# 3D Printing: Unlocking New Horizons in Perio Dontics

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**Abstract:**
Three-dimensional (3D) printing is an additive manufacturing process used to create three-dimensional objects layer by layer. 3D printing offers numerous advantages in process engineering and finds diverse applications in dentistry, including prosthodontics, oral and maxillofacial surgery, oral implantology, orthodontics, endodontics, and periodontology. This review explores the various applications of 3D printing in periodontology, emphasizing its role in designing surgical guides, personalized scaffolds for tissue regeneration, customized models for patient education and clinician training. Regenerative procedures involve the placement of materials that are biocompatible, bioresorbable, and capable of promoting cell growth and proliferation to facilitate defect restoration. These structures can be created using 3D bioprinting technology, which utilizes a variety of bioinks and diverse bioprinting techniques.

**Keywords:** Midline Additive manufacturing, Computer-aided design, Periodontal regeneration, Three-dimensional bioprinting, Tissue engineering.

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## INTRODUCTION:

Periodontitis is a multifactorial inflammatory disease of the periodontal tissues, primarily triggered by the host's immune response to periodontal pathogenic bacteria. It is marked by progressive periodontal attachment loss and alveolar bone destruction, which, if untreated, can eventually lead to tooth loss.1

The main goal of periodontal therapy is to restore or regenerate the damaged peri-odontium, ensuring its long-term health and stability. In recent decades, numerous treatment modalities have been proposed and utilized to restore the lost periodontal apparatus. These include approaches such as bone grafting procedures, guided tissue regeneration, growth factors, and the use of stem cells.2

Three-dimensional (3D) bioprinting is an advanced tissue engineering technique that utilizes additive manufacturing. It integrates 3D imaging technologies and com-puter-aided design (CAD) software to create tissues and organs layer by layer. This process employs a wide range of biomaterials arranged in customized and precise patterns.3

Charles Hull introduced stereolithography (SLA) in 1984, he was the first to invent 3D printing technology.4

The rapid growth in materials, printing processes, and equipment indicates that 3D printing will significantly transform traditional teaching and research methods. 3D printing technology uses CAD software to evaluate several hundred cross-sections and produce exact replicas of various products.5
In dentistry, this technology is employed to produce dental prostheses, custom- made impression trays, and stone models. Its potential role in advancing the develop-ment of tissue scaffolds for bone grafting procedures is also under investigation.6

Bioprinting represents the forefront of these advancements. Various 3D printing methods such as stereolithography, photopolymer jetting, selective laser sintering, fused deposition modeling, and powder binder printers have been documented in the literature along with their advantages and disadvantages. It is used in many branches of dentistry, particularly endodontics, orthodontics, periodontology, prosthodontics, oral and maxillofacial surgery, and oral implantology.7

## TYPES OF 3D PRINTERS

**1. Stereolithography (SLA) Technique**
Stereolithography is a highly efficient 3D printing technology known for its precision and versatility. It uses photochemical processes to cure liquid resin layer by layer, resulting in detailed and precise designs. While the laser-guided curing process can be time-consuming, it ensures smooth and precise final outputs. SLA's ability to create personalized, patient-specific designs has made it a valuable tool in dentistry. It is widely used for creating temporary and permanent crowns, fixed partial dentures, surgical guides, templates, and diagnostic models. Despite its advantages, one draw-back is the prolonged curing time required for even small designs.8

**2. Photopolymer Jetting**
Photopolymer jetting, also known as PolyJet 3D printing, offers a distinct benefit in dentistry: the capability to print in multiple colors. There are three types of printers: Thermal, piezoelectric, and mechanical. This technology employs inkjet printheads to deposit droplets of a fusing agent onto specific voxels within a powder bed. The pol-ymer powder is then melted and cured using infrared light, creating precise and de-tailed designs. A major challenge with this technology is the susceptibility of the print heads to clogging, necessitating frequent maintenance.9

**3. Selective Laser Sintering (SLS)**
SLS uses a high-temperature laser to selectively fuse powdered materials, which can range from ceramics and metals to polymers. This versatility makes SLS one of the few technologies capable of producing high-density materials essential for dental applications. However, a notable drawback of SLS is its requirement for a substantial infrastructure to operate effectively. In dentistry, SLS is particularly valuable for fabricating removable partial dentures, significantly reducing human errors associated with conventional methods. Additionally, it provides safer and more reliable outcomes as compared to traditional metal casting methods in dental applications.10

**4. Fused Deposition Modeling (FDM) Technique**
Scott Crump discovered this technology in 1988. Thermoplastic material is extruded onto the building platform via a nozzle in fused deposition modelling. Two materials are used in this process: a gel-like support material that acts as scaffolding and the modelling material that creates the finished product. The printhead moves along the X and Y axes to deposit the material layer by layer when material filaments are pulled from the printer's material bays. The base moves along the Z-axis to make room for the subsequent layer after a layer is finished. Occlusal appliances and pharmaceutical applications, like controlled-release drug delivery systems, are currently being produced using this technology.11 This printer is commonly used to develop multiphasic scaffolds for supporting periodontal regeneration.12

**5. Powder Binder Printers**
Binder jetting, also known as powder binder printing, is an effective method for pro-ducing

maxillofacial prostheses using medical-grade silicones and biocompatible elastomers. This process utilizes a water-based binder to selectively fuse layers of starch-based powder, followed by infiltration with silicone polymers. The material is then hardened during post- processing to achieve the desired properties. Binder jetting stands out for its ability to create patient-specific, color-matched maxillofacial de-signs, though the resulting materials often exhibit reduced mechanical strength, mak-ing them relatively fragile.13

The development of 3D printing technology has improved periodontal regeneration, making it possible to fabricate biocompatible membranes, scaffolds, and complex 3D functional tissues through "bioprinting," a technique that integrates living cells with supportive components.14 In 2015, Rasperini et al15 pioneered the development and application of the first 3D-printed scaffold for periodontal repair of hard and soft tissue on labial side. 3D printing technologies have been utilized in various periodontal treatments, including the management of gingival recession, the creation of surgical guides for gingivectomy, and smile design. Moreover, bioresorbable scaffolds are being explored for the regeneration of periodontal tissues like alveolar bone and periodontal ligaments (PDL), as well as for applications in sinus augmentation, socket preservation, and implantology.16

In periodontology, the periodontal tissues have a complex organization which requires multilayered biomaterial constructs to restore the structural and functional integrity at the bone-ligament interface. These scaffolds are termed multiphasic constructs due to their distinct compartments, which replicate the native structure of the periodontal complex. The commonly used biomaterials for 3D printing scaffold in periodontal regeneration are given in Table 1.13

## ADVANCEMENTS IN PERIODONTAL REGENERATION THROUGH 3D PRINTING

**1. Education Regarding Periodontal Regeneration**

3D-printed models like VANPERIO enhance patient education by simplifying complex periodontal treatment plans and improving understanding of tissue regeneration procedures. These models also aid clinicians in practicing regenerative techniques using bone grafts and membranes, facilitating accurate assessment of periodontal defects and the development of effective treatment plans.17

**2. Socket Preservation**

The use of 3D-printed scaffolds shows significant potential for maintaining the al-veolar ridge after tooth extraction. Goh et al. (2015) conducted a study assessing the effectiveness of a prefabricated 3D-printed polycaprolactone (PCL) scaffold, fabri-cated through fused deposition modeling (FDM), for socket preservation. Over the course of six months, the scaffold successfully retained the alveolar ridge's structure and integrity intact. While custom-made 3D scaffolds have shown greater potential compared to prefabricated ones, they have been associated with soft tissue dehiscence and minimal bone repair. These issues are likely a result of the slower degradation rate of PCL scaffolds, their limited osteoconductive properties, and their reduced ability to promote cell adhesion.18

**3. Three-dimensional Printed Bioresorbable Scaffold for Guided Bone And Tis-sue Regeneration**

Advancements in tissue engineering have introduced "3D- printed" scaffolds, which are designed to replicate the complex structures of the periodontium, integrat-ing both hard and soft tissues. 19 Polycaprolactone has been extensively used as a scaffold material because of its ability to promote bone regeneration. Its three-dimensional structure closely mimics the extracellular matrix, enhancing its potential for regenerative applications.20 In a 15-month follow-up case, Lei et al. demonstrated the effectiveness of guided tissue regeneration in treating a bony defect around the maxillary lateral incisor. By employing a 3D-printed scaffold combined with platelet-rich fibrin, the study achieved notable results, including a marked reduction in pocket depth and enhanced bone regeneration.21 Recently, 3D-printed soft tissue grafts have emerged as a promising solution for keratinized tissue augmentation. These innovative grafts enable precise coverage of larger and more complex defects, overcoming the limitations associated with donor site availability.22

### 4. Sinus Augmentation

Vertical bone loss following tooth extraction often complicates implant placement in partially edentulous patients, especially with limited bone height due to the maxil-lary sinus position. Traditionally, bone grafting, distraction osteogenesis, and guided bone regeneration have been employed for augmentation. Recent advancements in 3D printing technology provide innovative solutions with highly promising outcomes. In 2015, Mangano et al. studied the use of a customized 3D-printed calcium phosphate (CaP) ceramic bone substitute for monolateral sinus augmentation in a sheep model. Tissue analysis at 45 and 90 days post-grafting demonstrated the material's excellent osteoconductive properties, enabling full bone regeneration from the periphery to the center of the sinus cavity.23

### 5. Dental Implant Placement Using 3-D Printing

Guided implant surgery is an advanced technique that enhances the precision and predictability of dental implant placement. This method allows creation of customized surgical guides by using 3-D printing technology that direct the placement of implants according to pre-planned positions. This approach minimizes the risk of complications, optimizes bone utilization, and improves aesthetic outcomes.24 A static guide, also known as a stereolithographic guide, utilizes a fixed surgical template that does not permit any alterations to the predetermined implant position during surgery. In contrast, the dynamic approach uses motion-tracking technology, allowing adjustments to implant positioning during the procedure. These guides are manufactured using photo polymerization techniques. In order to prevent angular and linear deviations when using 3D-printed templates, it is recommended to use a bone-supported surgical guide with specialized guided drills, a physical drill stop, and at least three fixation screws in a tripod arrangement to increase stability and reduce inaccuracies.25

### 6. Ridge Augmentation

Sumida et al. (2015) concluded that using selective laser melting printing to create a customised titanium meshwork is a simple safe method. Guided bone regeneration is a new approach for reconstructing lost alveolar ridge before implantation.26,27 It has been demonstrated that acidic calcium phosphates, brushite, and monetite are osteoconductive and osteoinductive. They may be used in vertical bone augmentation treatments and 3D printed to provide a perfect fit with the host bone and implant structure.28

## CONCLUSION

3D printing has brought significant advancements to the field of periodontology, with a wide range of applications reported in the literature. These include 3D- printed scaffolds are used for socket preservation, periodontal repair, bone augmentation, peri-implant care, and implant education. Surgical templates enhance implant placement accuracy, minimize complications, and reduce surgery time. 3D-printed models also provide effective educational tools.

**Flow chart: Evolution of 3D Printing[5]**

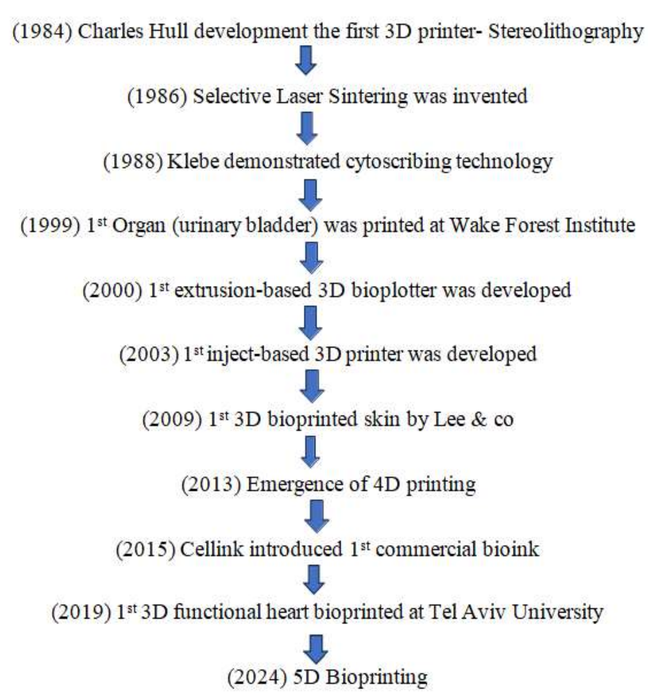

Table 1: Main biomaterials used in scaffold 3D printing13.

| Material | Advantages | Disadvantages |
|---|---|---|
| Natural polymers<br>Coll age n Algi nate Hyaluronic acid Chitosan | -Biocompatible<br>-Good cell affinity<br>-Hydrophilicity<br>-Antibacterial effect | -Low mechanical properties<br>-Fast degradation rate<br>-Lack of bioactivity |
| Synthetic polymers<br>Polycaprolactone (PCL) Polylactic acid (PLA) Polyglycolic acid (PGA) Polyethylene glycol (PEG) Poly(lactic-co-glycolic) acid (PLGA) | -Highly adjustable physiochemical and mechanical properties<br>-Wid range of degradation and resorption kinetics<br>-Good repeatability | -Low bioactivity<br>-Slow degradation rate<br>-Acidic byproducts |
| Bio-ceramics<br>Hydroxyapatite (HA) β-tricalcium phosphate (β-TCP) Bioactive glass | -Bioactive<br>-Biocompatible<br>-Osteoconductive<br>-Potential -osteoinductive<br>-Hydrophilicity | -Not compatible with cell encapsulation<br>-Stiffness<br>-Brittleness<br>-Low ductility<br>-Low flexibility<br>-Inconsistent cell reactions (variations in surface quality) |

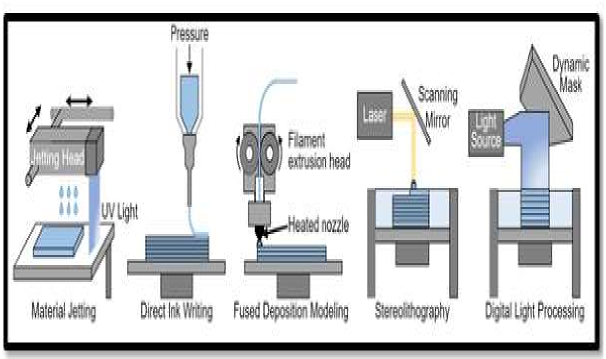


Fig.1: Types of 3D printers.

Despite its transformative potential, 3D printing faces challenges such as high costs, time constraints, and the need for advanced infrastructure. Current evidence is primarily based on preclinical studies, case reports, and limited clinical trials. To fully establish its efficacy and optimize its applications, further high-quality, randomized controlled trials are essential.

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