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Review Article

Augmented reality application in prosthodontics

Syeda Andaleeb Zaidi[1,*], C Ravi Kumar[1], M Sujesh[1], A V Rajanikanth[1], Kollu Sunitha[1]

[1] *Dept. of Prosthodontics, Mamata Dental College, Khammam, Telangana, India*

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ABSTRACT

Augmented reality refers to: “a technology that superimposes a computer-generated image on a user’s view of the real world, thus providing a composite view”. It has become resourceful in many fields including dentistry and medicine. Currently augmented reality is restricted to education, maxillofacial surgeries and implantology but further research and development can expand its uses to many other critical areas. In prosthodontics, visualization of a smile design or a prosthesis outcome becomes difficult to the patient. Augmented reality will make it easier for all the persons involved to establish a proper communication and desired treatment outcome for the patient as it will superimpose the desired outcome on the current patient situation. As augmented reality is becoming more common, its applications will become wider. This article presents a brief history of the development of augmented reality and its current applications in the field of prosthodontics.

1. Introduction

Modern dentistry is characterized by 3D digital technology, computer-aided design, and computer-aided manufacturing. With the increase in digital transformations, many innovations have been carried out to enhance dental education and clinical activities. The most prominent of them is the reality–virtuality continuum in form of augmented reality and Virtual reality.[1]

Traditional dental digital technologies commonly follow a three-step process: An image is scanned by a scanning device, and the operator can digitally adjust the tooth position or size, this data is either transported back to a solid state or remains digital as a wax-up.

With the advent of AR and VR, these processes have been simplified. AR and VR systems require real and virtual data sources, tracking, registration, visualization processing, perception locations, display types, and feedback methods. While virtual reality builds a virtual world, AR builds a link between the real and virtual worlds, allowing users to interact with both worlds.

Head-mounted displays, monocular systems, monitor-based interfaces and other combined technologies are the devices commonly used in augmented reality systems.[2]

AR focuses on clinical practice by allowing clinical information to be displayed on the patient immediately, combining digital and real-world data.

AR is most commonly used in dentistry to "enhance reality" by overlaying digital information on top of real-world things like photos, videos, and 3D models, and to build live communication systems between patients and dentists through photos, videos, and 3D models.

* *Corresponding author*.
E-mail address: andaleeb.zaidi296@gmail.com (S. A. Zaidi).

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2. Clinical Applications

Currently, AR is employed in plastic surgery, laparoscopic, and neurosurgery. In dentistry, its applications include oral and maxillofacial surgery, dental implant surgery, and orthognathic surgery.[3]

AR gadgets allow users to combine medical information, data, and images with reality. AR guiding devices show real-time intraoperative data right on the operating table, in contrast to image-guided surgery where the doctor has to look away from the surgical field. Thereby decreasing surgical risk.[4]

AR has been shown to improve dental implant results. An implant placement system with the realistically overlaid suggested position on the patient was presented in 1995. AR surgery A retinal imaging display was utilised to pioneer implant navigation systems.

AR can operate as an automatic data filter during implant placement. Allow surgeons to focus purely on implant placement by just showing them critical information. This cutting-edge technology can help dentists communicate better with the technician and the patient. Comprehensive virtual simulation can show patients the expected clinical consequences.

An augmented reality device can create a 3D model right in the patient's mouth. This allows for 3D aesthetic planning. An AR system can share the operator's reality with a dental technician or other specialists as well.

Fig. 1: SENSORAMA Sensorama Simulator patented by M. L. Heilig (1962). This invention is widely credited as being the first simulator designed to stimulate multiple senses. [Figure reproduced from Heilig (1962, Figure 5),

3. The development of Augmented Reality Through Years

Earlier to this level of technology, many intelligent people did amazing things using Augmented Reality. These are some of the important people and events that led to the development of Augmented Reality:

3.1. 1962

Sensorama, a motorbike simulator made by cinematographer Morton Heilig, is one of the earliest examples of immersive, multi-sensory technology that people have known about.

3.2. 1968

Ivan Sutherland's Sword of Damocles is the first Augmented Reality (VR) system. It was one of the earliest 6DOF trackers with an optical see-through head-mounted display.

3.3. 1975

Artist Myron Krueger created Video place, an Augmented Reality system that allowed users to interact with virtual things for the first time.

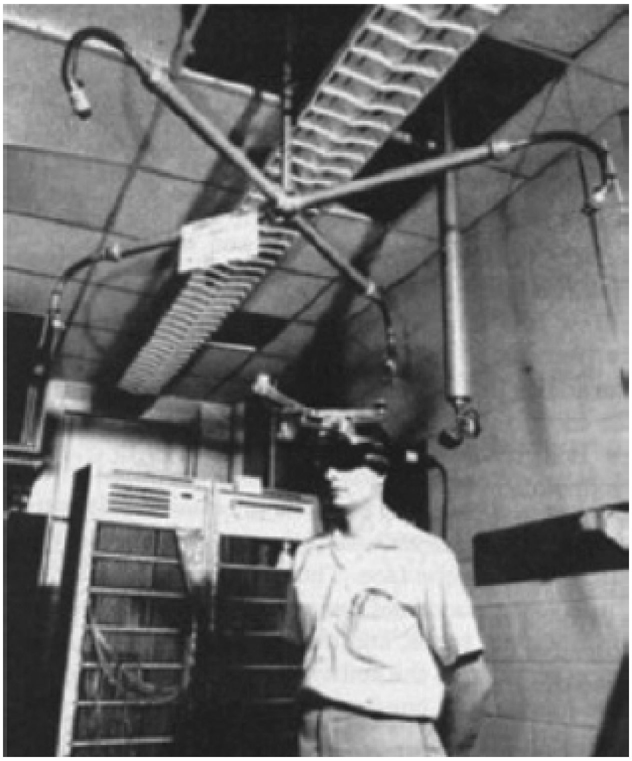

Fig. 2: The Sword of Damocles Optical Head-Mounted Display

3.4. 1992

"Augmented Reality" term is credited to Tom Caudell and David Mizell of Boeing's Computer Services' Adaptive Neural Systems Research and Development project. They did research and development to improve Boeing's production and engineering processes. They came up with software that could show where different wires were in the construction process.

3.5. 1996

Prototype NaviCam AR, created by Jun Rekimoto. Markers are actual or virtual artefacts or locations. A marker is what the computer recognises as the display position for digital data. This was one of the earliest marker systems to provide six-degree tracking. This marker is still used today.

3.6. 1997

Ronald Azuma, a pioneer in the subject, defines augmented reality as having these three properties: It merges the real and virtual worlds, it's interactive in real-time and is registered in 3D.

3.7. 1999

Total Immersion is founded and becomes the market's first provider of AR solutions. Total Immersion's D'Fusion is a cross-platform product. Hirokazu Kato released the ARToolKit. This package of tools allows you to merge real-world video with virtual objects and 3D graphics on any operating system. ARToolKit was used to create almost all Flash-based augmented reality on the web today. It allows users to interact with augmented reality information while wearing it. Hollerer, Feiner, and Pavlik created it. This technology warms up the AR browser.

3.8. 2000

1. Bruce Thomas and his colleagues created an augmented reality Quake. A six-degrees of freedom (6DOF) tracking system, GPS, a digital compass, and vision-based marker tracking were all featured in "AR-Quake."
2. In 2000, Simon Julier and his team created the Battlefield Augmented Reality System (BARS). This system provided vital information to ground troops. It had a head-mounted display, a wearable computer, and wireless networking.

3.9. 2001

Reitmayr and Schmalstieg develop a mobile augmented reality system. This concept showcased the possibilities of AR hybrid systems by merging mobile Augmented Reality with user participation in a shared Augmented Reality world.

3.10. 2004

Mathias Möhring demonstrated the first mobile 3D marker tracking system. The breakthrough allowed for 3D marker detection, separation, and integration into live video streams. This endeavour presented the first mobile phone augmented reality system.

3.11. 2008

Mobilizy now offers the Wikitude World Browser with AR. This programme combines GPS and compass data with Wikipedia pages over a smartphone's real-time camera view.

3.12. 2009

SPRXmobile has released Layar. Also, Layar uses GPS and compass data to register things. Layar is an AR browser that uses an open client-server platform with content layers much like a PC browser.

Augmented reality is used in advertising, task help, navigation, home and industrial art, entertainment, gaming, education, and social networking. Also, augmented reality is rapidly being used in dentistry for education.

Anatomy fascinates both medicine and dentistry. An atlas and a cadaver are used in traditional anatomy classes, which takes time and effort. In the absence of cadaverbare, the AR values are underlined. These images can also be used to show inside body parts, which is beneficial to teach anatomy.

AR can also be used in real-time with digital ultrasonography. The Virtual Reality Dentistry Training System and DenSim simulator (Image Navigation Ltd., NY) were created for dental education (Novint Technologies, Inc. and Harvard School of Dental Medicine, Albuquerque, NM). Because enamel, dentin, and pulp are all of the different hardness, multi-layered virtual tooth models were created for additional realism.

For dentistry students, enhanced video and audio rendering help prepare them for all-ceramic restorations. With augmented reality, DenSim and MOOG Simodont are geared for gold-only design. It was found that there were no significant variations in knowledge levels between standard instruction and AR for cavity preparation in Classes I and II. However, AR-trained students scored better in terms of depth, Class I cavity size, and Class II cavity proximal wall divergence

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4. Tooth Preparation[5]

Most root-canalized teeth require a prosthetic crown to prevent tooth loss. As a result, prepping teeth for a prosthetic crown is a typical treatment. The preparation must be flawless for the crown to have a higher rate of survival and service. Maxillary preparations are more challenging than mandibular preparations, and performing them on individuals with no preclinical expertise is tough. To prepare for clinical work, trainee dentists need to practise and evaluate their preparations.

All-ceramic tooth preparation for mandibular molars was evaluated using Preppr, a piece of software developed at the University of Otago in New Zealand. It was designed to be included in dental simulator systems because it showed students performing better than traditional methods.

5. Dental Implant Surgery Procedures[5]

Dental implants are increasingly used to treat edentulous people. Dental implant installation is a delicate procedure that requires extensive training. A careful placement with an adequate bone thickness on all sides is required to minimise excessive implant surface exposure. Treatment planning and pinpointing this specific area have been made easier with the help of AR technology. This makes the process less invasive and painful.

A low-cost stereoscopic display system and six degrees of flexibility in implant location were compared to three degrees of freedom in the virtual world by Seipel et al. If voxel-level computed tomography (CT) images are used, treatment plans can be changed in real-time.

Kusumoto et al. and Ohtani et al. developed systems that merged CT pictures of the jaw bone with a VR force-feedback haptic device to provide unskilled trainee dentists with a realistic experience. Xiaojun and his colleagues proposed CAPPOIS, modular software that aided in preoperative planning. The technology might then be applied to simulated jawbones before being applied to humans.

6. Available Dental Simulator Systems Include[5]

The public now has access to a wide selection of commercial dental simulators, recognising the value of AR-VR technology in medical and dental sciences. This technique is being used for student training with good results.

6.1. DentSimTM

DentSimTM, published in 2004, was one of the earliest dental simulators. It uses augmented reality and a lab mannequin. Typhodont teeth and student handpiece movement are optically captured and evaluated in real-time. The learner can examine the tracked images from various angles while working on the plastic teeth. According to Jasinevicius et al., using a dental simulator boosted student pr6eparations and decreased average preparation time.

6.2. Voxel-Man

A virtual middle ear surgical simulator, the Voxel-Man simulator, was later repurposed for dental treatments and now incorporates a range of carious disorders. Students can practise manual dexterity and problem-solving skills with simulated genuine teeth and force feedback enabled dental handpiece. The device provides a genuine experience by distinguishing between enamel, dentin, pulp, and carious tissue tactile sensations. A high-resolution 3D screen shows all models and instruments, and a foot pedal controls high and low-speed bursts. It can be expanded and viewed in cross-sectional images by utilising a virtual dental mirror.

The automatic skill evaluation tool evaluates student work by comparing it to a standard. In this way, pupils get instant feedback on their work. A pilot test model was utilised by Pohlenz et al. to assess the simulator's viability as an extra learning medium (92.7 per cent). To compare two training groups' ability to complete apicectomies while retaining key structures, Sternberg and his colleagues employed a simulator. The group with prior simulator training outperformed the group using cadaver models.

6.3. Dentist simodont®

The Academic Centre for Dentistry in Amsterdam developed Nissin Simodont® in conjunction with Moog Industrial Group in Amsterdam. An interactive touch panel, a 3D display viewer, stereo vision projectors, a virtual mirror, a handpiece gimbal, and a foot pedal are part of the hardware. It has an adjustable height and a hand and finger rest for user comfort.

To boost student learning, teachers can adapt the courseware to include current or custom cases and patient-specific exercises. Student work can be checked and reports can be issued based on performance.

Bakr et al. tested Simodont® at Griffith University in Australia, and found it to be a valuable extra teaching tool, although with technological limitations. In a randomised control experiment, Al-Saud et al. discovered that combining teacher recommendations with trainer feedback improved performance above either strategy alone. Zafar et al. found that the simulator can be used as an addition to dental training.

6.4. BoneNavi

Bone navi is a system for navigating your bones. Ohtani et al. created BoneNavi, a computer-aided implant surgical help system. For implant placement and surgical guide generation, the approach uses virtual reality force feedback and CT jawbone scans. These CT images are used for individualised treatment planning and practice before surgery. No existing research supports its validity.

6.5. Virteasy Dent

HRV (Changé, France) developed Virteasy Dental in collaboration with several universities, including Sheffield. It generates a virtual environment with a virtual patient and a virtual workspace. It includes restorations, endodontics, prosthodontics, implantology, and operator evaluation. The simulator's editor tool lets users import intra-oral images and create pathologies. The simulator has shown promise in providing clinically useful qualitative input.

6.6. Dental Education Assistant (IDEA)

IDEA is a prototype software for cavity preparation that can be loaded on any computer. It debuted in 2011. It has a six-degree stylus and a PHANTOM® haptic device (SensAble Technologies, Inc.). ManualDexterityTM, Scaling & Root-PlanningTM, OralMedTM, and PreDenTouchTM are among the preinstalled modules.

Cavity preparation uses 3D geometric shapes rather than actual tooth photos. The feedback system evaluates task completion time, tissue removal, and deviation from desired activity. Gal et al. concluded from their initial evaluation of the simulator that it could be used by both professionals and students. To go even further, we need to make a lot of improvements in sensory simulation and get more feedback from instructors and students.

6.7. SimImplanto

SimImplanto is a keyboard-controlled Falcon haptic device developed by Pires et al. in 2016 to simulate implant-based oral rehabilitation. Drilling resistance was calculated using CT scans of various bone densities. 3D jaw models were created using scanned dental casts. The literature had no more evidence to remark on the simulator's efficacy or applications.

6.8. Leonardo

The Leonardo dental simulator from GEOTAR Media captures real-time operations on tooth models and provides full feedback on all procedures. The simulator may take a patient's history, select an anaesthetic, and be customised. The technology tracks total operation time, effective times, healthy tissue removed, and needless motions. With real dental equipment and Polhemus electromagnetic motion tracking technology, it provided real-time feedback. The system can track six sensors at once and provide instant feedback.

6.9. SimEx is a dental simulation system (CDS-100).

The CDS-100 is an EPED, Inc. exclusive tool for dental simulation and evaluation in 3D. It helps novice dentists learn and can be used by practitioners to improve their skills. The simulator provides quick feedback and captures operational processes for users or assessors to review. The simulator's application appears promising, but no published research backs it up.

7. In maxillofacial Pro sthesis[6]

Patients with significant mouth injuries and high societal expectations make maxillofacial prostheses a difficult field to operate in. A detailed understanding of oral physiology, anatomy, and prosthetic designs and functions is required. Because maxillofacial prosthesis therapy is multidisciplinary, digital data presentation is crucial for treatment planning and patient education. Apps like Vuforia and Unity 3D were used to make them. They enable complex computer capabilities, including image and object recognition, as well as real-world interactions. A built-in camera collects a live video stream, and the CPU augments it by adding 3D models to the scene.

An AR application was devised that allows the prosthodontist to drag, rearrange, and resize photos to fit the treatment plan. Visual buttons were utilised to control visibility, movement, rotation, and size. Finally, the scene was saved as a downloadable Android app, with an icon for the final programme.

8. Future Prospects

The marker-based AT system, for example, allows the scale of real pictures to be modified. Markerless augmentation and head-mounted gadgets will prevent visual distortion in the future. An algorithm for oral surgery and prosthetics needs to be made, as well.

9. Conclusion

The advantages of AR are clear. Planning can help predict realistic outcomes. Using intraoperative navigation improves surgeons' chances of success and minimises dangers. AR simulations can be more instructive for students and residents. A head-mounted display proposed implant navigation system can help ease treatment planning and placement of dental implants.

However, several unknowns limit AR's use. Most of these difficulties should be addressed as technology advances. Legal issues connected to confidential data management should also be resolved. Because AR systems are still too expensive for frequent use in dental clinics, assessing the cost-benefit ratio is another difficulty.

Adding technologies to existing AR systems tends to improve their functionality. AR systems use dyes like indocyanine green and photon emission tomography to locate sentinel nodes and tissue vascularity. Another AR technology to combine is haptic force feedback with robotics.

10. Conflict of Interest

The authors declare no relevant conflicts of interest.

11. Source of Funding

None.

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Author biography

Syeda Andaleeb Zaidi, Post Graduate Student

C Ravi Kumar, HOD & Professor

M Sujesh, Professor

A V Rajanikanth, Professor

Kollu Sunitha, Reader

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