
# Applications of 3D Printing in Dentistry: Present and Future Perspectives

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*(Received: 11.09.2025; Accepted: 17.09.2025)*
**Web link:** https://ijths.com/volume-1-issue-1-july-september-2025/

***Abstract***

*Three-dimensional (3D) printing, commonly referred to as additive manufacturing, has revolutionised modern dentistry by facilitating the production of highly accurate, patient-specific devices and models. This cutting-edge technology enables the creation of a diverse range of applications, including prosthodontic restorations, orthodontic aligners, implant surgical guides, craniofacial prostheses, and regenerative scaffolds, all with remarkable precision. The integration of 3D printing into digital dentistry workflows has significantly enhanced treatment planning, shortened turnaround times, and improved patient outcomes. The versatility of materials—encompassing resins, polymers, ceramics, and metals—has broadened the scope of 3D printing across various dental specialities. However, despite these advancements, challenges remain, such as high costs, regulatory hurdles, discrepancies in accuracy among different printers, and concerns regarding the long-term durability of materials. Looking ahead, future developments in 3D printing are anticipated to focus on bioprinting functional tissues, incorporating artificial intelligence into design processes, promoting wider accessibility in clinical settings, and advancing biomaterials for regenerative applications. This review provides an in-depth exploration of the current applications of 3D printing in dentistry, while also evaluating emerging innovations that are set to transform the landscape of oral healthcare.*

***Keywords:*** *3D printing; Prosthodontic restorations; Craniofacial prostheses; Orthodontic aligners; Implants; Surgical guides; Bioprinting; Artificial intelligence*

## INTRODUCTION

Dentistry has experienced a significant digital transformation in recent decades, driven by innovations like computer-aided design and computer-aided manufacturing (CAD/CAM), cone-beam computed tomography (CBCT), and intraoral scanning, which together form the backbone of modern digital workflows (Goodacre *et al.*, 2016; Mangano *et al.*, 2018). Among these advancements, three-dimensional (3D) printing, also known as additive manufacturing, has emerged as a pivotal technology due to its capacity to create complex, customised, and precisely engineered objects layer by layer (Dawood *et al.*, 2015). In contrast to traditional subtractive manufacturing methods that involve removing material from a solid block, 3D printing constructs objects additively. This approach not only minimises waste but also allows for the creation of intricate geometries that would be impossible to achieve through conventional means (Alharbi *et al.*, 2016).

In dentistry, 3D printing was first utilised for producing study models and diagnostic aids. However, its applications have significantly expanded, now encompassing a diverse array of areas including prosthodontics, orthodontics, implantology, oral and maxillofacial surgery, endodontics, and periodontics (Choi *et al.*, 2002; Camardella *et al.*, 2017; Park *et al.*, 2019; Tandon *et al.*, 2021). The versatility of 3D printing has led to faster production, reduced costs, and enhanced precision, ultimately improving patient care (Alifui-Segbaya *et al.*, 2017).

The primary 3D technologies used in dentistry are –

- *Stereolithography (SLA)*: Vat photopolymerization using a UV laser to selectively cure photopolymer resin (high resolution; common for dental models, surgical guides, and provisional restorations) (Tian *et al.*, 2021).
- *Digital Light Processing (DLP)*: Vat photopolymerization that cures entire layers via a projected light pattern (faster than SLA; similar or better resolution). Widely used for models, guides, and small restorations (Gokmen *et al.*, 2024).

- *PolyJet / Material Jetting*: Drops photopolymer droplets cured by UV light; enables multi-material and high resolution, but equipment and materials are costly. Useful for realistic models, multi-material prostheses, and surgical planning models (Gokmen *et al.*, 2024).
- *Selective Laser Sintering (SLS) / Selective Laser Melting (SLM)*: Powder-bed fusion for polymers (SLS) or metals (SLM/EBM). SLM is used to produce titanium implant components, custom frameworks, and metal prostheses (Mobarak *et al.*, 2023).
- *Fused Deposition Modeling (FDM):* Extrudes thermoplastic filament; lower resolution but cheap and useful for educational models and some surgical templates. Limited clinical-use materials for intraoral devices (Jeong *et al.*, 2023).
- *Binder Jetting and Inkjet*: Used for sand or gypsum models and experimental dental ceramics (Rezaie *et al.*, 2024).

The global dental 3D printing market is projected to grow substantially, driven by increasing demand for aesthetic and functional dental solutions, a rise in edentulous populations, and advances in biocompatible materials (Zitzmann *et al.*, 2005; Dawood *et al.*, 2015; Alharbi *et al.*, 2016). Nevertheless, obstacles such as the high costs of equipment, insufficient training opportunities, and regulatory challenges persist, hindering the broad clinical adoption of this technology.

This review paper seeks to deliver a thorough overview of the current applications of 3D printing in dentistry, grounded in recent evidence, while also examining the future directions and potential advancements of this innovative technology.

## APPLICATIONS OF 3D PRINTING IN DENTISTRY

### Prosthodontics

Prosthodontics has emerged as one of the earliest and most significant adopters of 3D printing within the field of dentistry. The advent of additive manufacturing has revolutionized the production of highly accurate crowns, bridges, dentures, and removable partial dentures (Bae *et al.*, 2017; Barazanchi *et al.*, 2017). In *comparison* to traditional lost-wax casting methods, digital design combined with 3D printing offers improved reproducibility and a superior fit (Goodacre *et al.*, 2016). For complete dentures, the implementation of computer-aided workflows has notably reduced chairside time and the number of patient visits (Prpic *et al.*, 2018). Furthermore, the integration of digital design with additive manufacturing facilitates the creation of customized prostheses that closely mimic natural dentition (Bae *et al.*, 2017; Mangano *et al.*, 2018; Prpic *et al.*, 2018). A summary of the key applications of 3D printing in prosthodontics can be found in Table 1.

**Table 1:** Application of 3D printing in Prosthodontics.

| Application | Benefit | Reference |
|---|---|---|
| Crowns & Bridges | High accuracy, faster production | Balhaddad *et al.*, (2023) |
| Complete Dentures | Fewer patient visits, improved fit | Alghazzawi, (2016) |
| Removable Partial Dentures | Lightweight, patient-specific designs | Zhang *et al.*, (2019) |

### Orthodontics

Orthodontics has greatly benefited from advancements in 3D printing technology, particularly in the creation of aligners, retainers, and orthodontic models (Table 2). The implementation of digital workflows facilitates the swift production of sequential clear aligners that are customized to align with each patient's specific treatment plan (Camardella *et al.*, 2017; Park *et al.*, 2019; Tandon *et al.*, 2021). Surgical guides for orthognathic procedures are also commonly 3D printed, improving surgical accuracy.

**Table 2:** Application of 3D printing in Orthodontics.

| Application | Benefit | Reference |
|---|---|---|
| Clear aligners | Custom, fast production | Mantovani *et al.*, (2019) |
| Retainers | Better fit, reduced errors | Zinelis *et al.*, (2022) |
| Orthognathic guides | Precision in surgery | Kim *et al.*, (2023) |

### Implantology

In implantology, 3D printing is primarily used to create surgical guides, anatomical models, and customized implants (Table 3) (Patel, 2014; Ishida *et al.*, 2016; Wang *et al.*, 2016; Mangano *et al.*, 2018). Guided implant placement reduces surgical risks and improves prosthetic outcomes (Mangano *et al.*, 2016). Patient-specific implants and bone augmentation scaffolds are under development using biocompatible materials (Osman and Swain, 2015; Rasperini *et al.*, 2015).

**Table 3:** Application of 3D printing in Implantology.

| Application | Benefit | Reference |
|---|---|---|
| Surgical guides | Safer and more accurate placement | Mangano *et al.*, (2017) |
| Anatomical models | Better pre-surgical planning | Ciocca *et al.*, (2009) |
| Customized implants | Patient-specific design | Anderson *et al.*, (2022) |

### Oral and Maxillofacial Surgery (OMFS)

3D printing has revolutionized oral and maxillofacial surgery by enabling precise pre-surgical planning and the fabrication of patient-specific surgical guides and reconstruction plates (Choi *et al.*, 2002; Martelli *et al.*, 2016; Zhao *et al.*, 2018). Customized prostheses for craniofacial deformities significantly enhance functional and aesthetic outcomes (Table 4).

**Table 4:** Application of 3D printing in Oral & Maxillofacial Surgery.

| Application | Benefit | Reference |
|---|---|---|
| Surgical guides | Increased precision | Xia *et al.*, (2015 a & b) |
| Reconstruction prostheses | Custom design, improved outcome | Liu *et al.*, (2019) |
| Craniofacial implants | Better aesthetics and function | Kanno and Sukegawa, (2018) |

### Endodontics

In endodontics, 3D printing supports the production of tooth replicas for pre-clinical training, customized guides for minimally invasive endodontic surgery, and replicas of complex root canal anatomies for practice (Dawood *et al.*, 2015; Ishida *et al.*, 2016; Li *et al.*, 2020). These tools improve precision and reduce iatrogenic errors. The key applications of 3D printing in endodontics are summerised in Table 5.

**Table 5:** Application of 3D printing in Endodontics.

| Application | Benefit | Reference |
|---|---|---|
| Tooth replicas | Educational training | Moin *et al.*, (2016) |
| Surgical guides | Minimally invasive surgery | Connert *et al.*, (2018) |
| Root canal morphology models | Reduced errors in practice | Niemczyk *et al.*, (2024) |

**Table 6:** Application of 3D printing in Periodontics.

| Application | Benefit | Reference |
|---|---|---|
| Bone graft scaffolds | Support regeneration | Rasperini *et al.*, (2015) |
| Periodontal models | Case planning, training | Joda *et al.*, (2019) |
| Surgical guides | Precise flap management | Schneider *et al.*, (2021) |

### Periodontics

Periodontology is progressively harnessing the potential of 3D printing for developing bone graft scaffolds, creating models of periodontal defects, and designing surgical guides (Table 6). This technology enables the creation of highly accurate scaffolds that facilitate guided tissue regeneration and allow for the customization of solutions tailored to individual patients' periodontal needs (Resperini *et al.*, 2015; Wang *et al.*, 2016).

## MATERIALS, DIGITAL WORKFLOW, ADVANTAGES AND LIMITATIONS

### Materials in 3D Printing for Dentistry

The selection of material is crucial for the performance and durability of 3D-printed dental products. Currently, polymers and resins are the predominant choices due to their versatility and cost-effectiveness (Osman *et al.*, 2015; Barazanchi *et al.*, 2017; Revilla-Leon and Ozcan, 2019; Shim *et al.*, 2020). A summary of common materials used in dental 3D printing, including their applications, advantages, and limitations, can be found in Table 7. Although more challenging to work with, metals and ceramics are gaining traction in the fields of implantology and prosthodontics (Martelli *et al.*, 2016; Wang *et al.*, 2016; Barazanchi *et al.*, 2017; Tahayeri *et al.*, 2018). Bioprinting materials, particularly hydrogels and bio-inks, remain under development for regenerative applications (Rasperini *et al.*, 2015; Almutairi *et al.*, 2020; Zafar and Al-Samadani, 2020).

### Digital Workflow Integration

3D printing in dentistry does not operate in isolation but integrates seamlessly with digital technologies such as CBCT, intraoral scanners, and CAD software (Goodacre *et al.*, 2016; Prpic *et al.*, 2018). The digital workflow typically (Table 8) follows a cycle of data acquisition, computer-aided design, and additive manufacturing (Patel, 2014). This streamlined process reduces errors, accelerates production, and allows predictable outcomes.

**Table 8:** Stages in a digital dental 3D printing workflow.

| Stage | Technology | Example Output |
|---|---|---|
| Data Acquisition | CBCT, intraoral scanning | STL file of dentition |
| Design | CAD software | Virtual prosthesis or guide |
| 3D Printing | SLA, DLP, SLS, SLM | 3D printed model or appliance |
| Post-processing | Polishing, sintering, curing | Final prosthesis or guide |

**Table 7:** Common materials used in 3D printing for dentistry.

| Material Type | Applications | Advantages | Limitations |
|---|---|---|---|
| Resins/Polymers | Models, aligners, guides | Versatile, affordable | Limited strength, discoloration |
| Metals (Co-Cr, Ti) | Implants, frameworks | High strength, biocompatible | Expensive, requires post-processing |
| Ceramics | Crowns, bridges | Aesthetic, wear-resistant | Brittle, printing challenges |
| Hydrogels/Bio-inks | Bioprinting scaffolds | Supports cell growth | Early stage, low mechanical strength |

### Advantages of 3D Printing in Dentistry

The key advantages (Martelli *et al.*, 2016; Li *et al.*, 2020) include:

- Customisation for individual patients.
- Improved accuracy and fit of prostheses and guides (Ishida *et al.*, 2016).
- Reduced turnaround time compared to traditional methods.
- Cost-effectiveness in certain applications, especially when reducing clinical visits (Zitzmann *et al.*, 2005).
- Enhanced pre-clinical education through training models.

These factors have positioned 3D printing as an essential component of modern digital dentistry.

### Limitations and Challenges

Despite its benefits, several limitations (Martelli *et al.*, 2016) persist:

- Material performance: Some resins degrade under oral conditions (Shim *et al.*, 2020).
- Accuracy variability: Different printers and technologies produce variable accuracy (Ishida *et al.*, 2016; Camardella *et al.*, 20170; Shim *et al.*, 2020).
- High costs: Equipment and training expenses limit widespread adoption (Zitzmann *et al.*, 2005).
- Regulatory barriers: Approval of printed devices varies across jurisdictions.
- Long-term performance data: Clinical evidence regarding durability and safety is still limited (Choi *et al.*, 2002).

## FUTURE PERSPECTIVES

The future perspectives and their clinical implications have been tabulated in Table 9, and discussed hereunder.

**Table 9:** Future perspectives and their clinical implications.

| Innovation | Potential Clinical Impact | Key Challenges |
|---|---|---|
| Bioprinting | Regeneration of bone, gingiva, pulp | Vascularization, regulation |
| AI-driven workflows | Automated, reproducible design | Data standardization |
| Chairside manufacturing | Immediate prosthesis delivery | Material strength, speed |
| Global adoption | Affordable care in LMICs | Infrastructure, training |

### Bioprinting and Regenerative Dentistry

Bioprinting represents one of the most exciting frontiers of dental 3D printing. By layering living cells, growth factors, and biomaterials, bioprinting aims to regenerate functional tissues such as bone, gingiva, and pulp (Alifui-Segbaya *et al.*, 2017; Almutairi *et al.*, 2020). Numerous experimental studies have effectively demonstrated the printing of scaffold structures embedded with stem cells, highlighting their promising potential for alveolar bone regeneration and the repair of periodontal defects. However, to translate these advancements into clinical practice, it is essential to address significant challenges, including achieving adequate vascularisation, ensuring long-term cell viability, and navigating the complexities of regulatory approval (Almutairi *et al.*, 2020).

### Artificial Intelligence and Automated Workflows

The incorporation of artificial intelligence (AI) and machine learning into dental 3D printing workflows has the potential to significantly enhance the design and production processes (Zhao *et al.*, 2018). AI-driven algorithms can autonomously identify carious lesions, assess occlusal relationships, and recommend optimal treatment designs, thereby minimising reliance on manual input and improving reproducibility in outcomes. In the future, dental clinics may leverage this synergy of AI-based diagnostics, automated CAD design, and direct 3D printing to facilitate the "chairside" production of intricate restorations (Patel, 2014). This innovation could greatly expedite treatment, offering patients immediate solutions tailored to their specific needs.

### Personalised Dentistry and Chairside Manufacturing

The long-term vision for 3D printing in dentistry envisions the development of fully personalised dental treatments delivered in real-time (Choi *et al.*, 2002; Torabi *et al.*, 2015). Currently, chairside 3D printing has made it feasible to produce temporary crowns and surgical guides (Dawood *et al.*, 2015; Tahayeri *et al.*, 2021). Looking ahead, advancements in printer speed, material durability, and the integration of artificial intelligence could enable the direct fabrication of permanent restorations right in dental offices. This innovation not only reduces reliance on centralized laboratories but also lowers costs and significantly enhances turnaround times for patients.

### Expansion to Global Practice and Public Health

While 3D printing is currently concentrated in high-resource dental clinics, its adoption in low- and middle-income countries could transform oral health delivery (Zitzmann *et al.*, 2005). Affordable desktop printers and open-source software are lowering entry barriers. In resource-limited regions, locally produced prosthetics, aligners, and surgical models could expand access to dental care at a fraction of the cost of traditional methods.

## CONCLUSION

Three-dimensional (3D) printing has already established itself as a transformative technology in dentistry, revolutionising the way clinicians design, manufacture, and deliver dental care.

Its ability to create highly precise, patient-specific appliances, prostheses, and surgical guides has improved treatment accuracy, efficiency, and accessibility (Dawood *et al.*, 2015; Alifui-Segbaya *et al.*, 2017; Bae *et al.*, 2017; Revilla-Leon and Ozcan, 2019).

The impact of this technology in prosthodontics, orthodontics, implantology, and surgical planning is well-established, with robust evidence demonstrating its role in enhancing patient outcomes and reducing clinical time (Goh *et al.*, 2015; Martelli *et al.*, 2016; Barazanchi *et al.*, 2017; Camardella *et al.*, 2017).

However, several challenges persist. Variability in material performance, high equipment costs, limited long-term data, and regulatory barriers must be addressed to facilitate broader adoption (Tahayeri *et al.*, 2018; Li *et al.*, 2020; Shim *et al.*, 2020).

Looking forward, innovations in bioprinting, artificial intelligence, and chairside manufacturing are anticipated to further expand the possibilities in dentistry, paving the way for more personalised, efficient, and globally accessible care.

As this technology continues to evolve, interdisciplinary research, clinical validation, and alignment in regulatory standards will be essential for its successful integration into everyday dental practice.

The incorporation of 3D printing into mainstream dental practice signifies not just a technological advancement but also a fundamental transformation in the conceptualisation and delivery of oral healthcare in the future.

## Grant Support Details

The present research did not receive any financial support.

## Conflict of Interest

The author declares that there is not any conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/or submission, and redundancy, have been completely observed by the author.

## Life Science Reporting

No life science threat was practised in this research.

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