, requiring further studies to validate its effectiveness (LAN L. et al., 2023).

The three-dimensional visualization of medical images enhanced by augmented reality (AR) and virtual reality (VR) enriches the anatomical analysis, giving the neurosurgeon an in-depth understanding of clinical particularities (DURRANI S. et al., 2022). AR-based neuronavigation, surpassing conventional methods, enables real-time visualization of anatomical structures, allowing the selection and detailed examination of anatomical components and providing improved surgical guidance in complex cases (DE BENEDICTIS A. et al., 2023).

In addition, VR technology allows the creation of computer-generated images, specific to each patient and anatomically accurate, through pre-operative images. This suggests a direct application in preoperative planning, allowing neurosurgeons a detailed visualization of the patient's anatomy before surgery. There is significant research into immersive haptic feedback within the context of virtually simulated surgeries. The Leap Motion haptic interface, for example, has been used with VR simulators to produce increasingly realistic simulations, providing cost-effective and virtually accurate hand and finger sensations, which is extremely relevant for surgical training (DURRANI S. et al., 2022)

AR and VR are instrumental in detecting critical neuroanatomical structures in surgical procedures, enhancing the planning of tumor resections and the delimitation of lesions, providing precision and agility to preoperative planning (DURRANI S. et al., 2022; VAN GESTEL F. et al., 2023). These technologies are fundamental in the simulation of neurosurgical interventions, adaptable to each clinical case, providing detailed surgical planning and optimization of operative techniques (JEAN. W. C., 2022; ROSSITTO C. P. et al., 2023). Studies indicate that VR is considered effective in improving surgical decision-making, with residents exhibiting a more positive perception compared to specialists (DE BENEDICTIS A. et al., 2023).

However, virtual environments still do not fully replicate the real operational context (NATHEIR S. et al., 2023).

Virtual reality (VR) increases the diagnostic effectiveness and precision of surgical techniques, helping in both pre-operative and intra-operative planning (KAZEMZADEH. et al., 2023). During microsurgeries, VR and augmented reality (AR) allow the reach of hidden structures, being integrated with the surgical microscope to visualize cranial nerves, hidden vasculature in sphenoid wing meningiomas and perforation of the dorsal basilar artery in pterional approaches (DURRANI S. et al., 2022). AR is also associated with techniques such as magnetic resonance imaging and cerebral angiography, optimizing postoperative aesthetics and the safety of surgical intervention. The combination of VR and AR with other multimodal visualization systems has been shown to be effective in maximizing the safe extent of tumor resections and optimizing patient outcomes (CHIDAMBARAM. et al., 2023). Compared to traditional methods, immersive surgery results in shorter operative time, fewer complications and a reduction in hospitalization, benefiting both academic training and patient care (DURRANI S. et al., 2022).

Rossitto C. P. et al. (2023) addresses the application of augmented reality (AR) in conjunction with high-definition fiber tractography (HDFT) and diffusion tensor imaging (DTI) to enhance visualization of complex neuroanatomy during surgical procedures and in neurosurgical education. The integration of these technologies promises to overcome the challenge of structurally correlating white matter tracts with their functions, a difficulty present when these modalities are evaluated separately. The study illustrates, through three cases of awake craniotomies for glioma resections, how real-time intraoperative fusion of electrical cortical stimulation, RA, and HDFT can provide direct evidence of the function or deficit associated with stimulation of fiber tracts. This technique has proven qualitatively useful in guiding intraoperative decision-making regarding the extent of resection of gliomas. Future studies could focus on larger, prospective cohorts of glioma patients utilizing this methodology and further correlate postoperative imaging results with patients' functional outcomes. Ultimately, Chidambaram. et al. (2023) emphasizes the potential of AR to improve both preoperative planning and surgical training in neurosurgery, highlighting the importance of future research to validate and expand the use of these immersive technologies.

Chidambaram. et al. (2023) describe an innovative technique that incorporates augmented reality (AR) and high-definition fiber tractography (HDFT) during awake craniotomies for glioma resections. The technique enables the first and most direct in vivo evidence of fiber tract stimulation and attribution of function or deficit, through real-time intraoperative fusion of electrical cortical stimulation, RA and HDFT. This method proved to be qualitatively useful in guiding intraoperative decision-making regarding the extent of glioma resection. The results suggest that this approach can improve surgical planning and training in neurosurgery by providing surgeons with a more accurate visualization of neuroanatomy and critical functional pathways.

The research indicates a path for future studies with larger, prospective cohorts to correlate postoperative imaging results with patients' functional outcomes, thus enhancing the applications of AR in neurosurgical practice.

In the study published in "Neurosurgical Focus", it is demonstrated that mixed reality (MR) applications are extensively integrated

into multiple facets of contemporary neurosurgery, including, but not limited to, vascular procedures, oncology and spine surgery. The research highlights that MR is destined to play a central role in the future of neurosurgery on a global scale, facilitating everything from remote guidance of complex operations to the training of novice neurosurgeons in different parts of the globe. Combining MR with cutting-edge technologies such as robotics and artificial intelligence promises substantial advances; for example, a procedure rehearsed in virtual reality (VR) on one continent can be replicated on another, overcoming time zone barriers. Furthermore, by integrating AI, it is possible to collect image data from thousands of international patients with rare tumors, convert them into virtual models and test them in VR environments to evaluate different surgical approaches, thus optimizing operative strategies. This study points to a future democratization of access to advanced neurosurgical techniques, enhanced by the fall in equipment prices and the increase in internet access, culminating in direct benefits for patients on a global scale.

FINAL CONSIDERATIONS

The advancement of immersive technologies, such as virtual reality (VR) and augmented reality (AR), is significantly reshaping the practice of neurosurgery. These tools have proven increasingly crucial in surgical training and preoperative planning, offering substantial improvements in precision, effectiveness and the detection of neuroanatomical structures. Its application in complex procedures has demonstrated notable advances, providing neurosurgeons with innovative tools to face clinical challenges. However, there are areas that still require attention and development. Simulation fidelity on VR and AR platforms needs further investigation to further enhance the training experience. Furthermore, it is critical to establish a clear correlation between virtual reality training and long-term clinical improvements to fully validate the use of these technologies in educational and practical contexts. Mixed reality (MR), a fusion between VR and AR, holds immense potential for neurosurgery, but is still in its early phases of application and research. Future studies are needed to fully explore its capabilities and expand its use in various areas of contemporary neurosurgery. This review highlights the continued need for research and development in immersive technologies. Further investigation is vital to ensure the continued effectiveness of these tools, maximizing their positive impact on surgical training and preoperative planning in neurosurgery. As these technologies evolve, they are expected to continue to transform and enrich both neurosurgeon training and patient care.

REFERENCES

CHIDAMBARAM, Swathi et al. Intraoperative augmented reality fiber tractography complements cortical and subcortical mapping. **World Neurosurger**y, v.X, n. 20, p. 100226, 2023.

CHIOU, S.Y. et al. Augmented Reality Surgical Navigation System Integrated with Deep Learning. **Bioengineering**, v 10, p 617, 2023.

DE BENEDICTIS, A. et al. Vertical Hemispherotomy: Contribution of Advanced Three-Dimensional Modeling for Presurgical Planning and Training. **Journal of Clinical Medicine**, v. 12, n. 11, p. 3779, 2023.

DURRANI, S. et al. The virtual vision of neurosurgery: How augmented reality and virtual reality are transforming the neurosurgical operating room. **World Neurosurgery**, v. 168, p. 190-201, 2022.

FARAH, Ghassan J. et al. Resident Training in Spine Surgery: A Systematic Review of Simulation-Based Educational Models. **World Neurosurgery**, v. 174, p. 81 - 115, 2023

GONZALEZ-ROMO, Nicolas I. et al. Virtual neurosurgery anatomy laboratory: A collaborative and remote education experience in the metaverse. **Surgical neurology international**, v. 14, n. 90, 2023.

JEAN Walter C. et al. Virtual and augmented reality in neurosurgery: a timeline. Neurosurgical focus, v. 51, n. 2, p. E1, 2021.

JEAN, Walter C. Virtual and augmented reality in neurosurgery: the evolution of its application and study designs. **World neurosurgery**, v. 161, p. 459-464, 2022.

KAZEMZADEH, Kimia; AKHLAGHDOUST, Meisam; ZALI, Alireza. Advances in artificial intelligence, robotics, augmented and virtual reality in neurosurgery. **Frontiers in Surgery**, v. 10, e1241923, 2023.

LAN, Lucy et al. Immersive Virtual Reality for Patient-Specific Preoperative Planning: A Systematic Review. **Surgical Innovation**, v. 30, n. 1, p. 109-122, 2023.

NATHEIR,S. et al. Utilizing artificial intelligence and electroencephalography to assess expertise on a simulated neurosurgical task. **Computers in Biology and Medicine**, v. 152, p. 106286, 2023.

PELARGOS, Panayiotis E. et al. Utilizing virtual and augmented reality for educational and clinical enhancements in neurosurgery. **Journal Of Clinical Neuroscience, [S.L.]**, v. 35, p. 1-4, 2017.

ROSSITTO, C. P. et al. External Ventricular Drain Training in Medical Students Improves Procedural Accuracy and Attitudes Toward Virtual Reality. **World Neurosurgery**, v. 175, p. e1246-e1254, 2023.

RUPARELIA, Jigish et al. Virtual Reality in Preoperative Planning of Complex Cranial Surgeries. **World Neurosurgery,** v. S1878-8750, n. 23, p. 00782-9, 2023.

STEFAN, Philipp et al. Computer-assisted simulated workplace-based assessment in surgery: application of the universal framework of intraoperative performance within a mixed-reality simulation. **BMJ Surgery, Interventions, & Health Technologies**, v. 5, n. 1, 2023.

TAKOUTSING, B. D. et al. Assessing the impact of neurosurgery and neuroanatomy simulation using 3D non-cadaveric models amongst selected African medical students. **Frontiers in Medical Technology**, v. 5, p. 1190096, 2023.

VAN GESTEL, Frederick et al. Neuro-oncological augmented reality planning for intracranial tumor resection. **Frontiers in Neurology**, v. 14, p. 1104571, 2023.