APCCR
Advances in Pre-Clinical and Clinical Research

ASCENTIA PUBLISHERS

Review

Augmented Reality in Healthcare: Unveiling Its Potential, Addressing Its Challenges, and Charting Its Future

Ranjitha H [1*]

[1] Scientific Division, Ascentia Innovations, India

Abstract: Augmented Reality (AR) is rapidly transforming the healthcare sector by seamlessly overlaying digital information on the real world, significantly enhancing various medical domains. Augmented reality technology improves our understanding of the real world by adding new sensory experiences to what we see, touch, and hear in our surroundings. This review explores diverse applications of AR, including its revolutionary impact on medical training and education through 3D anatomical visualization and surgical simulation as well as its role in surgical assistance and navigation for increased precision. A keyway to experience AR is through Head-Mounted Displays (HMDs), such as Google Glass, Smart Glass, and Microsoft HoloLens, which allow users to view and interact with virtual elements that are integrated into their real-world view. The use of augmented reality in medicine has far-reaching implications, offering the potential to revolutionize patient care, diagnosis, and treatment. A thorough examination of existing research reveals numerous areas within the healthcare sector where AR can be effectively integrated. This article details the contributions of AR to diagnostics and imaging, remote collaboration in telemedicine, engagement in rehabilitation programs, and advancements in pharmaceutical research, along with critical challenges, including high implementation costs, technical limitations, data privacy concerns, and regulatory hurdles. Despite these obstacles, this review highlights the recent developments in AR adoption and its advantages in healthcare.

Keywords: Augmented reality; Virtual reality; Head-mounted displays; Visualization; Real-world

Citation: Ranjitha H. Augmented Reality in Healthcare: Unveiling Its Potential, Addressing Its Challenges, and Charting Its Future. Advances in Preclinical and Clinical Research. 2025; 6:202506.

***Corresponding Author**: hranjitha5103@gmail.com; Tel.: +91 99726 35103

Funding: None

Conflict of Interest: None

Received: 13 Jun 2025; **Accepted**: 10 Sep 2025; **Published**: 29 Sep 2025

Published by Ascentia Publishers; eISSN: xxxx-xxxx

Introduction

Augmented reality (AR) is an interactive technology that overlays digital information on real-world environments, allowing various computer applications to generate virtual objects. This concept has been evolving since the 1960s and has undergone substantial advancements since that time. [1] AR works by generating a virtual image on top of a real image, enabling interaction in real-time, and seamlessly blending 3D (or 2D) virtual objects with real objects. AR is a technology that merges digital information with the real world, creating an interactive experience in which objects are generated using computer software. This has sparked intense discussions among medical professionals and opened up new avenues for research. Consequently, the healthcare industry and policymakers have quickly recognized the advantages of AR, with education and training being notable applications in medical environments. [2-4] The Real Environment (RE) is the physical world we inhabit and is governed by the laws of physics. AR enhances this real environment by superimposing virtual elements onto it, allowing participants to simultaneously see both physical and digital realities. Conversely, Augmented Virtuality (AV) takes virtual reality as its primary setting but integrates real-world elements into it, meaning participants are immersed in a synthetic world while still perceiving some real components. Finally, Virtual Reality (VR) represents a completely synthetic, computer-generated world in which the participant is fully immersed, experiencing an entirely digital environment. The distinction between virtual reality and augmented reality is evident and can be illustrated using the Reality – Virtuality Continuum model proposed by Paul Milgram and Fumio Kishino, as depicted in Figure 1. [5]

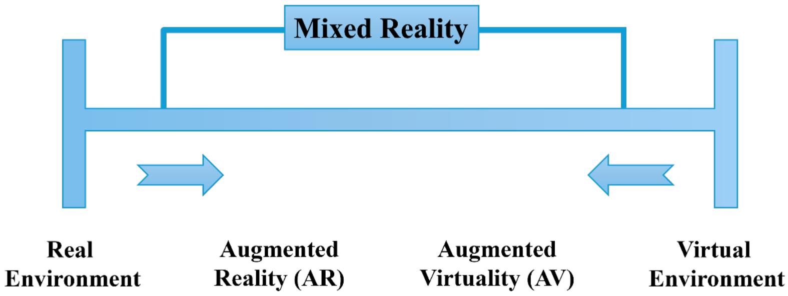

Figure 1. Milgram's Reality- Virtuality Continuum

AR enhances perception by overlaying digital information onto the real world, offering a deeper understanding and seamless integration of virtual and physical elements. This immersive experience is often facilitated by wearable devices such as Head-Mounted Displays (HMDs), smart glasses, Google Glass, and Microsoft HoloLens which allow users to effortlessly interact with virtual content within their actual surroundings. [6] This immersive technology allows healthcare professionals to interact with virtual elements while remaining connected to their physical environment, offering intuitive and contextual experiences. [7] An AR system comprises three basic steps: recognition, tracking, and mixing. In the recognition phase, any image, object, face, body, or space is identified as the target, where a virtual object is superimposed. Subsequently, during tracking, real-time spatial localization of the image, object, face, body, or space is performed, and finally, multimedia content in the form of video, 3D, 2D, text, and so on is overlaid onto it. [5] Augmented Reality (AR) technologies not only enable medical professionals to engage with and visualize information in three dimensions, requiring a broad understanding of technology for effective integration, [8-10] but also serve as a valuable resource for patient education. [11, 12] Patients can use AR applications on their smartphones to visually describe their symptoms to doctors, for instance, by pointing to areas of pain on an augmented anatomical model. This can lead to more accurate and efficient symptom reporting. [13] This allows doctors to visually clarify surgical procedures, medication functions, and new treatments, thereby enhancing patient experience, deepening understanding of intricate matters, and ultimately improving health outcomes. [14-16]

Application of AR in healthcare

Currently, AR technology is gaining substantial interest for creating applications that healthcare practitioners and patients can use directly. Augmented healthcare solutions can be applied in a wide range of fields, such as diagnosis, surgery, rehabilitation, monitoring, guidance, and education. In general, AR technology has enhanced healthcare systems by providing numerous services and platforms.

***Medical training and education**:* In the 21st century, technological advancements are accelerating at an unprecedented rate. This rapid progress is seen in young people, particularly in those studying medicine, who interact with cutting-edge digital tools. Consequently, educators are incorporating digital technology into the curriculum to enhance learning outcomes. [17, 18] Digital learning has become widely accepted in healthcare education. [19, 20] Digital technology has been fundamentally integrated into the teaching and learning processes. This integration ranges from simply converting traditional materials, such as textbooks, into digital formats like PDFs, to utilizing advanced digital tools, including video conferencing and virtual reality for dynamic and interactive learning experiences. [21] Most students and healthcare professionals have reported integrating digital technologies into their studies or daily clinical work. [22] AR significantly boosts students' understanding of anatomy and enhances simulated surgical practice, leading to improved skills during medical training, as shown in Figure 2. This technology enables risk-free surgical practice by providing interactive 3D anatomical models. [23] Medical schools are increasingly adopting AR for anatomy learning. Medivis's AnatomyX platform provides meticulously detailed 3D anatomical models that students can interact with in augmented reality, offering custom dissections and multi-user shared sessions for collaborative learning. [24] These models can be superimposed onto real bodies or mannequins, allowing for a dynamic understanding of complex structures, reducing both direct supervision and costs. Other applications like Anatomy.app and AR Anatomy (available on mobile platforms) offer detailed 3D human models for comprehensive study. AR also helps develop essential skills, such as speed, multitasking, precision, hand-eye coordination, and bimanual dexterity. Furthermore, recent advancements in AR allow experienced surgeons to provide remote training and expert consultations from anywhere globally. [25]

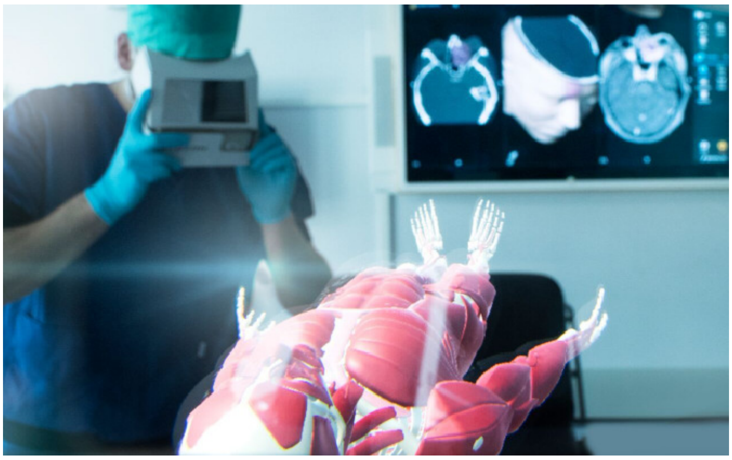

Figure 2. Using AR headset in the medical-educational area. [26]

Although the integration of augmented reality (AR) into medical education is still in its early stages, its benefits in various medical fields are already evident. For instance, AR allows surgeons to visualize organs before operations, [27] aids in the training of dental students, [28] and enhances pathology education. [29] Despite these proven advantages, AR technology has not yet achieved widespread adoption in tertiary medical or health education. Sutherland et al. and Tang et al. concluded that in medical education, augmented reality surpasses textbook readings and lecture-based instructions by offering a more immersive and realistic 3D visualization of human organs and their functions, providing a more authentic representation of the human body compared to traditional media. [11, 30] Moro et al. conducted a randomized controlled trial to assess the effectiveness of health science education via augmented reality (AR). The trial showed that participants who used both HoloLens and mobile-based AR devices achieved better test results, indicating the potential of AR in improving content delivery. Moreover, participants found learning through both devices enjoyable, suggesting that AR can be a novel and engaging method of instruction. [31]

***Diagnostics and imaging**:* AR is transforming how medical professionals interpret and interact with diagnostic information by converting 2D medical images (X-rays, CT scans, and MRIs) into interactive 3D models, allowing doctors to manipulate and explore them from various angles. This provides a more comprehensive understanding of a patient's condition and aids in more accurate diagnoses. [32] AccuVein a handheld device that emits near-infrared (NIR) light, which is absorbed by haemoglobin in veins, creating a digital image of the vascular pattern. This image is then projected as a visible map onto the patient's skin using augmented reality, providing real-time visualization. (figure 3) This technology greatly simplifies locating veins for blood draws or IV insertions, especially for patients with difficult-to-find veins, leading to significantly improved first-stick success and enhanced patient comfort during procedures. [33] Sakakibara et al, highlights the AccuVein's utility in breast cancer surgery, demonstrating its ability to visualize superficial breast veins. This aids in identifying lesions and perforating branches for safer procedures, regardless of examiner skill, ultimately improving patient outcomes. [34] Recent years in medical imaging have significantly improved disease diagnosis especially for conditions like cancer. [35] While the increased spatial resolution provides incredibly detailed views of complex anatomical structures, it also presents a challenge for doctors in efficiently review vast amounts of data. To address this, users are presented with a virtual image of the patient's examination results alongside a real-world view that adapts to the specific task, such as an integrated physical exam, medical imaging assessment, pre-operative planning, or an intraoperative procedure, the real-world image displayed would be the patient's actual anatomy. [36]

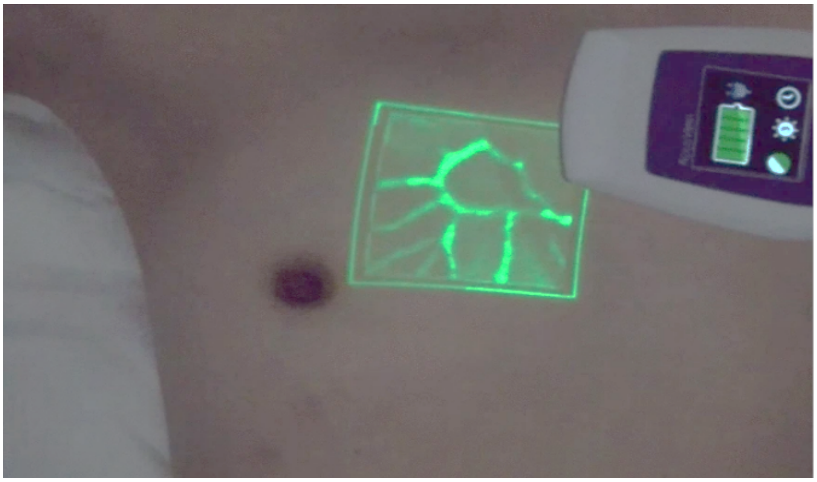

Figure 3. AccuVein® visualizes the subcutaneous mammary veins. [34]

AR can also be used to identify various eye diseases, including glaucoma and dry eye syndrome. It uses a digital contact lens to monitor the blood sugar levels in individuals with retinal implants. This technology is also used to diagnose breast cancer in sentinel lymph nodes and prostate cancer in prostatectomy samples. [37] Furthermore, it helps to understand the inner and deeper structures of the heart and analyze heart conditions based on normal, murmur, and extra-systolic sounds. Additionally, it provides cardiac data for examination, prediction, and treatment of cardiac arrhythmia. It is also used to identify skin incisions, skull craniotomy, and tumour locations. [38] A recent scoping review by Alnasery et al. (2024) explored AR integration in image-guided tumour ablations, synthesizing findings from five human studies that met the inclusion criteria, which focused on AR techniques in image-guided tumour ablation. These studies utilized various AR setups, including optical-based AR systems and head-mounted AR devices, and examined diverse tumour types. The collective findings from the reviewed studies consistently showed positive results including reduced radiation exposure, shorter procedure times, and improved navigation and targeting assistance. Overall, the review suggests that AR systems enhance image-guided tumour ablations by improving the accuracy of ablation probe placements and increasing efficiency, offering real-time guidance and enhanced visualization for optimal needle placement. [39]

Surgical precision and navigation: Historically, surgeons relied on 2D displays for complex operations. AR revolutionizes this process by projecting 3D images directly onto a patient's body. This significantly enhances their understanding of the surgical field, leading to more accurate and informed decision-making. AR surgical systems are becoming increasingly sophisticated, addressing the critical need for real-time precise visualization in complex procedures. [40] AR allows surgeons to superimpose vital information, such as internal structures and areas of concern, onto the patient in real-time, a core development is the refined ability to overlay high-resolution 3D images from pre-operative CT or MRI scans directly onto a patient's body during surgery making procedures safer and more efficient. [41]

AR systems can project precise surgical guides, optimal incision lines, and planned trajectories directly into the surgical field. This assists surgeons in achieving greater accuracy, particularly in highly precise procedures such as spinal surgery, neurosurgery, orthopaedic interventions, and dental implant placements. [28, 42, 43] In orthopaedic surgery, numerical and geometric data, as well as visual information from pre- and intraoperative medical images, are frequently utilized. Moreover, common mechanical orthopaedic procedures, such as screw, wire, or implant insertion and deformity correction, necessitate accurate knowledge of insertion point positioning in relation to the patient's anatomical structure. [44] Orthopaedic surgery encompasses a range of procedures, including hip, spinal, lower limb, shoulder, elbow, and knee operations. Sakai et al. studied the use of AR, VR, and MR in spinal surgery, verifying the advantages of minimally invasive procedures. [45] Longo et al. examined the potential of AR, VR, and AI in aiding pre-operative diagnoses. [46]

AR is widely used in neurosurgery, particularly for neuronavigation. Its advantages include reduced treatment complications, improved surgical outcomes, and shortened operative times. Neuro navigation systems, which have been around since 1986, utilize AR to superimpose pre-operative images onto the patient's visible surface, providing real-time anatomical visualization. [47] Hou et al. employed an augmented reality surgical navigation system on a low-cost iPhone. [48] Nevertheless, this method is limited in that it only displays AR images from particular viewpoints, rendering it unsuitable for real-world surgical scenarios. Schlueter-Brust et al. developed an AR-based guidance system to assist the placement of Kirschner wires for glenoid component placement in total shoulder arthroplasty. [49]

Telemedicine and Remote Collaboration: Telemedicine involves remote medical communication, a concept that originates from the use of telephones for information exchange between hospital systems. [50] AR significantly boosts telemedicine capabilities by enabling more interactive and visual remote consultations. [51] Specialists can provide real-time visual guidance and support to practitioners or even patients in remote areas, aiding in diagnosis, treatment, and emergency situations.

Rehabilitation and Therapy: AR is being increasingly integrated into rehabilitation to enhance traditional therapies and improve patient outcomes. [52] This technology superimposes digital information onto the real-world, creating more engaging physical and cognitive rehabilitation environments that motivate patients and provide real-time feedback during exercise. [53] Gamified exercises motivate patients, while AR provides a safe environment for practicing daily activities and refining motor skills, beneficial for stroke recovery, brain injuries, or managing conditions like Parkinson's. [54] Condino et al. introduced the first wearable AR system, designed to assist patients in regaining shoulder mobility by offering real-time performance monitoring and an immersive, dynamic experience. [55] Research by Lamichhane et al (2023 and Ku et al. (2019) highlights that AR-based training, particularly for balance and mobility can lead to significant improvements in scores on scales like the Berg balance scale, especially when conducted for long duration. [56, 57] While the field is still evolving, the existing research indicates AR's significant potential in making rehabilitation more engaging, effective, and accessible for a wide range of conditions, from neurological disorders. [52]

Pharmaceuticals and Drug Discovery: In the pharmaceutical sector, AR helps researchers visualize complex molecular structures and drug-target interactions in dynamic 3D, aiding drug design and optimization. AR application like molecular rift allow researchers to engage with 3D molecular representations, thereby enhancing their comprehension of how drugs interact with their targets. [58, 59] it's also used for patients education, helping them understand medications and administration instruction. [60]

Challenges and Limitations

Despite its immense potential, the widespread implementation of AR in healthcare has several significant challenges.

High Cost of Implementation: The initial financial outlay for advanced AR hardware (e.g. high-end AR headsets and specialized sensors) and the development of bespoke, medically validated software applications can be substantial. This poses a significant barrier to adoption for many healthcare institutions, particularly smaller clinics or those with limited budgets. [61]

Technical Limitations: AR technology, while rapidly advancing, is evolving. Current challenges include maintaining accurate and stable real-time tracking in dynamic clinical environments (e.g. accounting for patient movement during surgery), a limited field of view in some AR devices, display resolution limitations, and the need for robust, low-latency processing power to avoid motion sickness or lag.

Data privacy concerns: AR systems often process and display highly sensitive patient data (e.g. medical images and personal health information). Ensuring the privacy, confidentiality, and security of this information is paramount and requires stringent cybersecurity measures, robust data encryption, and strict adherence to regulatory guidelines, such as the Health Insurance Portability and Accountability Act (HIPAA).

User comfort and Ergonomics: Prolonged use of current AR headsets can lead to physical discomfort, eye strain, headache, and fatigue. Improving the design, weight distribution, and ergonomics of AR devices is crucial for their widespread and comfortable adoption by healthcare professionals during long shifts.

Lack of Robust clinical Evidence: While numerous pilot studies and anecdotal reports highlight the promise of AR, there is a need for more robust, large-scale, Randomised Controlled Trials to definitively demonstrate the long-term clinical efficacy, cost-effectiveness, and superior outcomes of AR applications compared to traditional methods. Some healthcare professionals may resist adopting new technologies due to a lack of familiarity, concerns about disruption to established workflows, or insufficient training. Comprehensive and user-friendly training programs are essential for facilitating adoption.

Current and future Outlook

AR continues to evolve rapidly and is a transformative force in the healthcare sector, with significant developments emerging from published research and industry innovations in late 2024 and throughout 2025. [62] The current trajectory sees AR moving beyond experimental phases into more integrated and practical clinical applications, driven by advancements in hardware, artificial intelligence (AI) integration, and a growing understanding of its benefits. AR surgical systems are becoming increasingly sophisticated, addressing the critical need for real-time precise visualization in complex procedures. [40] The convergence of AR with AI and the Internet of Medical Things (IoMT) is a significant current trend, leading to more intelligent and predictive healthcare solutions. AI algorithms are being integrated to make AR experiences more adaptive and personalized. Efforts are ongoing to integrate AR systems with existing Electronic Records (EHR) and hospital management systems to ensure smooth data and streamlined workflows.

The future points towards more miniaturized and comfortable AR devices (resembling normal glasses), deeper AI integration for personalized care, and expansion into home-based care and patient self-management. Making AR an increasingly pervasive and essential component of modern healthcare. [63] Surgeons are constantly looking for more efficient methods to perform surgeries with a higher success rate, and technology can also be used in the Metaverse for complex surgical procedures. [64] The global AR in healthcare market is experiencing significant growth Reports indicate a market size of approximately USD 3.05 billion in 2023, projected to reach around USD 3.95 billion by end of 2025. [65] North America currently leads the market due to its advanced healthcare infrastructure and ongoing innovations. [66]

Conclusion

AR has been successfully integrated into various sectors, including military, education, healthcare, and gaming. Augmented Reality is undeniably a transformative force poised to revolutionize the healthcare sector. Its ability to seamlessly blend digital information with the physical world offers a paradigm shift in medical education, clinical practice, and patient care. AR provides unparalleled opportunities for enhanced precision in diagnosis and surgery, more effective and engaging training methodologies, seamless remote collaboration among health care professionals, and empowered patient engagement in their own health journey. While challenges related to high implementation costs, technical limitations, data privacy, and regulatory frameworks currently exist, ongoing research, rapid technological advancements, and increasing investment are actively addressing these hurdles. As AR technology continues to mature and become more accessible, its deeper integration into healthcare will undoubtedly lead to a future in which medical interventions are more precise, training is more effective, healthcare delivery is more efficient, and ultimately, patient outcomes are significantly improved. The projected substantial growth of the augmented reality healthcare market underscores that AR is not merely a fleeting trend, but a fundamental and enduring shift in how healthcare will be delivered in the years to come.

References

1. Farronato M, Maspero C, Lanteri V, Fama A, Ferrati F, Pettenuzzo A, et al. Current state of the art in the use of augmented reality in dentistry: a systematic review of the literature. BMC Oral Health. 2019;19(1):135.
2. Dickey RM, Srikishen N, Lipshultz LI, Spiess PE, Carrion RE, Hakky TS. Augmented reality assisted surgery: a urologic training tool. Asian journal of andrology. 2016;18(5):732-4.
3. Khor WS, Baker B, Amin K, Chan A, Patel K, Wong J. Augmented and virtual reality in surgery-the digital surgical environment: applications, limitations and legal pitfalls. Annals of translational medicine. 2016;4(23):454.
4. Zhu E, Lilienthal A, Shluzas LA, Masiello I, Zary N. Design of Mobile Augmented Reality in Health Care Education: A Theory-Driven Framework. JMIR medical education. 2015;1(2):e10-e.
5. Amin D, Govilkar S. Comparative Study of Augmented Reality Sdk's. International Journal on Computational Science and Applications. 2015;5(1):11-26.
6. Dennler C, Bauer DE, Scheibler A-G, Spirig J, Götschi T, Fürnstahl P, et al. Augmented reality in the operating room: a clinical feasibility study. BMC Musculoskelet Disord. 2021;22(1):451.
7. Mendoza-Ramírez CE, Tudon-Martinez JC, Félix-Herrán LC, Lozoya-Santos JdJ, Vargas-Martínez A. Augmented Reality: Survey. Applied sciences. 2023;13(18):10491.
8. Blomqvist S, Seipel S, Engström M. Using augmented reality technology for balance training in the older adults: a feasibility pilot study. BMC Geriatr. 2021;21(1):144.
9. Hu M-H, Chiang C-C, Wang M-L, Wu N-Y, Lee P-Y. Clinical feasibility of the augmented reality computer-assisted spine surgery system for percutaneous vertebroplasty. Eur Spine J. 2020;29(7):1590-6.
10. Zhuang Y, Sun J, Liu J. Diagnosis of Chronic Kidney Disease by Three-Dimensional Contrast-Enhanced Ultrasound Combined with Augmented Reality Medical Technology. J Healthc Eng. 2021:5542822.
11. Tang KS, Cheng DL, Mi E, Greenberg PB. Augmented reality in medical education: a systematic review. Can Med Educ J. 2020;11(1):e81-e96.

12. Juanes-Méndez JA, Marcos-Pablos S, Velasco-Marcos MA, Izard SG. Medical Learning Through Simulations With Immersive Virtual Reality and Augmented Reality Devices. In: Marcos-Pablos S, Juanes-Méndez JA, editors. Technological Adoption and Trends in Health Sciences Teaching, Learning, and Practice. Hershey, PA, USA: IGI Global; 2022. p. 265-82.
13. Eckert M, Volmerg JS, Friedrich CM. Augmented Reality in Medicine: Systematic and Bibliographic Review. JMIR Mhealth Uhealth. 2019;7(4):e10967.
14. Baashar Y, Alkawsi G, Ahmad WNW, Alhussian H, Alwadain A, Capretz LF, et al. Effectiveness of Using Augmented Reality for Training in the Medical Professions: Meta-analysis. JMIR serious games. 2022;10(3):e32715-e.
15. Lee LN, Kim MJ, Hwang WJ. Potential of Augmented Reality and Virtual Reality Technologies to Promote Wellbeing in Older Adults. Applied Sciences. 2019;9(17):3556.
16. Yeung AWK, Tosevska A, Klager E, Eibensteiner F, Laxar D, Stoyanov J, et al. Virtual and Augmented Reality Applications in Medicine: Analysis of the Scientific Literature. J Med Internet Res. 2021;23(2):e25499-e.
17. O'Connor S, Andrews T. Mobile Technology and Its Use in Clinical Nursing Education: A Literature Review. J Nurs Educ. 2015;54(3):137-44.
18. Risling T. Educating the nurses of 2025: Technology trends of the next decade. Nurse Educ Pract. 2017;22:89-92.
19. Shachar M, Neumann Y. Differences Between Traditional and Distance Education Academic Performances: A Meta-Analytic Approach. The International Review of Research in Open and Distributed Learning. 2003;4(2).
20. Choules AP. The use of elearning in medical education: a review of the current situation. Postgrad Med J. 2007;83(978):212-6.
21. Car J, Carlstedt-Duke J, Tudor Car L, Posadzki P, Whiting P, Zary N, et al. Digital Education in Health Professions: The Need for Overarching Evidence Synthesis. J Med Internet Res. 2019;21(2):e12913-e.
22. Curran V, Matthews L, Fleet L, Simmons K, Gustafson DL, Wetsch L. A Review of Digital, Social, and Mobile Technologies in Health Professional Education. J Contin Educ Health Prof. 2017;37(3):195-206.
23. Iqbal AI, Aamir A, Hammad A, Hafsa H, Basit A, Oduoye MO, et al. Immersive Technologies in Healthcare: An In-Depth Exploration of Virtual Reality and Augmented Reality in Enhancing Patient Care, Medical Education, and Training Paradigms. Journal of Primary Care and Community Health. 2024;15:21501319241293311.
24. Song D, Lee JG. Chapter 5 - AI engineering in the Metaverse for human learning and performance. In: Nam CS, Song D, Jeong H, editors. Human-Centered Metaverse: Morgan Kaufmann; 2025. p. 75-87.
25. Bui DT, Barnett T, Hoang H, Chinthammit W. Usability of Augmented Reality Technology in Situational Telementorship for Managing Clinical Scenarios: Quasi-Experimental Study. JMIR Medical Education. 2023;9:e47228.
26. Palestini C, Basso A. The Photogrammetric Survey Methodologies Applied to Low Cost 3D Virtual Exploration in Multidisciplinary Field International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences. 2017;XLII-2/W8:195-202.
27. Cartucho J, Shapira D, Ashrafian H, Giannarou S. Multimodal mixed reality visualisation for intraoperative surgical guidance. Int J Comput Assist Radiol Surg. 2020;15(5):819-26.
28. Zafar S, Zachar JJ. Evaluation of HoloHuman augmented reality application as a novel educational tool in dentistry. Eur J Dent Educ. 2020;24(2):259-65.
29. Hanna MG, Ahmed I, Nine J, Prajapati S, Pantanowitz L. Augmented Reality Technology Using Microsoft HoloLens in Anatomic Pathology. Arch Pathol Lab Med. 2018;142(5):638-44.
30. Sutherland J, Belec J, Sheikh A, Chepelev L, Althobaity W, Chow BJW, et al. Applying Modern Virtual and Augmented Reality Technologies to Medical Images and Models. J Digit Imaging. 2019;32(1):38-53.
31. Moro C, Phelps C, Redmond P, Stromberga Z. HoloLens and mobile augmented reality in medical and health science education: A randomised controlled trial. British Journal of Educational Technology. 2020;52(2):680-94.
32. Gore H, Chaskar U, Borotikar B, Bhole K, editors. Medical Image Visualization using Augmented Reality. 2024 2nd DMIHER International Conference on Artificial Intelligence in Healthcare, Education and Industry (IDICAIEI); 2024.
33. Vyas V, Sharma A, Goyal S, Kothari N. Infrared vein visualization devices for ease of intravenous access in children: hope versus hype. Anestezjologia Intensywna Terapia. 2021;23(1):69-78.
34. Sakakibara J, Nasu K, Ikeda JI, Suzuki TH, Yokomizo J, Fujimoto H, et al. Clinical application of vein visualization apparatus AccuVein((R))500 in breast cancer surgery: a case report. J Med Case Reports. 2025;19(1):231.

35. Chen P-HC, Gadepalli K, MacDonald R, Liu Y, Kadowaki S, Nagpal K, et al. An augmented reality microscope with real-time artificial intelligence integration for cancer diagnosis. Nat Med. 2019;25(9):1453-7.
36. Douglas D, Wilke C, Gibson J, Boone J, Wintermark M. Augmented Reality: Advances in Diagnostic Imaging. Multimodal Technologies and Interaction. 2017;1(4):29.
37. Pereira-Azevedo NM, Venderbos LDF. eHealth and mHealth in prostate cancer detection and active surveillance. Translational andrology and urology. 2018;7(1):170-81.
38. Hemanth JD, Kose U, Deperlioglu O, de Albuquerque VHC. An augmented reality-supported mobile application for diagnosis of heart diseases. The Journal of Supercomputing. 2018;76(2):1242-67.
39. Al-Naser Y, Halka F, Alshadeedi F, Albahhar M, Athreya S. The applications of augmented reality in image-guided tumor ablations: A scoping review. Journal of Medical Imaging and Radiation Sciences. 2024;55(1):125-33.
40. Xiao SX, Wu WT, Yu TC, Chen IH, Yeh KT. Augmenting Reality in Spinal Surgery: A Narrative Review of Augmented Reality Applications in Pedicle Screw Instrumentation. Medicina. 2024;60(9):1485.
41. Lastrucci A, Wandael Y, Barra A, Ricci R, Maccioni G, Pirrera A, et al. Exploring Augmented Reality Integration in Diagnostic Imaging: Myth or Reality? Diagnostics 2024;14(13):1333.
42. Hey G, Guyot M, Carter A, Lucke-Wold B. Augmented Reality in Neurosurgery: A New Paradigm for Training. Medicina (Kaunas). 2023;59(10).
43. Jud L, Fotouhi J, Andronic O, Aichmair A, Osgood G, Navab N, et al. Applicability of augmented reality in orthopedic surgery - A systematic review. BMC Musculoskelet Disord. 2020;21(1):103.
44. Casari FA, Navab N, Hruby LA, Kriechling P, Nakamura R, Tori R, et al. Augmented Reality in Orthopedic Surgery Is Emerging from Proof of Concept Towards Clinical Studies: a Literature Review Explaining the Technology and Current State of the Art. Curr Rev Musculoskelet Med. 2021;14(2):192-203.
45. Sakai D, Joyce K, Sugimoto M, Horikita N, Hiyama A, Sato M, et al. Augmented, virtual and mixed reality in spinal surgery: A real-world experience. Journal of Orthopaedic Surgery. 2020;28(3):1-12.
46. Longo UG, De Salvatore S, Candela V, Zollo G, Calabrese G, Fioravanti S, et al. Augmented Reality, Virtual Reality and Artificial Intelligence in Orthopedic Surgery: A Systematic Review. Applied Sciences. 2021;11(7):3253.
47. Barcali E, Iadanza E, Manetti L, Francia P, Nardi C, Bocchi L. Augmented Reality in Surgery: A Scoping Review. Applied Sciences. 2022;12(14):6890.
48. Hou Y, Ma L, Zhu R, Chen X, Zhang J. A Low-Cost iPhone-Assisted Augmented Reality Solution for the Localization of Intracranial Lesions. PLoS One. 2016;11(7):e0159185-e.
49. Schlueter-Brust K, Henckel J, Katinakis F, Buken C, Opt-Eynde J, Pofahl T, et al. Augmented-Reality-Assisted K-Wire Placement for Glenoid Component Positioning in Reversed Shoulder Arthroplasty: A Proof-of-Concept Study. Journal of personalized medicine. 2021;11(8):777.
50. Teoli D, Aeddula NR. Telemedicine. StatPearls. Treasure Island (FL) 2025.
51. Bui DT, Barnett T, Hoang HT, Chinthammit W. Tele-mentoring using augmented reality technology in healthcare: A systematic review. Australasian Journal of Educational Technology. 2021;37(4):68-88.
52. Naqvi WM, Naqvi IW, Mishra GV, Vardhan VD. The future of telerehabilitation: embracing virtual reality and augmented reality innovations. Pan Afr Med J. 2024;47:157.
53. Balloufaud M, Boujut A, Marie R, Guinaldo A, Fourcade L, Hamonet-Torny J, et al. Augmented Reality Exergames for Upcoming Cognitive-Motor Rehabilitation: User-Centered Design Approach and User Experience of Healthy Children. JMIR Rehabilitation and Assistive Technologies. 2025;12:e69205.
54. Khokale R, G SM, Ahmed S, Maheen S, Fawad M, Bandaru P, et al. Virtual and Augmented Reality in Post-stroke Rehabilitation: A Narrative Review. Cureus. 2023;15(4):e37559.
55. Condino S, Turini G, Viglialoro R, Gesi M, Ferrari V. Wearable Augmented Reality Application for Shoulder Rehabilitation. Electronics. 2019;8(10):1178.
56. Lamichhane P, Sukralia S, Alam B, Shaikh S, Farrukh S, Ali S, et al. Augmented reality-based training versus standard training in improvement of balance, mobility and fall risk: a systematic review and meta-analysis. Annals of Medicine and surgery. 2023;85(8):4026-32.
57. Ku J, Kim YJ, Cho S, Lim T, Lee HS, Kang YJ. Three-Dimensional Augmented Reality System for Balance and Mobility Rehabilitation in the Elderly: A Randomized Controlled Trial. Cyberpsychology, Behaviour, and Social Networking. 2019;22(2):132-41.
58. Kircik L, Goldust M. The Role of Virtual and Augmented Reality in Advancing Drug Discovery in Dermatology. J Cosmet Dermatol. 2025;24(2):e70071.
59. Turhan B, Gumus ZH. A Brave New World: Virtual Reality and Augmented Reality in Systems Biology. Frontiers in Bioinformatics. 2022;2.

60. Adapa K, Jain S, Kanwar R, Zaman T, Taneja T, Walker J, et al. Augmented reality in patient education and health literacy: a scoping review protocol. BMJ Open. 2020;10(9):e038416.
61. Ara J, Karim FB, Alsubaie MSA, Bhuiyan YA, Bhuiyan MI, Bhyan SB, et al. Comprehensive Analysis of Augmented Reality Technology in Modern Healthcare System. International Journal of Advanced Computer Science and Applications. 2021;12(6):840-9.
62. Makarov A. MobiDev. 2025.
63. Augmented Reality (AR) in Healthcare: Shaping the Future of Medical Technology - Digital Health Canada. 2024.
64. Bansal G, Rajgopal K, Chamola V, Xiong Z, Niyato D. Healthcare in Metaverse: A Survey on Current Metaverse Applications in Healthcare. IEEE Access. 2022;10:119914-46.
65. Augmented Reality And Virtual Reality In Healthcare Market To Reach $11.3Bn By 2030. 2024.
66. Global AR in Healthcare Market Size, Top Share, Trends, Report to 2032. Straits Research.