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Benefits of emerging technologies in medical education

Beneficios de las tecnologías emergentes en la educación médica

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Abstract

The integration of medical education emerging technologies such as artificial intelligence (AI), virtual/augmented reality (VR/AR), and gamification is transforming medical education, offering significant benefits in the clinical training of medical students and patient safety. AI personalizes learning, simulates virtual patients, generates adaptive educational content, and provides access to training resources, even in resource-limited settings. VR/AR enables safe, repetitive, and metric psychomotor training in complex procedures, which can significantly reduce anxiety (by up to 45%) in emotionally charged scenarios and improve motivation, knowledge retention, and the development of non-technical skills such as mindfulness and emotional self-regulation. Despite these benefits, this systematic review identifies critical challenges, including the risk of bias and misinformation with AI, the barrier of cybersickness in VR, and ethical, pedagogical, and infrastructure challenges to using these technologies in educational settings. It concludes that, while these tools enhance personalized, immersive, and equitable learning, their implementation must be guided by sound pedagogical principles, rigorous evaluation, and clear ethical frameworks, ensuring that they complement and do not replace the development of human clinical judgment and interpersonal interaction essential in medical practice.

Keywords: *Medical education. Emerging technologies. Artificial intelligence. Virtual reality. Clinical simulation.*

Resumen

La integración de tecnologías emergentes en la educación médica, como la inteligencia artificial (IA), la realidad virtual y aumentada (RV/RA) y la gamificación, está transformando la educación médica, ofreciendo importantes beneficios en la formación clínica de los estudiantes de medicina y en la seguridad del paciente. La IA personaliza el aprendizaje, simula pacientes virtuales, genera contenido educativo adaptativo y brinda acceso a recursos de capacitación, incluso en entornos con recursos limitados. La RV/RA permite una capacitación psicomotora segura, repetitiva y cuantificable en procedimientos complejos, lo que puede reducir significativamente la ansiedad (hasta en un 45 %) en situaciones de gran carga emocional y mejorar la motivación, la retención de conocimientos y el desarrollo de habilidades no técnicas, como la atención plena y la autorregulación emocional. A pesar de estos beneficios, esta revisión sistemática identifica retos fundamentales, entre los que se incluyen el riesgo de sesgo y desinformación asociado a la IA, la barrera que supone el mareo virtual en la RV, y los retos éticos, pedagógicos y de infraestructura que plantea el uso de estas tecnologías en entornos educativos. Concluye que, si bien estas herramientas mejoran el aprendizaje personalizado, inmersivo y equitativo, su implementación

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debe guiarse por principios pedagógicos sólidos, una evaluación rigurosa y marcos éticos claros, asegurando que complementen y no reemplacen el desarrollo del juicio clínico humano y la interacción interpersonal, esenciales en la práctica médica.

Palabras clave: *Formación médica. Tecnologías emergentes. Inteligencia artificial. Realidad virtual. Simulación clínica.*

Introduction

Medical education is undergoing a process of transformation driven by the incorporation of emerging technologies, which seek to respond to the growing complexity of clinical practice, improve patient safety, and optimize teaching-learning processes. In this context, tools related to artificial intelligence (AI), virtual or augmented reality (VR/AR), high-fidelity medical simulation, telemedicine, distance learning, and gamification are playing an increasingly important role in the training of healthcare professionals[1-3].

These technologies allow for personalized learning, the simulation of complex clinical scenarios, the training of various technical and non-technical skills in a safe environment, and expanded access to medical education, especially in resource-limited settings[4]. In addition, the use of these technologies has been shown to increase anatomical understanding, knowledge retention, and student motivation, thus promoting active, student-centered learning.

However, their integration still faces significant challenges, such as the need for teacher training, the development of adequate technological infrastructure, and the opportunity of getting equitable access to these technologies, along with ethical frameworks that allow for their responsible use. For this reason, it is necessary to critically review the available evidence on their benefits and limitations[1,5].

This article aims to review the benefits of the main emerging technologies in medical education and discuss their impact on clinical education and the safety they offer to patients.

Development

Large language models such as ChatGPT are having an increasingly important impact on medical education. These technologies drive new ways of learning, practicing, and evaluating, and also offer solutions to current challenges in the training of healthcare professionals, such as limited access to patients, teaching workload, and the need for constant feedback. Their use has grown in digital environments, where they aid autonomous and flexible learning, sometimes even asynchronous[1,6-8].

One of the main advantages of these tools is the possibility to personalize learning. Language models adapt the content and pace of study to the needs of each student, helping them identify areas for improvement and allowing them to reinforce specific knowledge. Thereby promoting a more active, student-centered learning compared to traditional educational models[1,6].

Another relevant application is AI's ability to simulate patients. Through interactions similar to a clinical interview, users can practice taking medical histories, the reasoning necessary for diagnosis, and doctor-patient communication strategies in a safe environment. This type of simulation is especially useful in the early stages of training, as it allows for mistakes and learning without putting real patients at risk[8].

On the other hand, language models are also used to generate educational content, such as clinical cases, exam questions, and study materials, such as infographics or other resources. This eases the work of teachers and expands the availability of educational resources for students. Furthermore, the possibility of automation allows for immediate feedback, which promotes self-assessment and continuous or self-guided learning by the student.

Another major benefit is the extension and expansion of access to medical education. These tools can translate content and adapt it to different educational contexts/realities, allowing students from different parts of the world to access up-to-date medical information regardless of where they are located.

Despite its advantages, the use of AI in medical education also faces limitations. One of the main risks is the generation of faulty information that may appear adequate at first glance. For this reason, it is essential that students learn to question and verify the information they receive. Likewise, models may reflect biases present in the data with which they were trained and may not always clearly explain the process used to generate their answers[7].

Ethical considerations pose a further limitation to these technologies, such as data protection, privacy, and accountability for potential errors. In addition, overreliance on these technologies may affect the development of clinical judgment and interpersonal skills, which remain essential in daily medical practice[7].

Therefore, these innovative tools should be seen as support tools, not as substitutes for teachers or human clinical reasoning. Their proper use requires supervision, training in critical thinking, and clear ethical frameworks. If integrated responsibly, these technologies have the potential to strengthen medical education and contribute to the training of professionals who are better prepared for the challenges of today's clinical practice.

Gamification and mental well-being through the use of VR

In recent years, medical education has recognized the importance of integrating emerging technologies not only for the development of technical skills but also for the reinforcement of emotional skills that are essential in clinical practice, such as emotional self-regulation, mindfulness, and stress management in different situations. Beyond its application in clinical simulation, VR has begun to be developed and explored as a tool to support psychological interventions aimed at mental well-being[9].

VR/AR as immersive learning tools: challenges and benefits

Currently, there are no evidence-based guidelines on the recommended use time for VR specifically in medical education. To guide its safe and effective implementation in classrooms, simulation laboratories, and training programs, it is useful to analyze clinical protocols, as these have established dosage parameters according to specific objectives[10,11].

For objectives that require neuroplasticity and complex motor learning (such as in post-stroke rehabilitation), protocols typically employ longer sessions (30-60 min), frequent sessions (several times per week), and extended sessions over time[12]. In contrast, for objectives focused on anxiety reduction or phobic experience management, brief interventions (even 15 min) have been proven effective. This variability suggests that, in medical education, the ideal exposure time for acquiring a complex psychomotor skill (such as laparoscopic surgery) may differ from that needed to become familiar with the 3D anatomy of a region or to train in communicating bad news in a simulated environment[13].

Identification and mitigation of the main risk: cyber sickness

The main adverse effect that can limit the adoption and effectiveness of VR in medical training is cybersickness. Its symptoms, including nausea, vertigo, headache, disorientation, and visual fatigue, not only cause discomfort but also directly compromise learning ability, information retention, and effective practice time. This phenomenon is mainly attributed to a sensory conflict: a discrepancy between what the visual system perceives (movement in the virtual environment) and what the vestibular and proprioceptive systems register (the body is still). A specific contributing factor of headsets (Head Mounted Display) is accommodation-convergence conflict, where the fixed focal length of the device does not match the virtual distance of objects, causing eye fatigue[12]. Ergonomic factors, such as headset weight, pressure on the head, restricted movement, and heat, can worsen these symptoms. Therefore, for medical education, it is essential to select ergonomic equipment, design virtual experiences with smooth and stable movements, and implement short initial sessions for student adaptation[14].

Risks, challenges, and considerations of VR in medical education

Despite the favorable evidence, current development, and gain of popularity of VR's potential use in medical education, it is of utter importance to take account the risks and limitations of this kind of technology. The innovation and constant growth of VR must be accompanied by pedagogical planning and systematic evaluations, as it can be affected by costly interventions with limited educational impact or even adverse effects on those who use it. The narrative review published in the *Oman Medical Journal* by Baniasadi et al.[15] offers a critical analysis of the main challenges and practical considerations associated with the application of VR in both medical education and clinical settings.

One of the main issues identified is the potential impact of VR on human interaction, which is considered an essential element in medical learning. This is based on the decrease in opportunities for interpersonal communication and skill development with the excessive use of these virtual environments. Therefore, it is necessary to view this technology as a tool and not as a substitute for traditional clinical teaching.

The implementation of VR also entails the responsibility of training teachers and students in this field. The use of this tool requires specific technical skills that may not always be available within teams, which can limit the potential of VR itself or lead to its inappropriate use. Added to this are the high costs associated with

the development and maintenance of these VR systems, which ultimately represent a significant and costly barrier for the various educational institutions that exist[16].

In terms of risks to user health and well-being, various phenomena have been identified, such as cybersickness, visual fatigue, spatial disorientation, and physical discomfort after several hours of exposure. These effects highlight the importance of developing safety protocols, user selection criteria, and appropriate exposure times. Regarding evaluation and validation processes, it is noted that many VR programs and applications lack evidence to support their educational efficiency, as there are no standardized metrics to evaluate learning outcomes and clinical competencies[14].

The aforementioned risks highlight the need for adequate and strategic integration of VR in medical education. While VR opens up great avenues for enriching learning, clinical simulation, and clinical skills development, its implementation must be guided by appropriate pedagogical principles, competent evaluations, and clear ethical frameworks[16].

Methods

To write this article, a systematic review of previous literature on the topic was performed using search engines like PubMed, Google Scholar, and Scopus. This review follows the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) guidelines for better inclusion and exclusion of this literature. The search period for the information collected was limited to the years 2020-2025 to capture the most up-to-date and relevant information on the topics described.

Within the PRISMA framework, inclusion criteria were established for the selection of literature: original studies (clinical trials, cohort studies, and quasi-experimental studies) published in the aforementioned search engines in English or Spanish whose titles and content were relevant to the approach of this study. Studies that did not present clear quantitative or qualitative results on the teaching-learning process, or any other type of literature that did not meet the characteristics described, were excluded. The selection process was carried out in two phases: first, by reading titles and abstracts, and then by analyzing the full text to ensure the relevance of this work.

Finally, a synthesis of the information collected was carried out, providing a new analysis of the benefits of emerging technologies in their integration and adaptation in the pedagogical fields and the relationship that students have with these tools.

Discussion

The integration of emerging technologies into medical education is not simply an update of tools, but an essential change in training programs. As the analysis confirms, the ability to personalize and democratize learning is what makes these technologies valuable[17]. The use of VR/AR (metaverse) bridges the gap between theory and practice by providing an environment for safe and repetitive practice. Its effectiveness for complex psychomotor learning and the management of emotionally demanding circumstances is supported by evidence in both clinical and educational contexts. Based on models extrapolated from rehabilitation, the review proposes that the technological workload should be managed under a strategic pedagogical dosage. In this scheme, brief, high-cognitive-intensity interventions are optimal for objectives such as anatomical recognition or emotional resilience training. In contrast, the acquisition of advanced surgical skills requires extensive and systematic programs capable of inducing the neuroplasticity changes necessary for technical mastery[18].

The combination of these technologies, such as an AI tutor supervising a VR scenario with gamified components, promises an educational environment that is highly interactive and quantifiable. Instant feedback and detection of deficiencies in individual performance can be achieved through assessment using objective data (such as procedure time, accuracy of movements, or diagnostic options), which is an advantage of these strategies.

Conclusion

The integration and adaptation of emerging technologies such as AI and VR are redefining medical education. These technologies offer advantages that would be difficult to achieve without them. They allow us to increasingly personalize learning, making clinical simulation safer and standardizing the knowledge provided to students, enabling them to work on clinical and emotional skills. The integration of these tools allows students to obtain repetitive, immersive, and assessable training, which reduces their anxiety when faced with emotionally demanding clinical cases and addresses issues such as the democratization of clinical cases in face-to-face rotations, even in

contexts with limited resources. This presupposes an imperative advance in the fields of medical pedagogy.

However, these types of advances often present challenges that should not be underestimated. There are significant risks when adapting these emerging technologies. When AI is used in medical fields, students are exposed to misinformation and carelessness in their clinical decision-making, issues that should not be ignored. When VR is used, students are exposed to ergonomic challenges due to the physiological barriers presented by this type of equipment and to phenomena such as cybersickness, which hinders and can even alter the learning curve of users. Most importantly, the possible decline in individual clinical judgment and human interaction due to excessive or misguided use of technology means that these tools should be complementary to, rather than substitutes for, traditional training, always based on evidence and rigorous evaluation.

In conclusion, the successful integration and adaptation of these emerging technologies depends on a pedagogically structured introduction, always guided by clear ethical frameworks and close evaluation and monitoring of their educational and clinical outcomes. The development of critical thinking and digital skills in the use of these tools is becoming as essential as mastery of medical knowledge itself. It can be said that the future of medical education lies in knowing how to strike a balance and find the middle ground where technological innovation expands human capabilities without displacing the irreplaceable fundamentals of medical practice.

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Conflicts of interest

J. Loría-Castellanos is member of the editorial committee of the journal Anales Médicos. The other authors declare no conflicts of interest.

Ethical considerations

Protection of human subjects and animals. The authors declare that no experiments on humans or animals were performed for this research.

Confidentiality, informed consent, and ethical approval. This study does not involve personal patient data, medical records, or biological samples, and does not require ethical approval. SAGER guidelines do not apply.

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