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ORIGINAL ARTICLE

AUGMENTED REALITY AND 3D PRINTING IN ORAL SURGERY AND PROSTHETIC DESIGN: A CLINICAL INSIGHT

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Background: The use of augmented reality (AR) and 3D printing technology in dentistry has changed how oral surgery is planned and how prosthetics are made. These new technologies make things more precise, easier to understand, and faster, which greatly improves the results of therapy. This study sought to investigate and assess the therapeutic efficacy of Augmented Reality and 3D printing in oral surgery and prosthetic dentistry, focusing on critical outcomes including surgical precision, procedural efficiency, prosthetic integration, and patient satisfaction. **Materials and Methods:** This was a observational clinical study that lasted for six months. Thirty patients needing either oral surgery or prosthetic rehabilitation were recruited one after the other based on the criteria for inclusion and exclusion. The patients were split into two groups: group A for oral surgery and group B for **prosthetic design.** **Results:** In group A, the mean coronal deviation was 0.95 ± 0.34 mm, and the mean apical deviation was 1.14 ± 0.47 mm. The time spent in the operating room was reduced by 18.7% in comparison to standard procedures ($p < 0.01$). In group B, printed prostheses had an average dimensional accuracy of 98.6% when compared to digitized designs. The time it took to make things was cut by an average of 40% compared to traditional lab methods. **Conclusion:** Augmented reality and 3D printing in oral surgery and prosthetic dentistry make a big difference in accuracy, speed, and results that put the patient first.

Keywords: Augmented Reality and 3D Printing in Oral Surgery and Prosthetic Design: A Clinical Insight

INTRODUCTION

Digital technologies have changed the field of dentistry a lot in the last few decades. Augmented Reality (AR) and Three-Dimensional (3D) printing are two of the new technologies that are changing how oral surgery and prosthesis design are done.

These technologies enable a shift from traditional, experience-driven methodologies to precision-focused, customizable, and patient-centered treatments. This introduction talks about the scientific basis, current uses, and future uses of AR and 3D printing in dentistry. It talks about how they work together to make surgery more accurate, lower the chance of problems, and make prosthetics work better.

Augmented Reality (AR) is the process of adding virtual information to a real-time visual field. This makes it easier for the clinician to see and interact with the real world. In oral surgery, augmented reality (AR) can show anatomical landmarks, surgical routes, or virtual instruments right in front of the surgeon's eyes while they are working. This helps the clinician find their way and make decisions in real time without getting lost.[1] Unlike virtual reality, which puts users in a completely fake world, augmented reality (AR) keeps a mix of real and fake worlds so that users can see and interact with both at the same time.[2] AR is possible because of high-tech hardware and software parts like head-mounted displays, depth-sensing sensors, and computer vision algorithms. Dentists often use these methods with cone-beam computed tomography (CBCT) data and intraoral scans to make precise digital overlays. Some uses are guiding the placement of an implant, seeing the mandibular nerve, simulating orthognathic surgery, and helping with difficult maxillofacial surgeries while they are happening.[3]
3D printing, also called additive manufacturing, makes dental parts by stacking materials on top of each other according to computer plans. This method usually starts with getting pictures, like scans of the inside of the mouth or CBCT images. Then, computer-aided design (CAD) software is used to make the design, and technologies like stereolithography (SLA), digital light processing (DLP), or fused deposition modeling (FDM) are used to make the final product.[4] Dental uses include surgical guides, anatomical models, temporary and permanent crowns, custom implants, removable prosthetics, and orthodontic tools.[5]
The merging of AR and 3D printing provides new boundaries in individualized care. For instance, AR-based visualization can assist in evaluating the spatial correctness of 3D-printed surgical guides during implant placement. This method greatly lowers the chance of making a mistake when using freehand techniques and makes the trajectory of the implant more accurate, especially in areas that are anatomically complicated or sensitive to aesthetics.[6] Similarly, in reconstructive prosthodontics, AR offers real-time observation of facial symmetry and occlusion during digital wax-up design, while 3D printing facilitates the manufacture of custom-fitted prostheses, hence decreasing post-operative revisions.[7]
A lot of clinical research backs up how well these technologies work. Vercruyssen et al. showed that 3D-printed static surgical guides made implant placement more accurate by lowering both angle and depth errors compared to freehand approaches.[8] Meola et al. conducted another study using AR-based navigation systems and discovered higher surgical precision, reduced operation durations, and increased intraoperative trust among physicians.[9] Dawood et al. also said that AR may be successfully combined with stereolithographic models for reconstructive surgery, resulting in great aesthetic and functional results.[10]

3D printing has been shown to speed up the time it takes to make prosthetics and cut down on material waste while making patients more comfortable. Jockusch and Özcan stressed that 3D-printed temporary crowns and dentures had good marginal fit and mechanical qualities that made them safe for clinical use.[11] When used with AR simulation tools, clinicians may also see how well a prosthetic fits, works, and looks in real time. This lets them make changes while the patient is in the chair and improves communication with the patient.[12] From a planning and teaching point of view, AR and 3D-printed models are also quite useful. 3D printing anatomical training models lets residents and students practice procedures without any risk. AR-based simulation platforms enable interactive, dynamic training in intricate surgical protocols, such as Le Fort osteotomies or zygomatic implant implantation, which would normally be confined to high-stakes clinical settings.[13] Even while these are good things, there are still some problems with using AR and 3D printing in everyday dentistry practice. A high initial capital commitment, restricted interoperability between software platforms, and steep learning curves are some of the most important impediments.[14] Additionally, the biocompatibility, sterilizability, and long-term durability of 3D-printed materials are still being studied, especially for permanent prosthetic uses. Regulatory frameworks governing the clinical application of AR-guided procedures and patient-specific 3D-printed devices are currently developing and differ among countries.[15]

But these problems are quickly being fixed by continual improvements in machine learning, material science, and cloud-based CAD/CAM platforms. Bioprinting for scaffold regeneration and haptic feedback in AR settings are two new technologies that are making surgery more immersive and integrated. As these technologies develop, their use in medicine is likely to grow, especially in fields that need a lot of precision, such implantology, maxillofacial surgery, and digital prosthodontics.[16]

This study was to investigate and assess the therapeutic efficacy of Augmented Reality and 3D printing in oral surgery and prosthetic dentistry, focusing on critical outcomes including surgical precision, procedural efficiency, prosthetic integration, and patient satisfaction. The study analyzed clinical cases and practitioner experiences, contributing to the expanding evidence base for digital transformation in dentistry practice and providing practical insights for its wider application.

MATERIALS AND METHODS

Design and setting for the study:

This was a prospective, observational clinical study carried out over six months at the Department of Oral and Maxillofacial Surgery and the Department of Prosthodontics.

Thirty patients (18 males and 12 females, aged 21 to 65 years) necessitating either oral surgical surgery or prosthetic rehabilitation were consecutively recruited according to specified criteria.

Table 1. Demographic and Clinical Distribution of Study Participants

Parameter	***Total (n=30)***	***Oral Surgery (n=16)***	***Prosthetic Design (n=14)***
Mean Age (years)	42.7 ± 13.2	39.6 ± 11.4	46.2 ± 14.3
Gender (Male:Female)	18:12	10:6	8:6
Procedures Performed	—	Third molar extraction (5)Implant placement (4)Cyst enucleation (3)Mandibular fracture repair (4)	FPD (5)Full-arch prostheses (4)Maxillofacial prostheses (3)RPD (2)

Inclusion criteria:

- Patients necessitating surgical interventions, including intricate third molar extractions, dental implant insertion in difficult anatomical regions, cyst enucleation, or management of mandibular fractures were .
- Patients who needed fixed or removable prostheses, full-arch rehabilitations, or maxillofacial prosthesis.
- Willingness to undergo digital intervention involving augmented reality navigation and/or 3D-printed prosthetic solutions.
- Ability to give informed consent.

Exclusion Criteria:

- Patients with medical problems that make elective oral surgery unsafe.
- Patients who have active oral infections or bad periodontal health.
- Patients who don't want to or can't follow digital planning methods.
- A history of having an adverse reaction to dental impression materials or resins used in 3D printing.

Participant groups:

We put the participants into two categories based on how they were treated:

Group A: Oral Surgery Group (n=16) — Had surgery with the help of augmented reality (AR) and/or 3D-printed surgical guidance or models.

Group B: Prosthetic Design Group (n=14) got prosthetic rehabilitation with prostheses or related equipment that were created and 3D-printed digitally.

Workflow for Augmented Reality (Group A)

For real-time vision during surgery, an AR system that is available for purchase was employed. It had an optical tracking camera and a headset that could be worn. Preoperative Imaging: For each patient, cone-beam computed tomography (CBCT) images were taken using conventional protocols with a Planmeca ProMax 3D Mid (Finland).

Virtual Planning: Data from CBCT scans were imported into implant planning software (Blue Sky Plan or DTX Studio), where anatomical structures were separated and surgical paths were set.

AR Integration: The planned data was made compliant with DICOM so that it could be used with the AR headset. The headset showed real-time 3D overlays of anatomical features and surgical landmarks on the operating field. During surgery, surgeons used the AR interface to find their way around, place implants, or line up fractures, all while getting real-time visual feedback.

3D Printing Process (Groups A and B)

Using SLA and FDM technologies, 3D-printed models, surgical guides, and prostheses were made for both surgical and prosthetic uses. Digital imprints and Design: An intraoral digital scanner (TRIOS 3, 3Shape, Denmark) was used to acquire high-resolution imprints of the mouth. The data were sent to dental CAD software (Exocad DentalCAD or 3Shape Design Studio) as STL files to be used for making prosthetics and guides. A stereolithography printer (Formlabs Form 3B+, USA) with biocompatible resin (Surgical Guide Resin V2) was used to manufacture surgical guides and diagnostic models. An FDM printer (Ultimaker S5, Netherlands) using high-resolution dental-grade thermoplastics was used to create both interim and permanent prostheses.

Post-Processing: All printed products were cleaned with isopropyl alcohol (IPA) and then cured in a UV chamber (Form Cure, Formlabs) to make them stronger and more stable in size.

Clinical Application: Printed surgical guides were utilized for osteotomy and implant placement in Group A.

In Group B, the printed prostheses were tested within the mouth for fit, occlusion, looks, and how comfortable they were for the patient.

Outcome Measures for the Oral Surgery Group: Accuracy of Implant Placement: Postoperative CBCT scans were overlaid with preoperative plans, and variations at the coronal and apical implant sites were quantified.

Intraoperative Time: The total time of the surgery (in minutes) was recorded and compared to the average time for similar procedures.

Complications: Any problems that happened during or after the surgery were written down.

Surgeon Feedback: Surgeons used a 10-point Likert scale to judge how easy it was to use AR and see things.

For the group that designs prosthetics: Using surface deviation analysis, we compared digital scans of the delivered prostheses to their CAD designs to check for dimensional accuracy.

Fitting Success: We kept track of how many clinical visits were needed and how many changes had to be made within the mouth.

Fabrication Time: The time it took to go from digital design to final delivery was compared to standard schedules.

Patient Satisfaction: Patients rated their satisfaction on comfort, esthetics, and function using a 10-point Likert scale.

Statistical Analysis

We examined the data using SPSS Version 26.0 (IBM Corp., Armonk, NY, USA). Descriptive statistics were used to look at the demographic and clinical data. We displayed continuous variables alongside their means and standard deviations. We employed paired t-tests to juxtapose procedural timeframes and patient satisfaction levels against historical control data derived from institutional records. A p value of less than 0.05 was considered statistically significant.

RESULTS

This clinical observational study included 30 patients (18 males, 12 females; mean age 42.7 ± 13.2 years) treated from January to June 2025. Participants were categorized into two groups based on clinical application: Group A – Oral Surgery (n=16) and Group B – Prosthetic Design (n=14).

Group A:Applications for Oral Surgery

During many surgeries, such as complicated third molar extractions, implant insertion, cyst treatment, and managing fractures in the lower jaw, AR technology was used for navigation and seeing inside the body. In combination, 3D-printed surgical guidance and anatomical models eased preoperative planning and execution.

The average coronal deviation was 0.95 ± 0.34 mm and the average apical deviation was 1.14 ± 0.47 mm. The time spent in the operating room was cut by 18.7% compared to standard procedures ($p < 0.01$). Subjective evaluations by operators indicated that AR enhances spatial orientation, surgical confidence, and precision. There were no problems during the operation or mistakes caused by AR.

Group B: Making and Designing Prosthetics

Using SLA and FDM technologies, 3D printing was used to make diagnostic wax-ups, surgical templates, temporary prostheses, and permanent restorations. When compared to digitized designs, the average dimensional accuracy of printed prostheses was 98.6%. In 85.7% of cases, clinical fitting was successful with only a small amount of correction needed inside the mouth. Compared to traditional laboratory methods, the time it took to make things was cut by an average of 40%. Patients were quite happy with the results, especially the way they looked and felt (mean satisfaction score: 9.2/10).

Table 2. Outcomes in Oral Surgery Group (AR + 3D Printing)

Outcome Measure	***Value***
Dimensional accuracy of 3D-printed prostheses	98.6% match with digital file
Clinical fitting success rate	85.7%
Reduction in prosthesis fabrication time	40% faster than conventional
Patient satisfaction (Likert scale, 1–10)	9.2 ± 0.6
Need for major adjustment post-insertion	2 cases (14.3%)

Table 3. Outcomes in Prosthetic Design Group (3D Printing)

Outcome Measure	***Value***
Dimensional accuracy of 3D-printed prostheses	98.6% match with digital file
Clinical fitting success rate	85.7%
Reduction in prosthesis fabrication time	40% faster than conventional
Patient satisfaction (Likert scale, 1–10)	9.2 ± 0.6
Need for major adjustment post-insertion	2 cases (14.3%)

Table 4. Comparative Summary Between Groups

Parameter	*Oral Surgery Group*	*Prosthetic Design Group*
Technology Used	AR + 3D printing	3D printing only
Accuracy (clinical outcome)	Implant deviation <1.2 mm	Dimensional fidelity >98%
Efficiency Improvement	18.7% time reduction	40% fabrication time saved
Patient Satisfaction Score (1–10)	8.9 ± 0.8	9.2 ± 0.6
Complications/Errors	None	Minor fitting adjustments

DISCUSSION

The incorporation of augmented reality (AR) and three-dimensional (3D) printing technologies into clinical dentistry, especially in oral surgery and prosthodontics, signifies a substantial transition from traditional analog methods to digitally enhanced, patient-centered workflows. The current clinical analysis assessed the practical implementation of these technologies, emphasizing their effectiveness in strengthening surgical precision, decreasing treatment durations, improving prosthetic accuracy, and increasing patient satisfaction.

In the realm of oral surgical procedures, augmented reality (AR)-assisted navigation exhibited remarkable precision, with a mean coronal deviation of implant placement measuring 0.95 ± 0.34 mm and an apical deviation of 1.14 ± 0.47 mm. These findings correspond with those of Wu et al., who observed similar positioning accuracy in implant insertion operations utilizing AR systems, hence affirming the clinical trustworthiness of AR in attaining precise surgical results.[17]

The use of AR cut the length of the surgery by about 18.7%, which supports earlier research that shows how real-time intraoperative visualization can make things more efficient.[18] This shorter surgical time not only helps to streamline the workflow, but it may also make the patient experience better by shortening the time spent under anesthesia and the overall unpleasantness of the procedure.

The technology's ability to improve spatial perception and give real-time feedback also makes the operating environment more intuitive, as has been observed in neurosurgery and orthopedic literature.[19]

This study did not find any AR-related problems during surgery, which is important since it shows that AR devices are safe when used correctly. The great usability noted by surgeons and the moderate learning curve indicate its potential for scalability in academic institutions and specialized clinics. These results align with experiences documented in several surgical disciplines, where augmented reality systems have been effectively integrated into clinical processes following minimal training.[20] 3D printing improves the accuracy of prosthetics and the efficiency of workflows. The use of 3D printing in prosthetic dentistry resulted in a dimensional accuracy of 98.6% between printed and designed prostheses, corroborating the findings of Alharbi et al., who observed that additive manufacturing techniques, particularly stereolithography (SLA), yield clinically acceptable prostheses with negligible distortion.[21] It is very critical to be able to obtain a high level of anatomical congruence in maxillofacial prostheses and implant-supported full-arch restorations, because even little differences might influence function and appearance.

The fact that 85.7% of cases needed very little change inside the mouth shows how strong the digital design-to-delivery pipeline is.

The use of 3D printing cut the time it took to make things by 40% compared to traditional lost-wax or press-ceramic workflows, which take a long time and require a lot of skill. This finding corroborates existing literature that demonstrates digital workflows have significantly expedited delivery timelines without compromising fit or durability[22] Patient-reported satisfaction scores (mean: 9.2/10) confirm the clinical acceptability and aesthetic superiority of 3D-printed prostheses. These results support the findings of Revilla-León et al., who noted that patients frequently prefer digitally manufactured prostheses due to superior aesthetic outcomes and reduced appointment frequency. [23] Also, virtual grin design and digital mock-ups let changes be made in real time before the final prosthesis was made. This made the decision-making process more participatory, which could make patients happier and more involved. [24]

Both augmented reality (AR) and 3D printing were very helpful in clinical settings, but they were helpful at different points in the treatment process. AR mostly made surgery easier to navigate and more accurate, while 3D printing made it easier to plan for surgery and make prosthetics. This dual application supports the idea that both technologies work together instead of replacing each other, creating a seamless digital continuum from diagnosis to delivery.

The absence of surgical errors in the AR group and the minimal prosthesis misfits in the 3D printing group offer further evidence that these technologies are safe for biological entities and suitable for clinical application. Pellegrino et al. conducted a study that determined the application of augmented reality (AR) in dental implantology was linked to substantial safety margins, especially when integrated with digital planning.[25] Also, the fact that 3D printing works with biocompatible materials makes it safe for patients and improves functional rehabilitation.[26] Even while AR headsets, 3D printers, and design software cost a lot of money up front, the long-term return on investment looks good when you think about how much less time is spent in surgery, how many prostheses need to be remade, and how much less manual labor is needed. Also, digitizing workflows cuts down on mistakes made by people and reliance on technician expertise, which leads to more consistent results.

The educational effects of AR are very interesting. AR gives students and surgical trainees an immersive and engaging way to study, which helps them grasp anatomy better and feel more confident in their skills. A recent meta-analysis by Moro et al. showed that augmented reality (AR)-based training was better at helping people remember things and learn how to do things than traditional teaching techniques.[27] The integration of augmented reality into dental education may mitigate differences in clinical exposure and facilitate the learning of manual skills. Even though the findings look good, there are certain problems that need to be addressed. The small sample size (n=30) limits the statistical power and applicability of the results. The subjective nature of satisfaction and usability evaluations introduces the potential for bias. Future research requires larger sample sizes, randomized control methodologies, and longitudinal follow-up to assess long-term prosthesis survival, complication rates, and cost-effectiveness. The lack of consistency between software platforms and the differences in printer resolution and material properties could affect results and make it hard to repeat them in healthcare settings. Also, to reduce the risk of becoming too reliant on technology, professionals must keep up their basic diagnostic and surgical skills.

In the future, augmented reality (AR), 3D printing, and artificial intelligence (AI) will all work together. This could lead to automated diagnosis, better planning of treatments, and the ability to see mistakes as they happen. AI-powered algorithms could also help design prosthetics by suggesting the best materials and stress distributions. This would make them look better and work better.

Another possible new area of regenerative dentistry is bioprinting, which is 3D printing of scaffolds that contain living cells.[28] These kinds of technology could change how maxillofacial rehabilitation and craniofacial restoration are done when used with AR-guided surgical placement.

CONCLUSION

Augmented reality and 3D printing have made a big difference in oral surgery and prosthetic dentistry by making results more accurate, faster, and more focused on the patient. When used properly, these technologies can improve healthcare workflows, make results look and work better, and make procedures easier. Digital technologies will only work well in the clinic if they are standardized, trained, and tested through strong clinical trials.

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Competing Interests

The authors have no competing interests to declare.

Ethical Approval

The study was approved by the appropriate ethics committee and conducted according to relevant guidelines and regulations.

Informed Consent

Not applicable.

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