



Augmented Reality in Prosthodontics – A Literature Review

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ABSTRACT:

With the advent of new technology-based era, there is no dental speciality that is void of its applications and the branch of prosthodontics and implantology is no exception for this. A few current technologies that are having wide spread applications in prosthodontics includes artificial intelligence (AI), robotics, virtual reality (VR), augmented reality (AR) and many more. Being one of the most advanced and researched technology, Augmented Reality (AR) is being widely used various prosthodontic treatments.

The objective of this paper is to provide a compiled literature on this technology's applications in prosthodontics and that will help in further research in the application of AR in the unexplored areas of prosthodontics.

A large number of literatures was searched from various databases like PubMed, Scopus and Web Of Science, and 21 articles from indexed journals were selected to be used for this literature review based on different areas of applicability of AR being investigated in these studies.

The review of 21 articles has resulted in the amalgamation of all AR applications in Prosthodontics and a vision to the future research especially in the areas of removable prosthodontics, maxillofacial prosthetics and implantology.

The review concludes that the advancement in the AR technology has gone far more than understanding. However, there is still a lot of scope to apply this technology and improve the treatment outcomes among prosthodontic patients, better education among students, as a better teaching tool among dental professors, and as a better communicator between dental practitioner and the laboratory.

1. Introduction

The dental speciality is growing at a rapid rate with the advent of technology. The need for oral health is also multiplying with the increase in elderly population due to increased life expectancy and the economic growth^{1,2}. As per the statistics of World Health Organization, the total tooth loss rate was 30% among the older population in the age group of 65-74 years. These lead to a sustained increase in oral health needs for a long-term¹.

The newer technologies like the CAD-CAM, 3D Printing, Intraoral scanners are expanding the scope of dentistry by addressing the current needs². Apart from these, the newer computer-based technologies that are gaining wide-spread applications and usability in dentistry are the Artificial Intelligence (AI), Virtual Reality (VR), Mixed Reality (MR) and Augmented Reality (AR). (Figure 1) This article aims to focus on the augmented reality and its applications in prosthodontics.

Virtual Reality (VR) is a 3-dimensional experience simulated by a computer through VR glasses. An artificial interaction will be created between the user and the virtual environment as the user will be totally immersed in a composite virtual environment that simulates the user's feelings, senses and reactions through a computer^{3,4}. It allows users to interact with virtual entities in real time by combining multiple technology. VR has two main features: immersion and interaction. Immersion is the sense of presence in a virtual environment and interaction is the power to make modifications⁵.

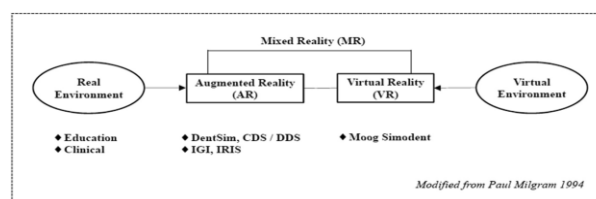


Figure 1: Difference between Augmented reality (AR) and Virtual reality (VR)¹



Augmented reality (AR), a term coined by Caudell and Mizell in the 1990's, is a type of technology that enhances an environment by superimposing virtual content over actual/real structure in 3 dimensions, thereby enhancing the sensory perception⁵. Looking back at history, the origin of AR happened at the time of World War II, when an airborne radar navigation system was developed in a British aircraft. However, the first AR system for medical purpose was developed by Sutherland in 1968 using head-mounted display (HMD). AR reciprocally registers the virtual and real images and it operates interactively in real time and this feature of AR gives the user, the sensory perception in real time. To achieve this, functionalities like the real and virtual data sources, tracking, technique of data registration, visualization processing, display, perception points and feedback mechanisms are essential and they should be operated and integrated with one another⁵.

2. Application of AR in Prosthodontics

a. AR as an Educational Tool –

The advancements in technologies like the intraoral scanners, milling and printing machines, dentistry is evolving technologically and its scope is also expanding. The improving technologies; invention of new materials like nanoparticles, PEEK; advanced surgical techniques like implant placements create a need to educate the dental students about these and train them with these so that they grow with the growing technologies. However, as the cost of the technology increases, so does the cost of incorporating them in the dental curriculum or the traditional teaching methods².

As professionals, the facts that are to be considered as of utmost importance is the patient's safety, understanding the irreversible nature of dental procedures and a responsibility to educate the next generation students through training and education. The solution to cut down this high-cost factor in dental education and training, is by exploring alternative training methods like incorporating technologies like online teaching, virtual reality (VR), augmented reality (AR) and mixed reality (MR). through these, learning will be enhanced, teaching can be made more practical and interesting while the cost will also be reduced. Literatures suggest that these technologies can be used to teach anatomy, pre-clinical activities, improve clinical skills, for patient education, treatment planning, address dental phobias, better

communication between dentist and patient, and many more^{2,6}. (Figure 2) (Figure 3)



Figure 2: VR-based dental education units⁵

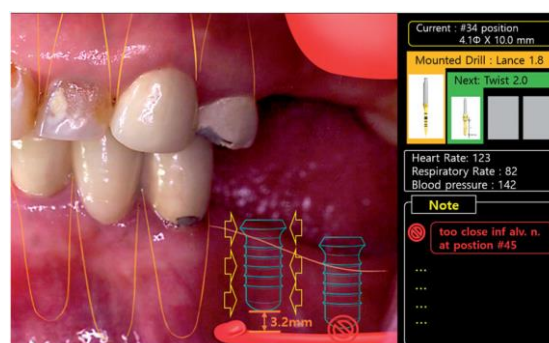


Figure 3: Proposed contents of AR display through head mounted display during implant installation⁵

Here, are a few applications of AR as an educational tool.

- i. Dental anatomy is an integral part of all dental specialities and prosthodontics is no different for this. During fabrication of CD/ CPD/ FPD/ FDP/ Overdentures/ Implant supported restorations and treating any TMDs, establishing, correcting or maintaining a proper occlusion is crucial and for this, a good knowledge of dental anatomy is a must. A study was conducted to evaluate and compare the efficacy of different technologies as educational tool in dental anatomy. Accordingly, four educational methods were evaluated – extracted human natural tooth, 3D virtual model displayed on a desktop screen with Chrome browser, a 3D printed model made from a 3D printer, and AR display⁷.

After educating the anatomy of maxillary first molar to students, their competency in identifying the tooth and the different characteristics of tooth was analysed through a survey with four questions on education



value, ease of use, accessibility, and interest level. The results of the survey showed that AR display was rated as the most interesting educational tool. However, extracted human natural tooth had the highest education value and the 3D printed tooth model was rated the easiest to use. With repeated use, a property that an AR display enables the user, the ease of use also improves with the AR display⁷. (Figure 4)

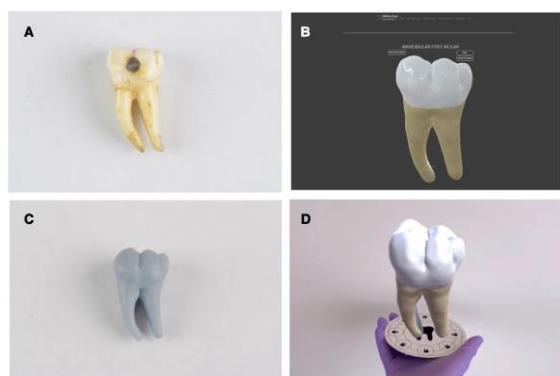


Figure 4: (A) Extracted natural mandibular first molar. (B) A virtual 3D model of a mandibular first molar. (C) Stereolithographic printed mandibular first molar. (D) Augmented Reality Image as seen by the user⁷

- ii. Another study evaluated difference in learning experience in tooth preparation between haptic simulator (HP-S) and typodont teeth set as training modalities. The preparations were assessed in the difference in total occlusal convergence (TOC) values between the two training modalities. The result showed that the participants were satisfied with the overall experience and expressed that the HP-S system was stimulating for learning as well as skill enhancement and was replicating the actual clinical environment in a high sense. The main difference between the HP-S and conventional typodont training as stated by the participants were – difference in the tactile sense during preparation, the degree of freedom in observation during tooth cutting, difference in the sense of vision in relation to distance and perspective, the influence of finger rest, occlusal simulation and the effect of water-coolant during preparation².

Another important observation from this study was the self-directed learning and software- assisted assessment and feedback of tooth preparation. This feature could be beneficial in achieving shorter preparation times on patients and reducing

supervision and instructor resources. The HP-S assessment score, by measuring the number of attempts and duration required to achieve an acceptable competency level, acts as a significant predictor of clinical crown performance. This indicates that, a participant achieving good results in a shorter time with haptics are 10 times more likely to perform better on the patient in clinic².

- iii. In another study by Jung et al., four applications of haptics were evaluated, namely, applicability of haptic simulator as a practical educational tool; anatomy of oral cavity and tooth anatomy; convenience in practicing haptics and the usability of haptics in terms of realism similarity; content of training. The results of the study when compared with the same applications of actual clinical practice, showed acceptable scores with applicability having the highest score and content having the lowest score for haptic simulators in comparison with clinical practice⁸. (Figure 5)

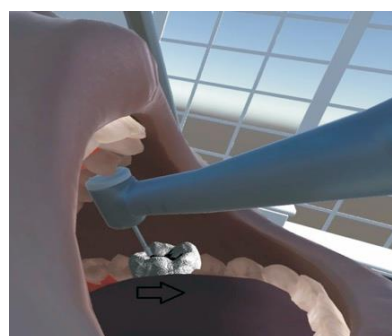


Figure 5: Virtual reality tooth preparation simulator: Practitioner's view⁸

- iv. Apart from application as an educational tool for conventional tooth preparation, cavity preparation, (VR) has also been applied as a training tool for veneer tooth preparation. A study was conducted using the haptic technology as this technology create a realistic clinical condition and thereby enables psychomotor skill development. These haptic simulators expose the participants to various clinical challenges, thereby improving the skills to operate on misaligned teeth and other complex conditions; and is highly unlikely to achieve with the phantom heads⁹.

The participants were evaluated based on the practical skill of veneer tooth preparation using a standardized assessment rubric comprised of four key



criteria – marginal integrity, preparation depth, proximal contour preservation, and surface smoothness. The results showed that veneer tooth preparation on phantom head and using haptic simulator were similar for all the four criteria. The study also compared the functionality of two commercially available haptic systems – Unidental and Simodont simulators using 70 questionnaires. The results showed that the display effect, synchronism of virtual and real dental instruments and the simulation of dental bur during preparation was not statistically significant between the simulators. However, the realism of odontoscope's reflection, force feedback and tooth preparation process were statistically significant between the simulators with Unidental showing better results for odontoscope's reflection and Simodont showing better results with other aspects. The participants perception towards the 2 simulators have led to the conclusion that both the simulators showed no significant difference in terms of skill enhancement; inspiring to learn; willingness to use and their suitability to be used for training purpose⁹.

Although the results show that simulators yield similar outcome as the traditional methods, certain advantages of these simulators add to their advantages – as the simulators do not require consumable materials, they are cost efficient for a long term; provide repeatable training; immediate feedback; self-learning; simulation of real environment enables better work experience for students. This suggests that simulators can be a good training tool and this conclusion of this study has been supported by my other similar studies⁹.

b. AR in oral health care:

Augmented Reality (AR), by superimposing the virtual data on real life condition, effectively enhances the user's real-life experience. Virtual reality (VR), through virtual environments created by computer, virtually simulates the user's senses, feelings and reactions and by this, creates an artificial interaction. The virtual reality systems function through a device, example – a helmet, to simulate user's response and create a 3D or 4D experience. Both AR and VR technologies have found great applications in dental profession for providing a total patient care system⁴.

In prosthodontics, these technologies are used to augment the rehabilitation, reconstruction, prostheses, designs onto the patient's existing anatomy without any

invasive procedure and visualise the proposed treatment outcome, measure its prognosis, anticipate the complications during the procedure, treatment planning, patient education and for a detailed transparent discussion of the treatment with the patient, thereby avoiding legal issues. These technologies also improve the hand-eye coordination and ergonomics without any risk of harming a patient⁴.

c. AR in auto-transplantation of teeth:

Alveolar ridge resorption is one of the major concerns for fabrication of CD especially the mandibular denture. The alveolar process begins to resorb immediately following tooth extraction and this further goes on till only the basal bone is left. The best resource that preserves the alveolar ridge and prevents its resorption is the tooth. There are various methods to maintain tooth in its socket – to preserve alveolar ridge. Some of the techniques are by fabricating tooth-supported overdenture; root submergence technique or tooth transplantation and using this transplanted tooth as overdenture abutment or for root submergence.

Tooth auto-transplantation is the placement of an autogenous tooth in the place of a debilitated tooth, indicated for extraction. Although implant placement also can be done for overdentures, tooth transplantation has certain advantages over implants such as the maintenance of proprioception through the intact periodontal ligaments; transplanted teeth can also be used for anterior teeth replacement as it gives the best esthetics, superior to the esthetics provided by implant restorations; transplanted teeth also enable orthodontic movements apart from preservation of alveolar bone and gingiva. Therefore, they can also be indicated in young patients with missing teeth due to trauma or congenital absence. However, the procedure of autotransplantation is highly technique sensitive and has to be done with extreme caution, otherwise, it can lead to the failure of the entire procedure¹⁰ (Figure 6).

A study on auto-transplantation of teeth by Raid-Deglow et al. has showed that the static navigation technique was more accurate in the apical positioning of the transplanted tooth than the free-hand positioning. The static navigation technique is very precise and accurate and thus allows to change the positioning of the tooth during transplantation in real time by blending the virtual 3D data on the patient's existing socket post-extraction and socket preparation, by giving a better intra-oral perception for the operator. Riad Deglow et al. also



evaluated and reported that using a surgical template manufactured by the computer-aided implant system (CAIS) to prepare socket for tooth auto-transplantation gives a more accurate apical positioning of the tooth¹¹.

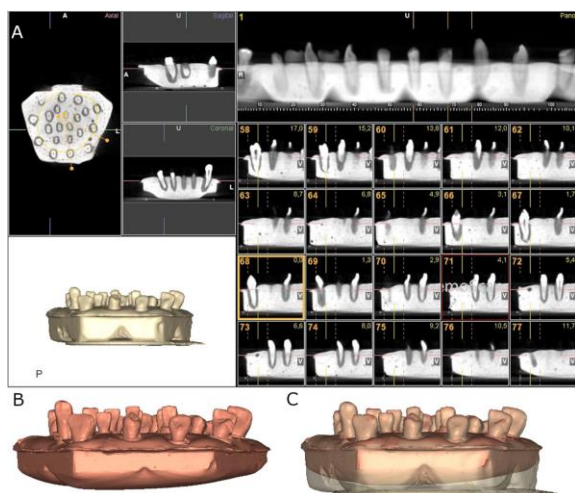


Figure 6: A CBCT scan, B STL digital files and C alignment of the digital workflow¹⁰

d. AR in personalized medicine:

The expression of a disease is highly person specific. If the treatment for a disease is also equally specific, then the outcome and prognosis of the condition will get better exponentially and this is called as Personalized Medicine. The approach to treat a patient using this requires information on the genetic make, epigenomic and clinic findings. Through this data, an understanding of the patient's system towards a disease can be achieved and treated with high specificity. In prosthodontics, there are many disabling conditions that require reconstruction or restoration. In these situations, adhering to the traditional, uniform standard operating procedures (SOPs), a personalized treatment approach would help achieve the desired results¹².

In a full mouth rehabilitation case, when the restoration of each tooth influences the final outcome in a major way, it is very crucial to assess each tooth for its periodontal, periapical and endodontic status and these are highly subject specific. With the power to visualize complex tissues in 3D, AR can give a structured treatment plan with sequencing. AR also evaluates the feasibility and prognosis of a treatment option based on various patient specific information along with the intra-oral findings. By projecting the virtual images on real-life condition it enables a great interdisciplinary approach, doctor – patient communication using smart AR glasses¹².

e. AR in Maxillofacial Prostheses:

i. Iris Positioning:

Anophthalmia, the absence of one or both eyes, is a condition caused by tumour, trauma, congenital defects or due to any systemic condition, indicated for surgical interventions to the orbital contents like the orbital evisceration, enucleation, or exenteration. The most common and acceptable methods to restore the orbital contents is through orbital prostheses. Although non-functional, the orbital prosthesis will restore the esthetics, social appearance and improves the psychological condition of the patients. However, to give an esthetic ocular prosthesis. The most important and critical step in its fabrication lies in a proper iris positioning in the prosthetic eye, as a slight mismatch in iris positioning will affect the esthetics and the purpose of rehabilitation will be lost¹³.

There are many techniques in the literature for iris positioning, but majority of them are subjective in nature, like, using the facial measurements and visual perceptions, and these have very low level of accuracy and precision in iris positioning. To overcome the drawbacks of these subjective methods, some objective approaches like CAD-CAM, modified Hanau face-bow, digital photographs, electronic vernier caliper and laser apparatus have come into picture. However, there is a marginal error even with the objective methods along with the drawbacks of these methods being expensive and technique sensitive¹³.

Augmented reality (AR), by overlapping the digital data of the patient's anatomy on to the patient's real face in real time, provides a more precise iris positioning in the prosthetic eye. It also guides during the procedure, enables to visualize the outcome and potential complications during the procedure. AR is an objective method for iris positioning and acts as a transformative technology through its sophisticated 3D modelling and real-time tracking capabilities. The advancing social networking sites like Instagram (by Meta Platforms) and Snapchat (by Snap Inc.) have further propelled the evolution of AR applications through its various filters giving an immersive experience to the users in real time¹³ (Figure 7).



Figure 7: Augmented reality applied for iris positioning¹³

ii. Shade matching of silicon for MFPPs:

A study by Nimonkar et al. has used AR through mobile phone colorimeter application for shade selection of maxillofacial silicon. The results of the study have proved it to be a reliable shade guide¹⁴

iii. VR in Cranial Reconstruction:

Cranial defects caused by degenerative disorders, congenital defects of cranium, trauma, tumour or any other acquired conditions, necessitates reconstruction for two reasons: esthetic purpose when the defects are small, 2-3 cm in size; and protecting the brain when the defects are large, exceeding 8 cm in size. Therefore, cranioplasty is indicated to address social stigma caused from disfigurement and to provide mechanical protection to intracranial structures¹⁵.

A study was done to compare the applications of computer-assisted surgery (CAS) with the conventional free-hand technique. The result showed that the CAS technology was more efficient and yielded reliable outcomes in cranial reconstruction. To minimize the trial-and-error change during cranial surgery, the application of virtual surgical planning (VSP) along with the CAD-CAM technique is found to be promising, as it enables a precise preoperative planning, anticipate, predict and proactively address surgical complications. Improving the standards of maxillofacial rehabilitation, CAS has four stages in its functioning – 1) visual analog scale (VAS), 2) 3D modelling, 3) surgical phase or intraoperative transfer of virtual design, and 4) postoperative evaluation. This static protocol of CAS can be overcome using augmented reality (AR), as it superimposes the digital

images onto the real patient, facilitating perception and interaction between the virtual image and actual patient simultaneously¹⁵.

AR enables multidisciplinary teams to collaborate more effectively to communicate in a better way and devise a more precise treatment plan and sequence. Both VR and AR create an interactive educational experience about their condition, the surgical procedure, treatment outcome for the patients and allow them to make an informed decision about their treatment options. Hence, AR can be a highly beneficial tool in cranial reconstruction by allowing the operator to carry out proper treatment with minimal or no complications¹⁵.

f. AR in post removal:

Teeth with compromised coronal tooth structure are commonly reconstructed with fiber post. Fiber post is mainly placed in the root canal 5mm above the apical gutta percha to retain the core-build-up material. However, conditions like re-infection of periapical region, need for apical surgery or endo-perio lesions necessitates re-RCT and fibre-post removal. A study on fiber post removal in maxillary molars was conducted by Martinho et al., and the study compared the viability of AR head-mounted device (HMD) through a dynamic navigation system (DNS) with the conventional technique for its viability at the surgical site. The results of the study have proved that the AR HMD through the DNS at the surgical site enables a safe removal of fiber post in maxillary molars¹⁶.

g. AR in Smile Designing:

In dentistry, smile reconstruction has gained a high level of significance due to its esthetic, social impact and influence on a person's self-esteem. This highly significant smile transformation can be achieved through a rigorous and detailed methodology and a proper communication between the operator, patient and the laboratory. Various modalities are used to record various features of a patient – picture-based strategy (PBS) like a set of photographs and software; tools like a mock-up, video analysis, 3D facial recontouring. Although with advancements, the immersivity of tools is improving, they do have major drawbacks of communicating this to the laboratory to obtain the desired outcome, mainly due to the complexity of the tools, in addition to time-consuming and high cost. This time and cost factor can be improved by different hardware and software technological evolutions¹⁷.

One such technology that automatically identifies the person using mathematical algorithms and facial



reference lines is the Facial recognition (FR). This is applied in the security systems for biometrical analysis due to unique facial measurements from person-to-person. AR also incorporates such methodologies and hence can be used as a tool in smile designing. There are two innovative software of AR, focused on an unobstructed communication between the dentist and the laboratory – using a set of pictures, known as automatized picture-based strategy (APBS); and using the front camera system of touchpad, known as enhanced mirror strategy (EMS)¹⁷.

A pilot study was conducted to compare these two AR strategies for smile designing. In the APBS strategy, a set of photographs taken from multiple point of view will be used and this is an automatized version of PBS. In the EMS strategy, as the front camera will be used, patient can directly try and modify the smile proposition and the camera here, acts as an enhanced mirror. Correction and evaluation of the smile can be done digitally and in real time using a large range of tools, that gives a scope to modify various dental and facial parameters like – facial midlines, tooth form and proportions, incisal edges, tooth dimensions, occlusal plane, arch width and inclination, and teeth shade selection. The result of this pilot study showed that, both the AR strategies were satisfying for the participants. However, EMS reported to have more immersivity than APBS and that, APBS strategy can be best used as a pedagogic tool for patient education, while The EMS strategy can be used for virtual try-in phase of the proposed smile design¹⁷.

h. VR in Pain Modulation:

With development and advancement in functional neuroimaging and pain neuroimaging, the understanding about the brain integration and the multidimensional course of pain has improved. This has also proved that various complementary medicine approaches, other than the conventional pharmacological means, do modulate the pain centres and one such complementary approach is mindful breathing (MB). MB is a widely accepted authentic treatment for pain and it is self-facilitated with minimal guidance in the initial period and also easy to implement with no other associated risk. The mechanism of action here is to pay attention to the dynamic interoceptive nature of breathing, avoiding distractions and re-focusing only on their breathing. This will gradually make the learner gain mental control and stability – by this they can reduce anxiety, stress, overcome depression and feel pain reduction. A study investigated a group of long-term Zen meditation practitioners with a high pain-thresholds and found a reduced activation in pain-evaluation areas i.e., the pre-

frontal cortex (PFC); and that there was a direct correlation between the level of PFC deactivation and the duration of meditation¹⁸.

Therefore, mindful meditation modulates pain by deactivating the PFC. However, maintaining focus and attention to breathing in itself is a task as it is a subjective interoception process. Virtual reality (VR), being a computer-simulated interactive experience, delivered through an audio-visual headset, modulates human sensory and emotional systems by an immersive sensory-exteroceptive experience. Studies have established that VR technology effectively manages pain caused from burns, cancer and dental procedures.

A study compared increase in pain thresholds between the traditional mindful breathing (TMB) and virtual reality breathing (VRB). The results showed both strategies to be effective in increasing pain threshold. However, the mechanism of pain modulation was different for both techniques. The TMB group showed increased serenity score, a mental state of being calm and at peace, and an increased fatigue score. The VRB group showed no changes in serenity score. In the TMB technique, the mechanism is that, the anterior PFC modulated attention and evaluation of sensory inputs. By increasing the functional interactions with the contralateral S1 (region that gets activated to noxious thermal stimulation), the posteromedial cortex (PMS) (a part of the neuron system) facilitated the sensory-interoceptive breathing process and this inhibited the S1, thereby increasing pain threshold. The VRB modulated pain by reduced the functional connection with S1 achieved by inducing an immersive 3D exteroception with augmented AV cortical activation; consequently, weakening the pain processing function of S1³. (Figure 8) (Figure 9)

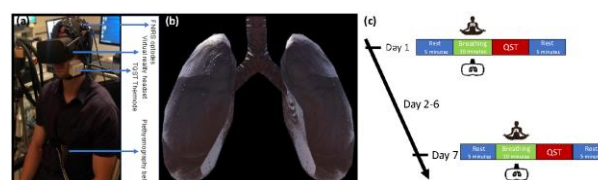


Figure 8: (A)The experimental setup with all the technologies integrated.
(B) The virtual 3D lungs from participants' view.
(C) The experiment protocol³

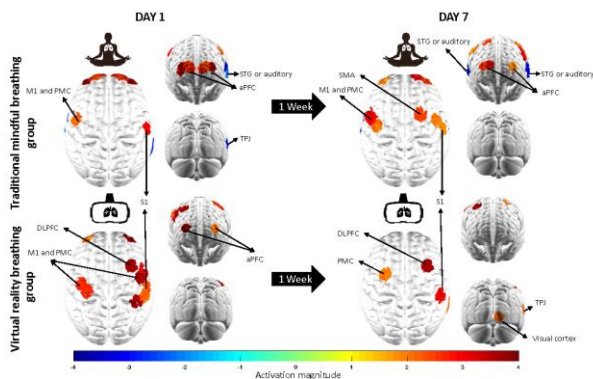


Figure 9: Brain activation map for the thermal quantitative sensory test sessions on visit days 1 and 7³

i. AR in Implantology:

Among all the applications of AR in prosthodontics, it is in implantology, that AR has gained wide spread applications with further research to its improved functioning. Computer-assisted implant surgery (CAIS), a guided technique, is the technology that is widely applied in implant surgery due to its minimal invasiveness, reduced surgical time and post-operative morbidity, ensuring optimal esthetics, function and prosthetic biomechanics. CAIS is of two types: static and dynamic navigation. In static CAIS, there will be fabrication of surgical template, digitally designed and milled, and this will be used to guide the surgical drills to prepare implant bed for implant placement. Dynamic CAIS, on the other hand, allows real-time monitoring of the implant-bed preparation, using CT or CBCT pre-operatively and this data guides the position of the surgical drills through special software and tracking methods. This dynamic CAIS is AR based as it superimposes digital images in real time on actual structures on a display¹⁹.

There are studies that have compared the accuracy of implant placement between the dynamic CAIS, free-hand and static CAIS. All the required data for dynamic CAIS was obtained to track the headset, drill marker and patient marker. The headset position will also be tracked and this tracked data will be projected after combining via sensor fusion in 3D space for the headset position and momentum (important during surgery). The markers guide the drill in the patient. The AR set up additionally also requires a VRD (virtual reality display) set and a computer to upload the surgical plan to the VRD. With this entire set-up ready, implant surgery can be performed by the dynamic CAIS technique by marking three dots at the surgical site representing the entry point,

angle and depth of the drill indicating the accuracy at each level in real time. For static CAIS, surgical templates were designed and milled using CAD-CAM, its fit was evaluated intraorally, stabilized with three guide fixation screws and surgery was carried out¹⁹. Post-operative CBCT of all the test groups was taken and primary outcome variables on angular deviation, global deviation, coronal global deviation, and apical global deviation was calculated and compared. The results of this study showed that the static and dynamic CAIS outperformed the free-hand approach and both static and dynamic CAIS performed equally¹⁹. (Figure 10) The results of this study are supported positively by various studies.



Figure 10: The experimental setup in the AR-based CAIS group (A), the free-hand group (B), and the static CAIS group (C)¹⁹

As a part of evolution and innovation, there are improvements even with the dynamic CAIS. The initial dynamic CAIS technique used a separate screen monitor to display tracking images. This needs the operator to look at the screen i.e., away from the oral cavity to follow the navigation and yet has to coordinate those with the hand, again without looking. This interrupts the surgical flow, increases the risks and error during surgery and also induces anxiety in the operator. To overcome these drawbacks, the AR glasses via a see-through head



mounted device (HMD) had been developed and merged with the dynamic CAIS to assist operators directly visualize the digital navigation information over the actual operating site to improve the real-time surgical performance.

A systematic review and meta-analysis were conducted to compare the implant placement accuracy between the free-hand, static CAIS, dynamic CAIs and AR-navigation techniques. The study examined the positional variations by analysing 6 variable – lateral coronal deviation (LCD), lateral apical deviation (LAD), global coronal deviation (GCD), global apical deviation (GAD), depth deviation, and angular deviation. The results showed that the AR navigation group displayed greater implant placement accuracy than all other groups for all the variables. The results of the meta-analysis showed that the deviations exhibited the AR navigation system was within the safe zone i.e., 1-2 mm horizontally and vertically, and 5° of angular deviation. Apart from this advancement, there are also marker-based and marker-free image registration and tracking systems. The marker-based method needs specific artificial marks to be placed on the template/ drill and the patient. The marker-free approach uses a point cloud-based registration method and tooth tracking methods to merge digital data with real environment. Although marker-free approach is simpler, convenient, time saving and hustle free, its application needs to be evaluated on a large population for reliability²⁰.

Further the see-through head mounted display (HMD) devices also can be categorized into two types based on the image display principles - optical see-through (OST), that uses translucent mirrors in front of the eye to optically combine real and virtual images; and video see-through (VST), that uses 2 mini video cameras on the headgear to capture actual images and electronically combine these with the virtual images. Recently, to further avoid the discomfort of wearing the HMD, there has been IV overlay device developed that will enable the surgeon's naked eye to visualize the AR navigation. This IV overlay display is an autostereoscopic display, that uses a fast image rendering algorithm to project digital image on the surgical site through a microconvex lens array using multiple rays²⁰ (Figure 11) (Figure 12).

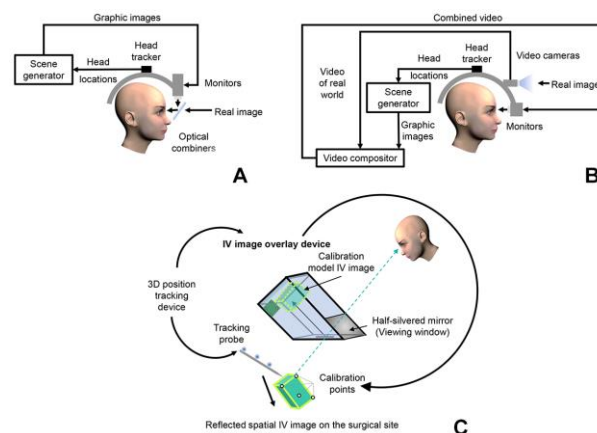


Figure 11: Augmented reality image display devices. (A) OST HMD device. (B) VST HMD. (C) IV image overlay device. HMD: head-mounted display; IV: integral videography; OST: optical see-through; VST: video see-through²⁰

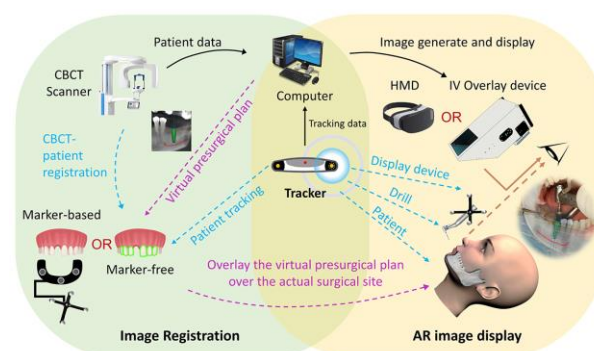


Figure 12: Augmented reality (AR) dental implant navigation system. CBCT: cone-beam computed tomography; HMD: head-mounted display device; IV: integral videography²⁰

To add more knowledge specifically about the influence of AR glasses on the accuracy of implant position in relation to deviation at entry point, apex, angular deviation or axis divergence, a randomized clinical study was done between implant placed using dynamic CAIS system, with and without AR glasses. The results of the study for each variable showed that no statistically significant difference in accuracy between the two groups. However, the implants placed using AR glasses by dynamic CAIS showed lower deviation in all aspects than those implants placed by dynamic CAIS without AR glasses²¹.



3. Conclusion

With technological advancements, AR is gaining widespread application in almost all branches of dentistry. This literature review gives a bird's view information to the applications of AR in the domain of prosthodontics and implantology. However, there are drawbacks in any technology and so does AR also has certain limitations and there is always scope for innovations and research in this aspect to better assist an operator and to provide a better treatment for the patient.

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