LITERATURE REVIEW

The application of virtual reality and augmented reality in dentistry – a literature review

Leelan Kanwal, Munnal Gulzar, Wafa Idrees, Fizzah Ikram, Rashna Hoshang Sukhia, Mubassar Fida

Abstract

In recent times, dentistry has seen significant technological advancements that have transformed various specialized areas within the field. Developed into applications for mobile devices, augmented reality (AR) seamlessly merges digital components with the physical world, enhancing both realms while maintaining their individual separateness. On the other hand, virtual reality (VR) relies on advanced, tailored software to visualize a digital 3D environment stimulating the operator's senses through computer generated sensations and feedback. The current advances use the application of VR, haptic simulators, the use of an AI algorithm and many more that provides new opportunities for smart learning and enhance the teaching environment. As this technology continues to evolve, it is poised to become even more remarkable, enabling specialists to potentially visualize both soft and hard tissues within the patient's body for effective treatment planning. This literature aims to present the newest advancements and ongoing development of AR and VR in dentistry and medicine. It highlights their diverse applications while identifying areas needing further research for effective integration into clinical practice.

Keywords: Augmented Reality, Haptic Technology, Virtual Reality, Computers, Dentistry, Handheld, Algorithms, Sensation, Artificial Intelligence, Augmented reality, Dental education, Endodontics, Implantology, Oral and maxillofacial surgery.

Introduction

In recent times, dentistry has seen significant technological advancements that have transformed various specialized areas within the field. To enhance both dental education and clinical practices, new innovations such as virtual reality (VR) and Augmented

Department of Surgery, Section of Dentistry, Aga Khan University Hospital, Karachi, Pakistan.
Correspondence: Rashna Hoshang Sukhia **Email:** rashna.aga@aku.edu
ORCID ID. 0000-0001-9210-6432

reality (AR) have been explored extensively. These technologies aim to elevate dentistry by creating simulated yet highly realistic representations of dentofacial structures using specialized software. These simulations not only depict anatomical structures but also simulate their functionality, providing a comprehensive and sophisticated virtual experience in real time.[1]

AR technology superimposes computer-generated virtual elements onto the real physical environment, generating an engaging and interactive sensory experience. Developed into applications for mobile devices, AR seamlessly merges digital components with the physical world, enhancing both realms while maintaining their individual separateness.[2] Conversely, VR is a computer-generated simulation that replicates real-life environments or scenarios, completely immersing users and giving them the sensation of being present within the simulated reality. VR primarily stimulates vision and auditory senses in real time. Its key aspects are immersion, indicating the feeling of being within the virtual environment, and interaction, referring to the user's ability to actively engage and modify elements within that environment.[3]

AR, while also interactive, differs from virtual reality as it involves user interaction with a unified image of patient's teeth and/or anatomical structures. It operates within a 3D environment registered through essential imaging methods, enabling users to interact and manipulate these elements. Therefore, AR enhances physical elements by integrating them with virtual components.[4] AR allows patients to visualize the potential outcome of their treatment, offering a preview of their appearance after undergoing dental procedures. This preview minimizes the need for multiple visits, cutting cost and saving time for both the patient and the dentist.[5]

On the other hand, VR relies on advanced, tailored software that visualizes a 3D environment, stimulating the operator's senses through computer-generated sensations and feedback. This technology enables users to engage with virtual realities closely connected to the physical world, blurring the line between virtual and physical realities. AR and VR exhibit distinct differences:

augmented reality empowers the users to manage their presence in the real world, whereas virtual reality operates by a system-controlled technology. Additionally, VR necessitates the use of a headset, while the AR can be operated using a smartphone device. Furthermore, virtual reality enhances fictional reality exclusively, while augmented reality has the capacity to enhance both real and virtual worlds.

To date various fields of social life have been influenced by AR/VR technologies extending to entertainment, marketing and even the industrial processing fields. Jawaid et al.[6] in their study concluded that AR is a useful tool to enhance user experience for learning as well as improves brand recall and can be used for marketing campaigns. AR/VR has also been extended to the field of medicine particularly surgically focused disciplines involving the minimally invasive approaches such as the endoscopic and laparoscopic procedures.[7] Nevertheless, the infiltration rate and standard adoption of augmented reality and virtual reality in dentistry still remains unclear. Dentistry requires a wide array of skills, including comprehensive knowledge of head and neck anatomy, technical expertise in various treatments (such as restorative, endodontic, periodontic, prosthodontic, and surgical procedures), refined clinical abilities involving communication and judgment, strong academic understanding, and leadership capabilities. The extensive field of dentistry presents multiple opportunities to utilize VR/AR for improvement in dental procedures. Hence, the aim of this literature is to present the latest advancements, document the continuous evolution of augmented and virtual reality in diverse areas of dentistry and medicine, and pinpoint areas requiring additional research to facilitate their practical implementation in clinical settings.

Materials and Methods

To conduct this review, an electronic search was carried out using databases such as PubMed, Scopus, Web of Science, and Google Scholar. The search terms utilized were "Augmented Reality," "Virtual Reality," "AR and VR," "AR and Dentistry," "VR and Dentistry," "Use of AR and VR in Dentistry," and "AR/VR and dental education" to gather published research articles from January 2011 to June 2023. The data was collected from these articles from 15th July to 15th September 2023.

This literature review included clinical trials, case-control studies, observational studies, and investigations specifically centred on the application of AR and VR within the field of dentistry. Additionally, only studies conducted and published in the English language were considered

eligible for inclusion. On the other hand, exclusion criteria encompassed short communications, letters to Editors, and studies published in languages other than English.

Application of augmented and virtual reality
Education and training in dentistry

Dentistry encompasses various levels of skills, which incorporates the learning of head and neck anatomy as well as physiology, with the accumulation of complex technical skills in the subjects of restorative/endodontics, periodontics, prosthodontics and surgical therapy.

The virtual reality patient model (VRPM) designed by the University of Michigan is one of the examples of advances in dental education aiming to improve the diagnosis and treatment planning of orthognathic surgery cases.[8] Sytek et al.[9] reported increased readiness to accept VR simulations when they compared the effectiveness of this model to a 3D computer-assisted surgical simulation (CASS) planning method and the conventional 2D method.[10]

Immersive VR has been reported to be as effectual as the traditional learning methods, that may benefit from VR enhancing the educational experience and knowledge retention of dental students by compounding head and neck anatomy, CBCT/OPG images and immersive VR technology in learning of the anatomy, 3D imaging and radiology concepts.[11,12] A device that helps dental students become proficient with the use of indirect vision by carrying out mirror training exercises like the *Mirrosistant* is an example of one such application of VR.[13]

AR on the other hand is a computer-generated artificial virtual scenario. By overlaying digital information onto the real environment, it furnishes learners with a heightened level of interactivity and immersive experience. AR based tooth carving practice tool (AR-TCPT) is a mobile-friendly application that provides a 3D model of the maxillary canine and first premolar, mandibular first premolar and molar for practicing tooth carving.[14] Advances in VR/AR will definitely evolve the way of education and learning in dental education as it provides many areas for the implementation of this technology.

DentSim[15] stands out as one of the pioneering virtual reality systems designed for teaching restorative dentistry. It offers students a platform to practice clinical procedures on a simulated patient, providing real-time visual tracking, feedback, and performance assessment. Widely adopted in dental schools across North America and Europe since the early 2000s, Studies[16,17] have shown its effectiveness. Students can work independently,

Table-1: Various systems employed in dentistry for educational and training purposes.

System	Field	Uses
Moog Simodont dental trainer	Operative Dentistry	Cavity preparations
Virteasy dental trainer	Operative Dentistry	Caries removal practice
SensAble OMNI and SensAble PHANToM OMNI haptic device	Operative Dentistry	Caries identification
The Geneva System	General Dentistry	Teaching of dental anatomy
PerioSim	Periodontics	Training in periodontal procedures
The Forsslund System	Maxillofacial surgery	Training in third molar extraction

critically evaluate their performance, and self-monitor without constant supervision from a teacher.

The Virtual Reality Dental Training System (VRDTS), developed through collaboration between Novint Technologies and Harvard School of Dental Medicine, focuses on cavity preparation using virtual reality technology.[16] This simulator's software replicates various dental instruments and materials required for the process, allowing for virtual tooth restoration. However, a drawback is its inability to enforce or assist with proper positioning or hand/finger rests since the student holds the interface in the air.[18] Table I provides an overview of various systems employed in dentistry specifically for educational and training purposes.

Restorative dentistry and endodontics

Preclinical training in the areas of endodontics and operative/restorative dentistry has mainly focused on verbal and written instructions as well as practice on phantom heads and plastic models. The current advances use the application of VR and haptic simulators to enhance the teaching environment. Haptic technology provides immersive situations using its tactile and realistic force feedback for the user to experience the scenarios as though they were present in the actual environment.[19] VR incorporates physical interactivity through this haptic technology and tactile force feedback that provides the user with sensorimotor training.

Dentify, a multimodal simulator combines an immersive head-mounted VR display with a haptic pen that simulates dental drilling and exposes the user to different clinical scenarios.[20] Carpegna et al.[19] reported the increased effectiveness of one such haptic-based VR simulation for the preclinical practice of endodontic microsurgery procedures. Chen et al.[21] validated an AR-guided endodontic microsurgery (ARG) simulation with a customized 3D alveolar bone model and artificial periapical lesions (APLs) for facilitating inexperienced residents to perform precise osteotomy and root apex location in endodontic microsurgery. Similarly, the integration of an AR head-mounted device into a 3-dimensional dynamic navigation system (3D-DNS) for

osteotomy and root-end resection (RER) is one of the many prospects provided by VR/AR.[22]

Not limited to just preclinical training, AR also shows the potential for guiding endodontic procedures. Farronato et al.[23] evaluated the accuracy of an AR system for guiding an access cavity preparation in 3D-printed jaws. They found the use of AR as a digital guide for endodontic access cavity preparation to be promising and with the potential for clinical use.

Orthodontics

The learning outcomes of orthodontics generally require varied psychomotor skills, such as wire bending, bracket positioning, and interproximal reduction (IPR), as well as competency in dealing with patients their guardians and the psychological concerns they face. Sipiyaruk et al.[24] in their systematic review listed various works being done in VR/AR for the field of orthodontics. The use of an AI algorithm for the identification to analysis of points on 2D images introduced by Rao et al.[25] provides new opportunities for smart learning.

Studies have also compared the effectiveness of using virtual reality patient vs 2D prediction tracing methods for diagnosing and treatment planning on various cases.[26] They found improved understanding in students with both methods. Similarly, with the development of AR-guided bracket positioning, we can look forward to these technologies replacing conventional techniques in the clinics soon.[27,28] Going on from the same concept of AR-guided bracket positioning, using it for orthodontic mini-implants, the navigation techniques based on augmented reality technology yielded more accurate results.[29]

Prosthodontics

Training in prosthodontics usually requires phantom heads, plastic teeth or in some cases extracted natural teeth for preclinical practice. Anda et al.[30] introduced patient-specific virtual simulation using an intraoral scanner and Simodont Dental Trainer for training before teeth preparation in clinics.

VR has been applied to different fields of medicine and dentistry. One such virtual reality software, FitJaw mobile, is being used for physiotherapy in patients with temporomandibular disorders.[31] Its goal was so that the exercises were done in a more agile and favourable way

by participating in a VR-aided videogame.

Oral and Maxillofacial surgery

Pulijala et al.[32] presented a collaboration of Leap Motion devices and Oculus Rift headset in a virtual reality surgical simulator that grants an immersing multiple sensory and comprehensive surgical training experience for the operator. Interactive close-up stereoscopic 3d videos enable the learners to engage with the various components of the maxillofacial anatomy and practice on multiple surgical instruments.

CAD/CAM guides may be superior to AR-aided surgical guides for bone cutting in maxillofacial osteotomies but with more precision and accuracy they may come on equal standings with the current gold standard.[33] An example of this is the MentorEye system that incorporates a virtual surgical plan (VSP) software using CAD/CAM support.[34,35] A head-mounted wearable system facilitating augmented surgery developed by Badiali et al.[35] as a standalone, video-based device which facilitates maxillofacial bone surgery yielded great results for wafer less maxillary repositioning.

Although AR technology still requires some improvements, with new advances it can already be predicted that the use of AR/VR for in vivo testing to assess surgical accuracy under real clinical conditions will be initiated soon.

Paediatric dentistry

A major concern when treating any dental patient is to tackle the issue of fear and anxiety which has an inversely proportional relation to the quality of dental treatment being provided. Paediatric dentistry in this regard demands expertise beyond conventional dental knowledge and skills to provide high quality dental care effectively. The application of VR as a non-invasive technique to reduce anxiety in dental patients has many potentials.

The comparison of virtual reality distraction (VRD) to conventional methods in paediatric patients was appraised by Bagher et al.[36] Both methods scored equally on the Venham Anxiety and Behavioural Rating Scale (VABRS) making VRD an acceptable tool to use clinically. VRD has also been successful in reducing anxiety in children during primary teeth extraction.[37-39] More has to come from virtual and augmented reality for paediatric dentistry, especially with its potential use in autistic and other neurotypical patients.

Dental implantology

The ways of diagnostics, treatment planning and clinical workflow in dentistry has been drastically advanced by the intra-oral scanners (IOS), cone beam computed tomography (CBCT) and CAD? CAM. Traditional implant surgery usually uses a static surgical guide. Mangano et al.[40] used AI algorithms in a segmented 3D data set acquired from CBCT and IOS and performed AR-guided implant surgeries using the HoloLens 2® headset.

Kivovics et al.[41] compared the efficiency of Magic Leap One, an AR-based navigation system with a head-mounted virtual retinal display, to computer-aided implant surgery (coDiagnostiX software) and a free hand method. They found the accuracy of AR-based navigation systems and computer-aided implant surgery to be comparable, and both were found to be superior to the free-hand method. Current AR that's constructed on the dental implant surgery navigation system performs complete image guidance using markers.[42] Dong et al.[43] have further progressed this technology by putting forth an effective marker-less image guidance method. With the application of artificial intelligence and AR/VR for 3D planning of implant surgery these future machineries may soon replace the conventional methods.

Limitations

AR and VR offer promising avenues in dentistry, yet they face several constraints. These include the substantial initial investment for technology setup, technical complexities leading to potential user experience issues, and the challenge of limited content and customization. Users may also encounter a learning curve, and ethical considerations arise regarding patient acceptance and privacy. Furthermore, the scarcity of comprehensive evidence-based data supporting their long-term clinical effectiveness, integration into current practices, and accessibility in all regions are additional hurdles. Overcoming these limitations through technological advancements, cost-effective solutions, robust research validation, and improved user experiences will be pivotal in fully leveraging the potential benefits of AR and VR within the dental field.

Future recommendations

VR/AR presents dental surgeons and students with a valuable learning platform to practice dentistry safely and effectively, providing consistent feedback. The criticality of infection control in healthcare settings has been severely underscored with the enduring pandemic, amplifying the relevance of augmented and virtual reality in the field of dentistry. Post-pandemic, these technologies may hold even greater significance. It's crucial for educationalists and clinicians to carefully weigh the advantages and disadvantages of these necessary AR/VR tools before staking on it. Future research should focus on collaboration between experts in Medical and

Public Health Informatics, and clinicians to integrate procedures and treatment planning based on the up-and-coming AR/VR technologies in routine clinical settings. Additionally, in order to enable the dental practitioners to exclusively perform diverse treatments, the effectiveness of AR/VR in dental education needs to be investigated further.

Conclusion

A cutting-edge advancement in dentistry, encompassing VR, AR, and MR, presents a sophisticated and intricate device equipped with powerful visualisation capabilities. This marks a significant leap forward in dental education, offering a new paradigm for learning and comprehending concepts. This evolving technology is set to become even more remarkable, enabling specialists to potentially visualize both soft and hard tissues within the patient's body for effective treatment planning. Despite being well-explored in the field of AR and showing a positive trajectory in its application, its integration into dentistry remains at an early stage, with limited adoption in clinical practice. Future research endeavours ought to prioritize the establishment of robust technological standards that ensure the use of high-quality data. Additionally, there is a need to create scientifically validated AR/VR devices tailored specifically for dental practice.

Disclaimer: None.

Conflict of Interest: None.

Funding Disclosure: None.

References

1. Fahim S, Maqsood A, Das G, Ahmed N, Saquib S, Lal A, et al. Augmented reality and virtual reality in dentistry: highlights from the current research. Appl Sci 2022;12:3719. Doi: 10.3390/app12083719.

2. Feiner SK. Augmented reality: a new way of seeing. Sci Am 2002;286:48-55. doi: 10.1038/scientificamerican0402-48.

3. McCloy R, Stone R. Science, medicine, and the future. Virtual reality in surgery. BMJ 2001;323:912-5. doi: 10.1136/bmj.323.7318.912.

4. Huang TK, Yang CH, Hsieh YH, Wang JC, Hung CC. Augmented reality (AR) and virtual reality (VR) applied in dentistry. Kaohsiung J Med Sci 2018;34:243-8. doi: 10.1016/j.kjms.2018.01.009.

5. Kwon HB, Park YS, Han JS. Augmented reality in dentistry: a current perspective. Acta Odontol Scand 2018;76:497-503. doi: 10.1080/00016357.2018.1441437.

6. Jawaid M, Siddiqui ZA, Siddiqui AS, Karim MU. Augmented reality: A new learning experience among health care professionals. BioMedica 2021;37:185-90.

7. Cabrilo I, Bijlenga P, Schaller K. Augmented reality in the surgery of cerebral arteriovenous malformations: technique assessment and considerations. Acta Neurochir (Wien) 2014;156:1769-74. doi: 10.1007/s00701-014-2183-9.

8. UMichDent. Dentistry and VR—Jaw surgery simulation. [Online Vid] 2019 [Cited 2020 May 15]. Available from URL: https://www.youtube.com/watch?v=YCyrqmrMwPQ&t=3s.

9. Sytek L, Inglehart MR, Ramaswamy V, Aronovich S, Edwards S, Kim-Berman H. Comparisons of orthodontic residents' performance and attitudes using 2D, 3D, and virtual reality surgical simulation methods. J Dent Educ 2021;85:1415-26. doi: 10.1002/jdd.12598.

10. Xia JJ, Gateno J, Teichgraeber JF, Christensen AM, Lasky RE, Lemoine JJ, et al. Accuracy of the computer-aided surgical simulation (CASS) system in the treatment of patients with complex craniomaxillofacial deformity: A pilot study. J Oral Maxillofac Surg 2007;65:248-54. doi: 10.1016/j.joms.2006.10.005.

11. Kim-Berman H, Bui D, Lee K, Mitchell V, Bonine B, Benavides E, et al. Student learning of head and neck anatomy using cone beam computed tomography and immersive virtual reality. J Dent Educ 2023;87:1180-7. doi: 10.1002/jdd.13224.

12. Alsufyani N, Alnamlah S, Mutaieb S, Alageel R, AlQarni M, Bukhari A, et al. Virtual reality simulation of panoramic radiographic anatomy for dental students. J Dent Educ 2023;87:1200-9. doi: 10.1002/jdd.13240.

13. Chu F, Zheng J, Wang Q, Lu X, Chen Y, Zhong Y, et al. Mirror training device improves dental students' performance on virtual simulation dental training system. BMC Med Educ 2023;23:315. doi: 10.1186/s12909-023-04300-6.

14. Lim EJ, Kim YS, Im JE, Lee JG. Mobile educational tool based on augmented reality technology for tooth carving: results of a prospective cohort study. BMC Med Educ 2023;23:462. doi: 10.1186/s12909-023-04443-6.

15. Zheng JW, Cao X, Lin YH, Zhang JZ, Feng XP. An introduction of DentSim in pre-clinical dental training and practice. Shanghai Kou Qiang Yi Xue 2014;23:749-54.

16. Welk A, Splieth Ch, Wierinck E, Gilpatrick RO, Meyer G. Computer-assisted learning and simulation systems in dentistry--a challenge to society. Int J Comput Dent 2006;9:253-65.

17. Rees JS, Jenkins SM, James T, Dummer PM, Bryant S, Hayes SJ, et al. An initial evaluation of virtual reality simulation in teaching pre-clinical operative dentistry in a UK setting. Eur J Prosthodont Restor Dent 2007;15:89-92.

18. Wang D, Li T, Zhang Y, Hou J. Survey on multisensory feedback virtual reality dental training systems. Eur J Dent Educ 2016;20:248-60. doi: 10.1111/eje.12173.

19. Carpegna G, Scotti N, Alovisi M, Comba A, Berutti E, Pasqualini D. Endodontic microsurgery virtual reality simulation and digital workflow process in a teaching environment. Eur J Dent Educ 2023. Doi: 10.1111/eje.12946. [ahead of print]

20. Rodrigues P, Esteves A, Botelho J, Machado V, Zagalo C, Zorzal ER, et al. Usability, acceptance, and educational usefulness study of a new haptic operative dentistry virtual reality simulator. Comput Methods Programs Biomed 2022;221:106831. doi: 10.1016/j.cmpb.2022.106831.

21. Chen Y, Liu L, Qiu S, Hu C, Wang L, Li Y, et al. Application of Real-time Augmented Reality-guided Osteotomy and Apex Location in Endodontic Microsurgery: A Surgical Simulation Study Based on 3D-printed Alveolar Bone Model. J Endod 2023;49:880-8. doi: 10.1016/j.joen.2023.05.011.

22. Martinho FC, Griffin IL, Price JB, Tordik PA. Augmented Reality and 3-Dimensional Dynamic Navigation System Integration for Osteotomy and Root-end Resection. J Endod 2023;49:1362-8. doi: 10.1016/j.joen.2023.07.007.

23. Farronato M, Torres A, Pedano MS, Jacobs R. Novel method for augmented reality guided endodontics: An in vitro study. J Dent 2023;132:104476. doi: 10.1016/j.jdent.2023.104476.

24. Sipiyaruk K, Kaewsirirat P, Santiwong P. Technology-enhanced simulation-based learning in orthodontic education: A scoping review. Dental Press J Orthod 2023;28:e2321354. doi: 10.1590/2177-6709.28.3.e2321354.oar.

25. Rao GK, Srinivasa AC, Iskandar YH, Mokhtar N. Identification and

analysis of photometric points on 2D facial images: A machine learning approach in orthodontics. Health Technol 2019;9:715-24. Doi:.10.1007/s12553-019-00313-8.

26. Sakowitz SM, Inglehart MR, Ramaswamy V, Edwards S, Shoukri B, Sachs S, et al. A comparison of two-dimensional prediction tracing and a virtual reality patient methods for diagnosis and treatment planning of orthognathic cases in dental students: a randomized preliminary study. Virtual Reality 2020;24:399-409. Doi:.10.1007/s10055-019-00413-w.

27. Lo YC, Chen GA, Liu YC, Chen YH, Hsu JT, Yu JH. Prototype of augmented reality technology for orthodontic bracket positioning: an in vivo study. Appl. Sci 2021;11:2315. Doi:.10.3390/app11052315.

28. Ströbele DA, Othman A, Meier MA, Aboulazm K, von See C. Augmented reality in orthodontics for bracket placement using conventional mobile devices: Technical note. J World Fed Orthod 2023;12:280-3. doi: 10.1016/j.ejwf.2023.08.003.

29. Riad Deglow E, Zubizarreta-Macho Á, González Menéndez H, Lorrio Castro J, Galparsoro Catalán A, Tzironi G, et al. Comparative analysis of two navigation techniques based on augmented reality technology for the orthodontic mini-implants placement. BMC Oral Health 2023;23:542. doi: 10.1186/s12903-023-03261-y.

30. Slaidina A, Ozolins K, Berzina S, Abeltins A. Patient-specific virtual simulation in the clinical training for prosthetic dentistry. Eur J Dent Educ 2023. doi: 10.1111/eje.12949. (ahead of print.)

31. Arroyo-Cruz G, Orozco-Varo A, Domínguez-Cardoso P, Árbol-Carrero AB, Jiménez-Castellanos E. FitJaw Mobile, a virtual reality device applied to dentistry: An analysis based on two patient treatments. J Prosthet Dent 2023:S0022-3913(23)00274-3. doi: 10.1016/j.prosdent.2023.04.018. (ahead of print.)

32. Pulijala Y, Ma M, Pears M, Peebles D, Ayoub A. An innovative virtual reality training tool for orthognathic surgery. Int J Oral Maxillofac Surg 2018;47:1199-205. doi: 10.1016/j.ijom.2018.01.005.

33. Alwadeai MS, Al-Aroomy LA, Shindy MI, Amin AA, Zedan MH. Aesthetic reconstruction of onco-surgical maxillary defects using free scapular flap with and without CAD/CAM customized osteotomy guide. BMC Surg 2022;22:362. doi: 10.1186/s12893-022-01811-9.

34. Pietruski P, Majak M, Świątek-Najwer E, Żuk M, Popek M, Świecka M, et al. Replacing cutting guides with an augmented reality-based navigation system: A feasibility study in the maxillofacial region. Int J Med Robot 2023;19:e2499. doi: 10.1002/rcs.2499.

35. Badiali G, Ferrari V, Cutolo F, Freschi C, Caramella D, Bianchi A, et al. Augmented reality as an aid in maxillofacial surgery: validation of a wearable system allowing maxillary repositioning. J Craniomaxillofac Surg 2014;42:1970-6. doi: 10.1016/j.jcms.2014.09.001.

36. Bagher SM, Felemban OM, Alandijani AA, Tashkandi MM, Bhadila GY, Bagher AM. The effect of virtual reality distraction on anxiety level during dental treatment among anxious pediatric patients: a randomized clinical trial. J Clin Pediatr Dent 2023;47:63-71. doi: 10.22514/jocpd.2023.036.

37. Pathak PD, Lakade LS, Patil KV, Shah PP, Patel AR, Davalbhakta RN. Clinical evaluation of feasibility and effectiveness using a virtual reality device during local anesthesia and extractions in pediatric patients. Eur Arch Paediatr Dent 2023;24:379-86. doi: 10.1007/s40368-023-00801-6.

38. Du Q, Ma X, Wang S, Zhou S, Luo C, Tian K, et al. A digital intervention using virtual reality helmets to reduce dental anxiety of children under local anesthesia and primary teeth extraction: A randomized clinical trial. Brain Behav 2022;12:e2600. doi: 10.1002/brb3.2600.

39. Koticha P, Katge F, Shetty S, Patil DP. Effectiveness of Virtual Reality Eyeglasses as a Distraction Aid to Reduce Anxiety among 6-10-year-old Children Undergoing Dental Extraction Procedure. Int J Clin Pediatr Dent 2019;12:297-302. doi: 10.5005/jp-journals-10005-1640.

40. Mangano FG, Admakin O, Lerner H, Mangano C. Artificial intelligence and augmented reality for guided implant surgery planning: A proof of concept. J Dent 2023;133:104485. doi: 10.1016/j.jdent.2023.104485.

41. Kivovics M, Takács A, Pénzes D, Németh O, Mijiritsky E. Accuracy of dental implant placement using augmented reality-based navigation, static computer assisted implant surgery, and the free-hand method: An in vitro study. J Dent 2022;119:104070. doi: 10.1016/j.jdent.2022.104070.

42. Wang J, Shen Y, Yang S. A practical marker-less image registration method for augmented reality oral and maxillofacial surgery. Int J Comput Assist Radiol Surg 2019;14:763-7. doi: 10.1007/s11548-019-01921-5.

43. Dong S, Du C, He B, Zhu Z, Han D, Jin W, et al. Application of an effective marker-less augmented reality image guidance method in dental implant surgery. Int J Med Robot 2023;19:e2523. doi: 10.1002/rcs.2523.