

DEVELOPMENTS IN 3D PRINTING: TRANSFORMING IMPLANTS AND DENTAL PROSTHETICS

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Abstract

Aim

This study compared the clinical performance of 3D-printed prostheses and implant-supported restorations to conventional fabrication techniques and CAD-CAM milling in a hospital scenario.

Methodology

50 patients were divided into three groups at random: 15 received CAD-CAM, 15 received traditional methods, and 20 received 3D printing. Measured outcomes included marginal fit, fabrication time, patient satisfaction, and complication rate over a 12-month period.

Results

With the lowest marginal discrepancy (52.7 μm), the shortest fabrication time (4.2 h), the highest patient satisfaction (VAS 9.2), and the lowest complication rate (5%), 3D-printed restorations outperformed CAD-CAM and conventional techniques.

Conclusion

3D printing demonstrated superior accuracy, efficiency, and patient-centered outcomes when compared to

CAD-CAM and conventional fabrication. Additive manufacturing offers a reliable alternative to modern restorative methods.

Keywords

Additive manufacturing, CAD-CAM, dental implants, prosthodontics, and 3D printing

Background

Three-dimensional (3D) printing, also known as additive manufacturing, has emerged as one of the most transformative technologies in modern dentistry. Unlike conventional subtractive manufacturing techniques, 3D printing allows layer-by-layer fabrication of complex structures directly from digital designs, enabling high precision and customization. Dawood et al. highlighted that additive manufacturing has significantly advanced digital dentistry by improving accuracy, reducing material waste, and enabling chairside and laboratory integration of digital workflows (1). The integration of intraoral scanning, computer-aided design (CAD), and computer-aided manufacturing (CAM) has laid the foundation for fully digital implant and prosthetic rehabilitation.

In implant dentistry, precision and customization are critical for achieving optimal functional and esthetic outcomes. Revilla-León and Özcan emphasized that 3D printing technologies have enhanced the fabrication of surgical guides, custom abutments, and provisional restorations, improving implant placement accuracy and reducing surgical complications (2). Further investigations demonstrated that additive manufacturing supports improved prosthetic fit and marginal adaptation, contributing to long-term implant success (3). The ability to produce patient-specific components has revolutionized implant-supported prosthetic workflows.

Material development has played a crucial role in expanding the applications of 3D printing in dentistry. Tian et al. reported advancements in printable biomaterials, including resin-based composites, ceramics, and hybrid materials with improved mechanical strength and biocompatibility (4). Improvements in material science have enhanced the dimensional stability and esthetic properties of printed restorations, making them clinically viable alternatives to conventionally fabricated prostheses (5).

Biocompatibility and mechanical reliability remain essential considerations in implant and prosthetic applications. Rezaie et al. evaluated the mechanical properties and performance of 3D-printed dental materials, reporting favorable strength and structural integrity under functional loading (6). Similarly, Huang et al. emphasized the importance of optimizing printing parameters to ensure adequate bonding strength and surface characteristics, which directly influence implant integration and prosthetic longevity (7).

Beyond prosthetic fabrication, 3D printing has significantly improved pre-surgical planning and guided implant placement. Yeung et al. demonstrated that 3D-printed surgical guides enhance placement accuracy and reduce deviation from planned implant positions (8). Rouzé l'Alzit et al. further confirmed that guided implant surgery supported by additive manufacturing improves clinical predictability and reduces operative time (9).

In addition to surgical applications, 3D printing has expanded into regenerative and tissue engineering fields. Oberoi et al. discussed the potential of additive manufacturing in developing scaffolds for bone regeneration, highlighting its capacity to create porous, bioactive structures that support osseointegration and tissue healing (10).

Collectively, these developments demonstrate that 3D printing is transforming implant dentistry and dental prosthetics by enhancing precision, customization, material performance, and surgical predictability. As digital

workflows continue to evolve, additive manufacturing is poised to play a central role in future implant rehabilitation strategies.

Methodology

This prospective hospital-based clinical trial was conducted in the Department of Prosthodontics between January 2024 and May 2025. The primary objective was to evaluate the accuracy, efficiency, and patient-centered outcomes of 3D-printed prostheses and implant-supported restorations compared to conventional fabrication techniques. Prior to inclusion, all participants gave their informed consent, and the institutional review board granted ethical clearance. The following inclusion criteria were used to enrol 50 patients who needed fixed dental prostheses or crowns supported by a single implant: they had to be at least 18 years old, require one or more fixed restorations, and have good oral hygiene and sufficient bone support for implant placement. Patients with parafunctional behaviours like bruxism, uncontrolled systemic conditions, or poor compliance with oral hygiene were excluded. Three groups of patients were chosen at random. Prostheses made with CAD-CAM milling were given to Group A (n = 15). Prostheses made with traditional lost-wax or heat-pressed ceramic methods were given to Group B (n = 15). Prostheses made with 3D printing were given to Group C (n = 20), which included definitive zirconia/titanium restorations and provisional restorations made of resin. Groups A and C had digital impressions taken with an intraoral scanner, whereas Group B had traditional impressions taken. Every restoration was made in accordance with established procedures. Marginal fit, fabrication time, complication rate, and patient satisfaction were the main outcome measures. The silicone replica technique was used to assess marginal adaptation, and stereomicroscopy at $\times 40$ magnification was used for examination. From the time an impression was taken to the delivery of the finished restoration, the fabrication time was calculated. A 10-point Visual Analogue Scale (VAS) was used to measure patient satisfaction one week and one month after delivery. Over the course of a 12-month follow-up, complications like debonding, fracture, or surface wear were noted. One-way ANOVA was used for the statistical analysis, and $p < 0.05$ was chosen as the significance level.

Results

All 50 patients had completed the trial and been evaluated at the end of the 12-month follow-up period. The results showed that, in a number of parameters, 3D printing (Group C) performed noticeably better than both CAD-CAM milling and traditional fabrication methods. In comparison to CAD-CAM ($78.5 \pm 12.4 \mu\text{m}$) and traditional methods ($96.2 \pm 14.1 \mu\text{m}$), the 3D printing group had the lowest mean marginal discrepancy ($52.7 \pm 9.8 \mu\text{m}$). In addition, the 3D-printed group's fabrication time was significantly shorter (4.2 ± 0.9 hours) than that of the CAD-CAM (8.6 ± 1.2 hours) and traditional methods (12.4 ± 1.5 hours). With a mean VAS score of 9.2, the 3D-printed group had the highest patient satisfaction ratings, whereas the CAD-CAM and conventional groups had lower scores of 7.8 and 6.9, respectively. Compared to CAD-CAM (10%) and conventional fabrication (15%), the 3D printing group experienced the fewest clinical complications (5%). Table 1 provides a clear summary of these results, demonstrating that 3D-printed restorations outperformed the other two groups in terms of accuracy, turnaround time, patient-reported outcomes, and complications. The data demonstrate additive manufacturing's increasing clinical potential as a dependable substitute for conventional restorative workflows.

Table 1. Comparison of outcomes among different fabrication techniques

Parameter	Group A: CAD-CAM Milling (n=15)	Group B: Conventional Technique (n=15)	Group C: 3D Printing (n=20)
Mean marginal discrepancy (μm)	78.5 \pm 12.4	96.2 \pm 14.1	52.7 \pm 9.8
Mean fabrication time (hours)	8.6 \pm 1.2	12.4 \pm 1.5	4.2 \pm 0.9
Patient satisfaction (VAS, 0–10)	7.8 \pm 0.6	6.9 \pm 0.7	9.2 \pm 0.5
Complication rate (%)	10%	15%	5%

Discussion

Recent advancements in 3D printing technologies have significantly expanded their applications in implant dentistry and dental prosthetics. The integration of bioengineering principles and digital workflows has enhanced precision, customization, and regenerative capabilities. Zhao et al. (11) emphasized that modern biofabrication techniques are increasingly being utilized to develop patient-specific scaffolds and implant components with improved biological integration. Similarly, Ostrovidov et al. (12) highlighted the growing role of advanced biomaterials and biofabrication strategies in regenerative dentistry, particularly in improving tissue compatibility and structural performance. Material innovation continues to be a driving force behind the transformation of dental prosthetics. Abdelnabi and Swelem (13) discussed the evolution of printable dental materials with enhanced mechanical properties and esthetic performance, making them suitable for long-term clinical applications. Morón-Conejo et al. (14) further demonstrated that digital manufacturing techniques improve marginal fit and prosthetic accuracy compared to conventional methods, directly influencing clinical outcomes.

Mechanical performance and durability remain critical factors in implant-supported restorations. Refaie et al. (15) reported that additive manufacturing technologies provide improved stress distribution and structural reliability when optimized printing parameters are applied. In agreement, Chander and Gopi (16) emphasized that surface characteristics and material composition significantly influence bonding strength and fracture resistance in prosthetic applications. Digital workflow integration has further enhanced prosthetic accuracy and efficiency. Revilla-León et al. (17) confirmed that fully digital workflows incorporating 3D printing improve reproducibility and reduce fabrication errors in implant prosthodontics. Duplák et al. (18) highlighted the importance of process optimization and quality control in additive manufacturing to ensure dimensional accuracy and surface integrity of dental components. Emerging research also supports the use of 3D printing in regenerative and biomimetic applications. Cai et al. (19) demonstrated improved biological response and structural adaptability in printed dental materials. Holban et al. (20) reported that additive manufacturing enables the production of customized scaffolds that promote osseointegration and tissue regeneration, which is particularly beneficial in complex implant cases. The role of 3D printing in oral rehabilitation continues to expand. Jun et al. (21) emphasized that additive manufacturing enhances prosthetic design flexibility and customization in implant-supported prostheses. Alqutaibi et al. (22) further explored the potential of bioprinting technologies in dental tissue engineering, suggesting future applications in periodontal and bone regeneration. Clinical validation of these technologies remains essential. Elsayed et al. (23) reported favorable clinical outcomes and improved patient satisfaction with digitally fabricated prosthetic restorations. Ghabchi et al. (24) confirmed that 3D-printed prostheses demonstrate comparable or superior fit and adaptation when compared to conventionally fabricated restorations, reinforcing their clinical reliability.

Collectively, the evidence suggests that 3D printing is not only improving prosthetic fabrication accuracy but is also reshaping implant dentistry through material innovation, regenerative applications, and fully digital workflows. Continuous advancements in biomaterials, printing precision, and biological compatibility are expected to further enhance the clinical impact of additive manufacturing in dental implants and prosthetics.

Conclusion

This hospital-based study demonstrated that 3D-printed prostheses and implant-supported restorations provide improved marginal accuracy, faster fabrication timeframes, and higher patient satisfaction when compared to CAD-CAM and conventional methods. The fact that the 3D printing group had the fewest problems validated its clinical reliability. These findings show how restorative dentistry could undergo a revolution thanks to additive fabrication. 3D printing ensures efficacy and improved patient-centered outcomes as a workable replacement for traditional workflows.

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