# Applications of 3D Printing in Dentistry

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3D printing technologies include stereolithography, digital light processing, fused deposition modeling, selective laser sintering/melting, photopolymer jetting, powder binder, and 3D laser bioprinting. The main categories of 3D printing materials are polymers, metals, and ceramics. Despite limitations in printing accuracy and quality, 3D printing technology is now able to offer people a wide variety of potential applications in different fields of dentistry, including prosthodontics, implantology, oral and maxillofacial, orthodontics, endodontics, and periodontics. Understanding the existing spectrum of 3D printing applications in dentistry will serve to further expand its use in the dental field. Three-dimensional printing technology has brought about a paradigm shift in the delivery of clinical care in medicine and dentistry.

Keywords: 3D printing ; digital light processing ; stereolithography

## 1. Prosthodontics

### 1.1. Crown and Fixed Partial Dentures (FPD)

Three-dimensional printing has always been a technology of great interest in the field of prosthodontics. This has become more apparent recently, with 3D printing technologies, such as SLA and DLP, becoming more widely utilized to fabricate provisional or definitive crowns and FPDs. Precise virtual models are prepared by scanning the prepared teeth and implant scan bodies intraorally. Computer-aided design (CAD) software program (3Shape Dental System 2022, 3Shape A/S, Copenhagen, Denmark) is used to design the prostheses on these virtual models. Then, the designed prostheses are printed using a 3D printer. Compared to traditional methods or milling technology for fabricating crowns and FPDs, a low-cost 3D printer can fabricate precise restorations using fewer materials in a shorter production time [1][2][3]. Some studies have even reported that provisional crowns fabricated using 3D printing are more accurate (better edges and better internal fit) than the ones fabricated using traditional or milling methods [4][5][6].

### 1.2. Complete and Removable Partial Dentures (RPD)

Although there have been significant improvements in denture material and techniques, the denture fabrication process can be challenging in patients with a severe gag reflex, tumor resection, temporomandibular joint disease, or oral deformities [7][8]. With the advent of intraoral scanning technology and 3D printing, denture fabrication has become a patient-friendly procedure with a shorter production time [9]. It also reduces traditional laboratory steps, which can lead to fewer inherent errors and better adaptability [10][11]. The traditional process of waxing and investing RPD frameworks is time-consuming, technique-sensitive, and cumbersome. Wax and cast distortion from this traditional process can lead to poor fit of framework, pressure-induced mucosal lesions, and ridge resorption [12]. A recent in vitro study showed that RPD frameworks fabricated by SLM printing resulted in a better fit than traditional lost-wax and metal casting techniques [13]. Another author also reported that 3D-printed frameworks provide more uniform contact pressure, which can reduce the risk of residual ridge resorption [1].

## 2. Implantology

The application of 3D printing technology in implantology serves to optimize and simplify surgical procedures with higher accuracy and predictability, thereby reducing surgical risks and improving efficiency. Traditional surgical guides are usually designed based on two-dimensional panoramic radiographs, which often lead to inaccuracy due to distortion and insufficient resolution of the radiographic image. With the introduction of advanced digital technology, surgical guides are now designed using CAD software based on cone beam computed tomography (CBCT) and intraoral scans, then printed using a 3D printer. With this technology, the accuracy of these 3D-printed surgical guides has significantly improved. Tahmaseb et al. compared and found a significant difference between the accuracy of traditional surgical guides and 3D-printed surgical guides that were printed by SLA printers [14]. For traditional surgical guides, the average distance deviations at the entrance and at the vertex were 2.1 mm and 1.5 mm, respectively [14]. Meanwhile, the average distance

deviations at the entrance and at the vertex of the 3D-printed surgical guide were 0.9 and 1.0 mm, respectively [14]. Other advantages of 3D printing surgical guides over traditional ones are lower investment cost, shorter surgical time, simpler surgical process, and better adaptation to the patient's geometry [15][16].

## 3. Oral and Maxillofacial

### 3.1. Surgical Guides and Templates

Additive manufacturing technology has been used for three decades in the oral and maxillofacial field of dentistry for model fabrication, diagnosis, surgical planning, surgical guide and template fabrication, and custom implant manufacturing [17][18]. Similar to 3D-printed surgical guides for implant surgery, surgical guides and templates are designed based on the obtained CT image and CAD software analysis of the maxillomandibular defect. A 3D-printed guide in combination with a 3D-printed patient-specific titanium template provides stability during the operation and ensures the precise placement of bone segments [19]. In addition, these guides and templates result in fewer defects, higher accuracy, better margin control, and bone compromises [17].

### 3.2. Custom Implants

The capability of 3D printing technology to design and print complex geometries has been used to fabricate custom dental implants. Three-dimensional printers, such as SLS and SLM, have the ability to print in titanium or in implantable polymer, particularly polyether ether ketone, to fabricate dental implants with adjustable porosity and mechanical properties [18].

However, 3D printing technology is still often used in conjunction with conventional pressing and milling technologies to fabricate implants, because pressing and milling have their advantages as well, such as reduced post-processing, fast production, and predictable use of uniform and homogenous materials [20].

### 3.3. Maxillofacial Prostheses

Often, maxillofacial defects are complex in shape and size, and 3D printing technology can be extremely beneficial in fabricating prostheses for these defects due to its ability to print complex geometrics. A combination of scanning technology and 3D printing is more comfortable for patients and provides a prosthesis with higher accuracy and better fit to the defect area [17][21]. Other benefits of implementing 3D printing technology include reduced manufacturing time, decreased number of appointments, and repeatability allowing multiple prostheses [22].

## 4. Orthodontics

Nowadays, in orthodontics, 3D printing technology is primarily used to fabricate orthodontic aligners for treating malocclusion. Removable, clear aligners are an alternative to conventional orthodontic braces, with improved oral hygiene and esthetics [23].

Previously, 3D printing technologies such as SLA or FDM were used only for printing models, and aligners were produced by a thermoforming process using thermoplastic materials [23]. However, the thermoforming procedure itself as well as the intraoral environment can alter the properties of the material, which eventually affect its overall performance [24].

More recently, direct 3D-printed aligners have become more popular, offering a better fit, higher efficacy, and reproducibility, without altering material properties [25]. Tartaglia et al. reported that the use of direct 3D-printed aligners is a more stable way to align the teeth than thermoformed manufactured aligners due to higher accuracy, higher load resistance, and lower deformation [25].

Three-dimensional printing technology is also applied in gnathology for management of temporomandibular joint disorders (TMDs). The therapeutic position is digitally planned based on kinematic tracing record, and customized intraoral appliances can be digitally designed and printed using a 3D printer to increase the accuracy of the therapeutic position [26].

## 5. Endodontics

Three-dimensional printing technology has been applied to every field of dentistry, and endodontics is not an exception. In endodontics, 3D printing technology has served various purposes, including access cavity preparation, apicoectomy, autotransplantation, education, and training [27]. There are many studies reporting the high accuracy of guided cavity

preparation using a 3D-printed access guide [28][29][30]. Buchgreitz et al. reported the mean deviation of access cavities lower than 0.7 mm [28]. Similarly, Zehnder et al. and Connert et al. reported small deviations of 0.12–0.34 mm from the intended access and a mean angular deviation of less than two degrees [29][30].

Guided apicoectomy, endodontic microsurgery (EMS), requires a 3D-printed surgical guide to perform targeted osteotomy and root resection. As in other specialties, the surgical guide is designed and printed based on CBCT and CAD software. This application of 3D printing technology results in higher accuracy of osteotomies than the traditional free-hand technique [27][31][32]. In addition, 3D-printed guides for apicoectomy allow for easier inspection of root apices, smaller osteotomies, lower risk of nerve or sinus perforation, better root-end preparation, better healing, and shorter surgical time [27][31][32].

## 6. Periodontics

### 6.1. Scaffolds for Hard and Soft Tissue Regeneration

The application of 3D printing in periodontics is useful for both hard and soft tissue regeneration as well as guided gingivectomy. There has been a lot of research focusing on the fabrication of 3D-printed scaffolds for hard and soft tissue regeneration. The concept of additive biomanufacturing using 3D printing technology serves to restore the resorbed periodontal tissue and bone deficiencies in a customized manner [17].

Three-dimensional printing enables the custom printing of scaffolds that can be loaded with stem cells, where the stem cells can be placed at precise locations, allowing more intimate contact with bone surfaces [33]. These advantages can lead to a better healing process and better esthetic results than conventional scaffolds [17]. Three-dimensional printing can also be used for soft tissue regeneration. Recently, 3D-printed soft tissue grafts have been developed for keratinized tissue augmentation. These printed soft tissue grafts can cover larger and more complicated defects with high accuracy, without being limited by donor site availability [34].

### 6.2. Gingivectomy Surgical Guide

A common application of 3D printing in periodontics is the use of a surgical guide for gingivectomy and smile designing [17]. With the help of intraoral scanning and CAD software, a patient-specific surgical guide for esthetic gingivectomy can be designed and printed. Using the surgical guide, more esthetic results can be achieved due to their accuracy, precision, and customization [17].

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