BRIDGING THE GAP: HOW AUGMENTED REALITY ENHANCES ORTHODONTIC PRACTICE - A SCOPING REVIEW

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ABSTRACT

BACKGROUND: Digitization in the field of dentistry has led to an expansion of the relevance of stimulation learning in various fields of orthodontics. The application of Augmented reality [AR] enables the operator for precise diagnoses and treatment planning of malocclusions. The ever-increasing advancements have led to multisector applications of Augmented reality, improving treatment outcomes and increasing patient compliance.

AIM: This paper looks at the applications of AR in orthodontic diagnosis and treatment planning.

MATERIALS AND METHODS: 38 articles were selected from Scopus, Pubmed, and Cochrane databases. The use of AR in the field of Orthodontics was assessed from these articles and compiled together.

RESULTS: AR has shown promise as a technology during orthognathic surgeries, Implant placement, Bracket Positioning, Appliance fabrication, patient education, and training. The wide range of applications of Augmented Reality has enabled orthodontics to enhance the quality of care provided by orthodontic practices.

CONCLUSION: With the advent of the technological application of AR in successful clinical orthodontic practice. AR will surely help the operator to achieve better treatment results in the near future.

KEYWORDS— Augmented Reality, Digital Dentistry, Orthodontics, Virtual Reality, Patient education.

INTRODUCTION

Technological advances in digital innovations have significantly enhanced the applications of Augmented reality in solving various medical problems effectively. The ground-breaking work in the field of graphics designing has expanded the scope of virtual reality [VR] in healthcare. In VR, a person enters a completely immersive environment that is isolated from the real world and replaced by artificially created scenarios[1]. According to a 2021 article published in Seminars in Orthodontics, Artificial Intelligence, Virtual Reality, and Augmented Reality provide a collaborative platform known as a “Human-AI Hybrid Model,” resulting in enhanced learning sciences, real-time modeling, and diagnostic decision-making[2,3]. Virtual reality (VR) offers a transformative solution by delivering immersive simulations, enabling students to refine their skills in a secure setting before engaging with actual patients.[4]

On the other hand, AR adds graphics, sound, and smell to the real world while enhancing it with artificial images. Ivan Sutherland created the first AR gadget in 1968 by mounting a 3D display on the observer’s helmet, allowing them to see a cube in real time. A virtual and real-time image is co-displayed in augmented reality (AR), allowing the user to interact with elements from both images simultaneously. AR technology combines virtual and real-time images into a real-life environment that enables the operator to visualize the intraoperative field in a 3-dimensional view. Applications of augmented reality in orthodontic treatment have gained traction and are facilitated by personalized AI-driven treatment. AR can be efficiently used for the diagnosis of different craniofacial syndromes and facial malformations. It also enables the orthodontist to explain the patient’s chief complaint properly. Recent technological advances are enabling new applications of AR in various fields, such as restorative dentistry, orthodontics, and endodontics. AR technology can be effectively applied in Orthodontics to improve diagnosis, treatment, and education outcomes9. AR has shown to be a promising technology during Orthognathic surgeries, Implant placement, Bracket Positioning, Appliance fabrication, Patient Education, and training.

There are multiple articles on the applicability of AR in Contemporary clinical practice in orthodontics. However, all these articles are individualized studies with applications of Augmented reality in multiple aspects of orthodontic practice. Cumulative data that provides a brief understanding of the application of AR is limited for the orthodontic practitioner. This study aims to provide an update on the recent applications of Augmented Reality in various fields of Orthodontics, enabling the translation of research into clinical practice. The study was conducted at the Orthodontics Department of Dr. D. Y. Patil Dental College & Hospital, Pimpri, Pune.

MATERIALS AND METHOD

Focused Questions

What is the role of Augmented reality (AR) in Orthodontics? What are the different aspects of clinical orthodontic practice where AR can be applied, and what are the associated challenges and opportunities for clinical and research applications?

Search strategy

A detailed literature analysis was conducted to retrieve all available records from the Scopus, PubMed/Medline, Embase, and ScienceDirect databases. Another study was conducted using Google Scholar to identify unavailable articles that explore the possible grey area. The systematic review was conducted using all significant articles from the last decade up to June 2024. The search question included various MeSH terms, such as "Orthognathic Surgery", "Orthodontic Bonding", "Appliance Fabrication using Machine Learning", "Cephalometric tracing", "Implant placement", "Patient education," and "Training of Orthodontic residents." Papers written in English were included. Prisma chart was made following 2020 guidelines[10].

Eligibility Criteria:

The studies that were selected were in comprehension of the following inclusion criteria

(i) All the studies focused on the application of Augmented reality in Orthodontic practice.
(ii) Studies that have used any AR system for orthodontic diagnosis and treatment planning were considered.
(iii) Studies that were available in full-text format and written in the English language were selected for the review.

However, studies that did not focus on AR applications in clinical orthodontic practice were excluded from the study. Studies classified as reviews of any type, protocols, conference proceedings, perspective articles, commentaries, short communications, letters to editors, or opinions/viewpoints were also excluded.

Selection Process

All the retrieved articles were subjected to primary screening based on the titles and abstracts using Zotero 5.0. Secondary screening was conducted to identify full-text articles available in the English language. Two independent reviewers conducted these screenings, and any differences of opinion were resolved through discussion or by the opinion of a third reviewer. All the articles included in the study fulfilled the inclusion and exclusion criteria.

Study Characteristics

Out of 38 studies, 13 were case-control studies, 7 were experimental case studies, 7 were pilot studies, 4 were Systematic reviews, 2 were book chapters, 2 were Questionnaires, 2 were scoping reviews, and 1 Was an Online Blog. A total of 445 studies were found on 4 databases; 147 studies were removed as duplicate records. 23 studies were eliminated as they were inaccessible during the search leaving 275 articles. As the inclusion criteria only included studies with English Language 31 other studies were eliminated. From the remaining 244 studies, 91 studies were removed as they had partial records. Later from 153 studies were subjected to inclusion and exclusion criteria 88 studies were eliminated as they were not adhering the selected criteria. 27 other studies were removed as the studies found were from before year 2000. After scrutiny of all the articles 38 articles were selected for analysis in this review.

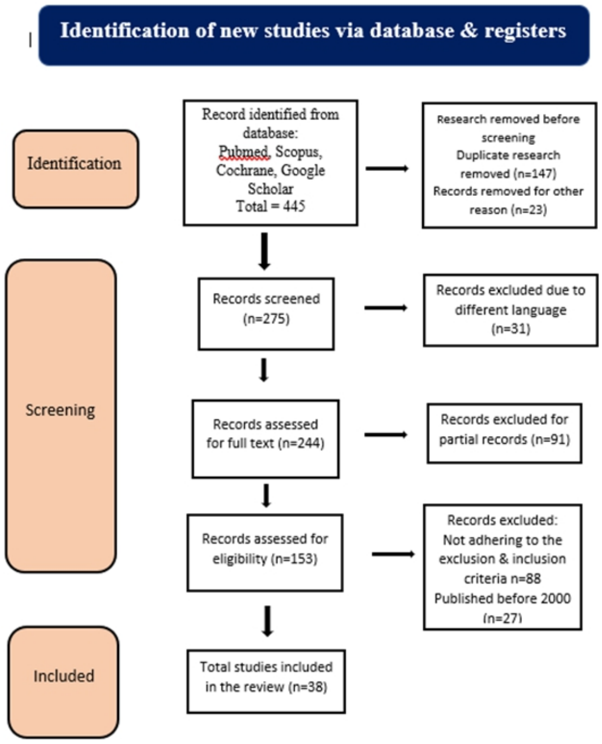

Figure 1: PRISMA flow chart

Data Extraction

The Data extraction table provides a comprehensive overview of the articles included in the study. The parameters included in the data include author and year of publication, study setting, study design, sample size, type of AR technology used, application in orthodontics, and conclusion. Two reviewers independently reviewed this data extraction table, and any differences of opinion were resolved through discussion.

Data analysis

The extracted data was analysed using performance metrics and presented in figures, flowcharts, tables, and narrative descriptions.

- Study Id (Name of author & year)
- Region (Country)
- Study design (type of study)
- Sample size
- AR model and software used
- Conclusion

RESULTS & DISCUSSION

Orthognathic Surgery

Visualization of intraoperative fields and adjacent structures is the primary concern during surgical operations in clinical practice. Advancements in computer-assisted oral and maxillofacial surgery (OMS) technologies have significantly improved visualization in surgical procedures[11]. The OMS technologies primarily consist of surgical simulation used in the preoperative phase and surgical navigation performed during the intraoperative phase. The preoperative phase involves creating an image using computed tomography, which enables the formulation of a detailed treatment plan. The intraoperative phase utilizes the image registration technique, which tracks the position and alignment of surgical instruments in virtual space. The AR system consists of a Camera, a marker, and a display device, allowing the surgeon to design a 3D model. This image registration software utilizes computer graphics (CG), which simulate the surgical reality onto which the augmented image is applied. During the surgical procedure, the surgeon wears a 2D head-mounted display (HMD) that uses a computer-generated virtual scene superimposed on the real scene through mixed reality. The intraoperative procedure uses optical markers and Electromagnetic (EM) motion tracking. Augmented reality-based navigation systems provide overlay images of the actual scenario for proper surgical planning and guidance.

In 2014, Wang et al.[13] used makerless AR-based technology in orofacial surgery, overlaying the maxillofacial structures on a 3D anatomic model. It overlays a 3D anatomic model, including maxillofacial bones, nerves, and arteries, and tracks the patient's location using a real-time video image. Ceccariglia F et al. 11 employed a head-mounted display (HMD) to display superimposed images. The AR-based system creates a three-dimensional model of the patient's mandible. This model is then overlapped using the HMD device over the virtually planned 3D surgical guide. The HMD displays superimposed images, enabling oral surgeons to follow the planned surgical procedure in real-time video tracking virtually and using an Augmented reality-based system that superimposes a 3D patient model. A head-mounted display (HMD) displays a virtual 3D model of the surgical template onto the actual surgical screen[14].

AR technology helps guide the surgeon in the proper alignment of titanium plates during a genioplasty procedure, thereby eliminating errors that can occur during manual adjustments. In 2017, Wang et al. [15] introduced a makerless AR-based technology for orofacial operations. It overlays a three-dimensional anatomic model, including maxillofacial bones, nerves, and arteries, and tracks the patient's location using a real-time video image [Figure 2]. Lin et al. [16] applied Augmented reality technology to facial plastic surgery. Augmented reality technology can also train residents to practice complex treatment procedures. The surgical fixation uses a tactile feedback mechanism. The recent systematic review of 2019 suggests that AR has a clinical application of up to 44% in the field of Oral surgery and up to 4% in clinical orthodontics. Additionally, using AR in Oral surgeries can reduce treatment time by up to 60 minutes. [17]

Figure 2: CG generated virtual scene superimposed on the patient for maxillary osteotomy surgery using a based navigation system[13].

Orthodontic Bonding

The position of the bracket on each tooth is one of the most crucial steps of successful orthodontic treatment. AR plays an important role in precise bracket positioning, which is essential for completing orthodontic finishing and reducing treatment time. Andre Aichert et al.[18] (2012) use CBCT scans of patients' jaws combined with pretreatment photographs and digital volume tomography of the tooth structure to precisely evaluate the site of bracket placement in both horizontal and vertical axes. The image-guided tracking system allows the operator to accurately determine the bracket position in both vertical and horizontal access. It utilizes a color-coded grading system that enables precise bracket positioning. When there is an error in bracket position the colors, start highlighting for error identification. This creates feedback that enables easy and immediate evaluation for students and new practitioners, leading to better accuracy. The recent study by Stobele et al.[19] [2023] created a digitally modified virtual model using Autodesk Netfabb 2021.1 and OnyxCeph to position orthodontic brackets during bonding accurately. This study demonstrated that smartphone AR apps hold promise for the future of orthodontics. The efficiency of prosthodontic workflows has significantly increased with the usage of AI and iOS. In a 2021 study by Lo Y-C and coworkers, 20 a prototype for an efficient bracket navigation system was devised, which showed improvement in the accuracy of bonding for both expert and novice orthodontists and reduced errors to an acceptable clinical error of 0.5 mm [Figure 3].

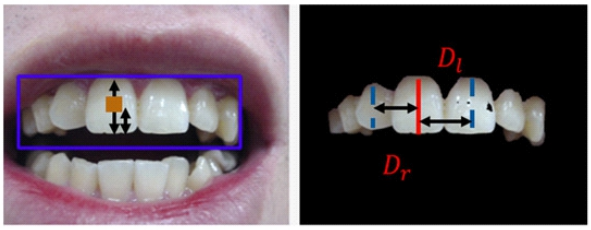

Figure 3: Image guiding system used for precise bracket position on FACC point. [Facial Axis of Clinical Crown][20]

The AR interface generated an immersive and interactive model that allows visualization of the teeth. The tactile device replicates the sensation of picking and positioning the attachment on the anterior surface, providing the operator with a sense of accurate bracket positioning[20]. In an article published by Fan Ye et al. in 2021, a surgical stimulator was constructed for use in the orthodontic bracket bonding procedure, utilizing a bimanual haptic tool with Unity software. They created a force rendering algorithm that utilized an optimized six degrees of freedom configuration, which realistically creates a multipoint and multiplanar interaction between the haptic tools and the digitally generated virtual field of operation. This enabled better visualization of the dental structure, improving the accuracy of bracket placement and treatment planning[21].

Appliance Fabrication using Machine Learning

Thurzo A and coworkers[22] explained the integration of augmented reality with machine learning in the fabrication of customized appliances for patients with craniofacial defects or abnormalities, such as cleft lip and palate obstructive sleep apnea. The use of intraoral scanners and face scanners enables clinicians to design personalized appliances using 3D printers, providing a viable treatment option for these patients[22]. Technological advances in the field of digital dentistry have resulted in the development of 3D intraoral scanners that replicate a patient's intraoral cavity in a three-dimensional digital replica. The integration of this digital model enables an accurate assessment of the dentofacial structure. Different 3D software uses digital models to fabricate 3D-printed models into which various orthodontic appliances can be fabricated[22]. The video images are integrated into a computer-implemented display of a model that is generated from a 3D scan of a patient in the form of a Digital impression. Once a digital impression is formed, any orthodontic appliance with preadjusted values can be designed and fabricated for that patient[24,25]. Intraoral scanners and 3D editing software can be used to generate STL files and 3D designs for the fabrication and customization of Orthodontic Appliances, such as Hyrax expanders, trans palatal arches, Lingual Arches, Lingual Expanders, and lingual bonded retainers[26,27].

Cephalometric tracing

Cephalometric radiographs provide an important assessment of a patient's craniofacial structure, enabling the orthodontist to formulate an ideal treatment plan. However, the application of anatomic definitions to these cephalometric points on lateral cephalograms has shown a significant amount of inter- and intraoperative error. To reduce the error in tracing cephalometric landmarks, it is important to devise advanced solutions to improve 3D visualization of skeletal landmarks. AR improves the quality of X-rays, making it easier to locate landmarks by adjusting the contrast of important structures. It also enables us to superimpose and evaluate treatment outcomes[28]. Romaniuk et al. [29] presented a paper on the use of AR in landmark identification on cephalometric X-rays. They used the software Cranexplo, developed by the TCI Society, which showed promising results. In 2016, Li G et al.[30] used augmented reality in linear 3D cephalometric measurements, utilizing 3D holograms with the Hologram lens, and concluded that there is significant potential in Hologram measurements for accurately measuring linear distances that can be used in surgical planning. An article published by G. K. Lakshmana Rao et al. [31] in 2018 suggests a novel technique that uses 3D AR visualization to objectively validate the landmark location and identification of lateral cephalograms, which would reduce the human error associated with landmark identification and decrease the time taken for cephalometric analysis. [Figure 4]

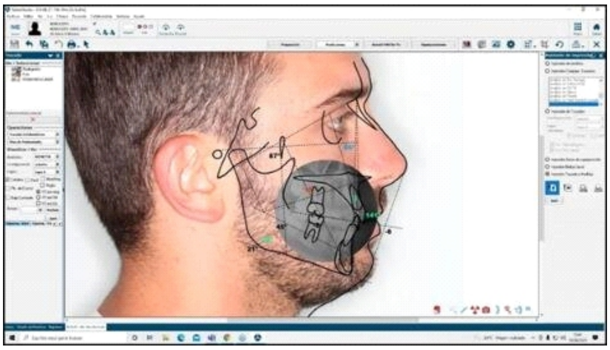

Figure 4: Automated cephalometric tracing

Implant placement

During the placement of a mini-implant, the orthodontist must possess precise knowledge of the patient's craniofacial structures. In digital visualization of the implant site, guidance can be provided using augmented reality technology with retinal navigation imaging, which superimposes the patient's critical anatomical structures. Li G et al. [30] assessed the efficiency of dental implants. He compared it with traditional manual implant placement techniques and concluded that AR-assisted surgical guides significantly decrease the risk of implant failure. The surgical template guides the operator in achieving accurate implant angulation, thereby reducing placement deviation. Francesco Guido Mangano et al. [32] integrated Artificial intelligence and Augmented reality in guided surgical implant placement. Their study concluded that AR and AI could successfully integrate 3D models with CBCT segmentation, resulting in a more precise guide for implant placement compared to conventional software.

Meng-Chu Hsu et al.[33] (2024) conducted a pilot in vitro study using cone-beam computed tomography (CBCT) and a patient-printed model, along with augmented reality (AR), to help plan the position of mini-implant placement and compared it with the traditional method of implant placement. The study reported that the AR-aided system demonstrated an 83% improvement in accuracy in the mesiodistal position. Riad Deglow et al. in 2023 compared the precision in implant placement using Augmented reality with the traditional method of implant placement. They concluded that AR-assisted implants showed more accurate results compared with the free-hand technique[34].AR technology enables the operator to create a 3D stent, allowing for precise planning and positioning of the orthodontic mindscrew. AR-based navigation has been shown to reduce intraoperative errors[35].

According to the latest systematic review by Leon et al.[36] [2021], Artificial Intelligence technology can recognize the possible implant type in relation to the site of implant placement, considering the thickness and quality of bone, as well as the biomechanics of tooth movement, and successfully predict the success of the implant by optimizing the implant design. In reference to these articles, the use of AR in the placement of miniscrew or bone screws can be initiated. The application of AI in generating VR and AR models is an emerging trend in general dentistry; however, significant research in the field of orthodontic implant placement is still lacking[37].

Patient Education

AR helps with proper patient counselling, allowing us to show patients an overview of the treatment options that may be required. This would increase patient cooperation, thereby improving the success of orthodontic treatment. The AR-based system generates a full set of tooth models and instruments. The software includes a simple registration of the instrument, along with real-time tracking with an accuracy of 38% [Figure 5]. Another review by Sipiyaruk K in 2023 stated that the use of AR technology in creating awareness and educating patients about successful orthodontic treatment has shown comparable results to the traditional method of patient education. [39]

Figure 5: Augmented reality in patient education[38]

Training of Orthodontic residents

In a 2021 study by Sytek et al.[40], participants were compared in terms of performance and attitude during surgical simulations using 2D, 3D, and virtual reality. The study concluded that there is increased reliability with 3D and VR simulations compared to 2D surgical simulations. It was also observed that the orthodontic residents showed a greater readiness to accept VR stimulation.

The use of a Haptic device has enabled operators to expand their skills in tooth preparation by allowing them to feel the force applied during the treatment procedure. A real-life environment can be simulated using AR technology, which can train orthodontic residents in placing mini-implants, performing bonding procedures, and bending archwires[41,42]. A study conducted by Kim Berman and colleagues evaluated the validity and reliability of the digital data system used by 109 dental residents. The AR tooth identification tool evaluated the ease of use for operators in a virtual testing procedure. The research showed that tooth identification using AR demonstrated a positive correlation with that done by dental residents[43]. In a survey conducted by Gredes T et al.[44] in 2022, orthodontic residents and practicing orthodontists showed a more positive and accepting attitude towards the newer AR technological simulation in treating their patients.

A study by Naser-ud-Din S et al.[45] in 2015 suggested that the use of AR with an application-based scenario in the training of orthodontic professionals has shown a higher acceptance rate among students and a shorter learning curve. In an article published in the Seminar in Orthodontics in 2024 by Divakar Karanth,[46] the author explained the comprehensive use of Augmented reality in training Orthodontic residents by using interactive content, stimulated e-learning labs, and orthodontic virtual treatment planning [Figure 6]. Technology-enhanced learning enhances and enriches the learning process by providing hands-on learning through digital tools. It elevates and enriches the learning experience[47,48].

Figure 6: Augmented reality guiding orthodontic residents in the localization of impacted tooth[47]

LIMITATIONS:

This study aimed to provide a comprehensive understanding of the application of AR in clinical orthodontic practice. The study offers a retrospective analysis of the available data. Some studies have a very small sample size, so the applicability of these results to a larger population is questionable. The review consists of a mix of heterogeneous articles; hence, a meta-analysis of the data cannot be done. However, the applicability of these clinical modalities is not only expensive but also involves a learning curve for the user. The Availability of this AR software is challenging or expensive for routine clinical practice, particularly with a small sample size of patients. This would tend to increase initial treatment time until the operator has acquired a significant understanding of machine and software usage[45].

CONCLUSION

There is a rapid increase in technological advancements in the fields of VR/AR technology, enabling orthodontics to upgrade their practices. Although Augmented reality cannot replicate the five human senses of reality, the increasing technological advances in VR and AR technology can solve many problems in the future. Advanced technologies, such as haptics and robotics, can enhance the role of AR in orthodontics. This amplifies the immersible potential of current AR technology. The major concern with AR applications lies in the added cost of the necessary equipment and the need for specialized training to ensure easy and accurate use in day-to-day practice. Haptic force feedback and robotics are generally integrated with AR technology in numerous dental research. The true potential of Augmented reality is yet to be determined as compared to traditional procedures in routine dental practice. With ongoing advances in VR/AR technologies, it will become more affordable and accessible to all academic institutions and dental practices, with the advent of AR technology applications in successful clinical orthodontics in the near future.

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