



# Sculpting Smiles in Layers: The Power of 3D Printing in Dentistry

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## Abstract

The adoption of 3D printing technology in contemporary dentistry has transformed the way dental materials and devices are produced. This review examines the detailed mechanics of 3D printing, highlighting its layer-by-layer construction and high precision, which allow the fabrication of intricate dental structures. We discuss various 3D printing techniques, including stereolithography (SLA), digital light processing (DLP), and fused deposition modeling (FDM), each offering distinct mechanical characteristics and clinical applications. The review also explores the manufacturing of 3D-printed biomaterials, emphasizing advances in material science that ensure prosthetics and implants are biocompatible, durable, and functionally reliable. Additionally, the applications of 3D printing in dentistry—such as crowns, bridges, orthodontic appliances, and surgical guides—are addressed, demonstrating how these innovations improve patient outcomes and optimize clinical workflows. Overall, this review highlights the critical role of mechanical accuracy in 3D printing, which continues to drive advancements in dental care.

**Keywords:** Additive Manufacturing; Digital Fabrication; Layer-Wise Construction; Accuracy, Dental Applications

## Abbreviations

DLP: Digital Light Processing; FDM: Fused Deposition Modeling; SLS; Selective Laser Sintering; SDL: Selective Deposition Lamination; LAB: Laser Bioprinting; LOM: Laminated Objects Manufacturing; FGMs: Functionally Graded Materials; PLA: Polylactic Acid; ABS: Acrylonitrile Butadiene Styrene; SLCM: Stereolithographic Ceramic Manufacturing; FPDs: Crown and Fixed Partial Dentures.

## Introduction

3D printing marks a groundbreaking advancement in manufacturing, enabling the creation of complex designs and geometries directly from digital files. Its high precision, adaptability, and compatibility with diverse materials have

transformed multiple industries, delivering economical and efficient solutions for both prototyping and final production.

In healthcare, especially medicine and dentistry, the rise of patient-specific equipment designed through 3D printing has greatly improved clinical outcomes. Unlike conventional subtractive manufacturing, additive methods such as 3D printing excel in customization and flexibility, making them unparalleled in meeting individual needs [1].

In addition, the development of 3D bioprinting carries immense promise for transforming transplantation and tissue regeneration, as it allows for the fabrication of functional biological tissues and organs. At the same time, the integration of digital workflows and the use of stereolithography techniques have introduced remarkable

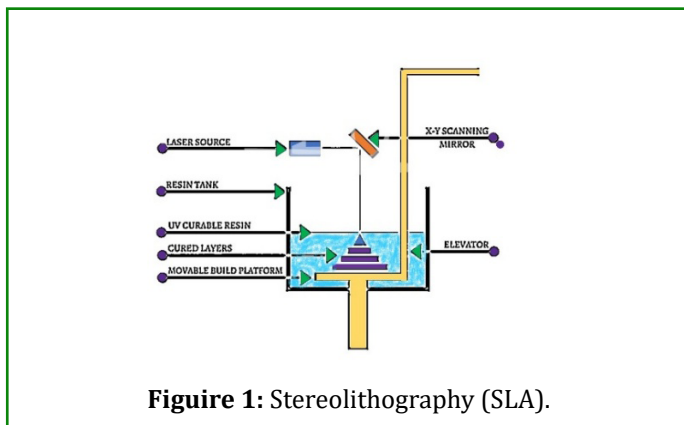
progress in modern dental practice. [2].

Although light-cured resin remains the most widely used material in dental 3D printing, alternative techniques such as Fused Deposition Modeling (FDM) and Selective Laser Sintering (SLS) provide viable options. Resin-curing processes, in particular, have been instrumental in advancing dental 3D printing and shaping its widespread adoption [3].

This paper seeks to chart the progression of Stereolithography (SLA) and Digital Light Processing (DLP) technologies within dental 3D printing, highlighting their influence on dentistry as well as allied medical domains. By exploring the underlying printing mechanisms and the diverse range of dental materials available, the study sheds light on how these technologies are applied across multiple dental specialties.

### 3D Printing Technologies

**Stereolithography (SLA):** Widely recognized for its efficiency, precision, and adaptability, SLA relies on photopolymerization, where liquid resin is cured layer by layer to produce highly detailed and accurate structures. [4]. Although SLA involves a comparatively longer beam-curing process, it reliably produces highly accurate and smooth outputs. This consistency has established it as a key technology in dentistry, particularly for fabricating customized crowns, dentures, surgical guides, and diagnostic models [5] (Figure 1).

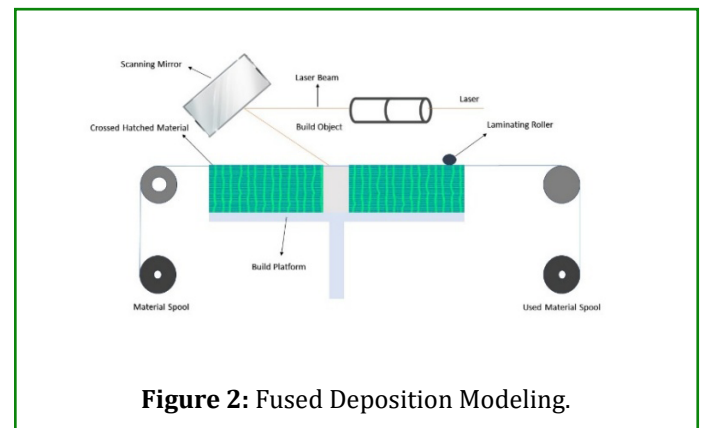


**Figure 1:** Stereolithography (SLA).

**Digital Light Processing (DLP):** Designed to overcome the limitation of extended fabrication times, DLP employs a light source to cure photopolymer resins layer by layer. This approach enables the rapid production of complex and finely detailed designs with high precision [6]. DLP surpasses SLA in printing speed, as it cures whole layers simultaneously with a single burst of light [7]. In DLP printing, resolution is governed by voxel size, where larger voxels result in reduced detail and accuracy. Extensively applied in dentistry, DLP facilitates the fabrication of crowns, dentures, and prosthetic

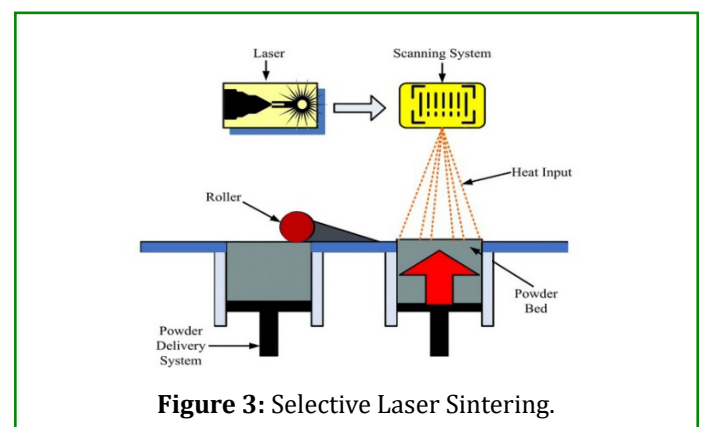
appliances, thereby simplifying clinical workflows and improving treatment outcomes [5].

**Fused Deposition Modeling (FDM):** FDM is a flexible 3D printing technique used in multiple healthcare applications, where semi-solid thermoplastic filaments are extruded and deposited layer by layer. Although it provides robust interlayer adhesion, its material compatibility is restricted to thermoplastics [8] (Figure 2).



**Figure 2:** Fused Deposition Modeling.

**Selective Laser Sintering (SLS):** SLS provides time-efficient manufacturing by using a high-powered laser to selectively fuse powdered ceramics, metals, and polymers, producing dense, dental-grade components. Despite its need for substantial infrastructure, SLS is utilized in dentistry to fabricate frameworks for removable partial dentures, reducing errors and offering a safer alternative to conventional casting techniques [9] (Figure 03).



**Figure 3:** Selective Laser Sintering.

**Photopolymer Jetting Printing (PolyJet 3D printing):** PolyJet 3D Printing: Notable for its capability to produce multi-colored prints, PolyJet technology is especially valuable in esthetic dentistry. It works by depositing droplets of fusing agents via inkjet printheads onto a powder bed, which are then cured using infrared lamps. While it allows for multi-material fabrication, PolyJet requires regular printhead maintenance and has limited mechanical strength for certain

dental applications [5].

**Powder Binder Jetting:** Employing biocompatible elastomers and medical-grade silicones, powder binder printing is well-suited for fabricating maxillofacial prostheses. In this process, a water-based binder infiltrates silicone polymers to selectively fuse layers of starch-based powder, producing patient-specific, customized designs [11]. However, the mechanical properties of powder binder prints are relatively weak, constraining their use in dentistry [5].

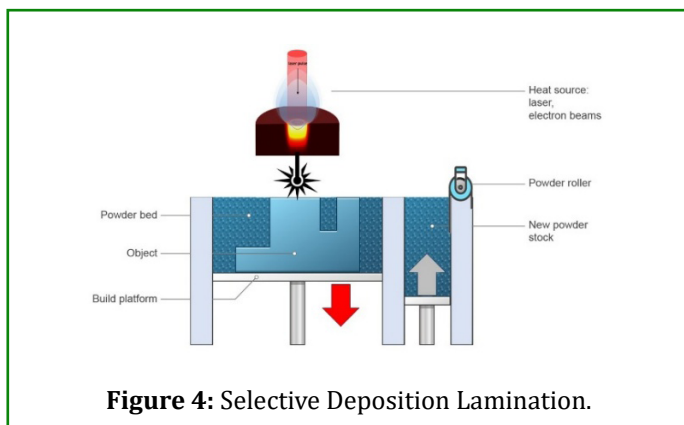
**Selective Deposition Lamination:** The process starts with a sheet of paper placed on the build platform. Glue is then selectively applied, with a lower concentration in support regions and a higher concentration in working areas to facilitate easy removal of supports. A paper-feeding mechanism then lays a new sheet over the glued one. The build plate is pressed against a heated plate to ensure uniform adhesion. Once the desired height is reached, a sharp-edged tool cuts the paper according to the design specifications, defining the part's edges. This cycle repeats, with each new sheet quickly added and bonded, until the complete part is constructed [12,13].

A comprehensive evaluation of Selective Deposition Lamination (SDL) was performed via a survey to justify its terminology:

**Selective:** The system increases adhesive application in the working regions while reducing it in support areas, which simplifies support removal. By contrast, LOM applies glue across the entire sheet, making detachment more difficult.

**Deposition:** SDL uses a paper cutter to precisely apply glue, a process requiring skill, whereas LOM achieves uniform adhesion by coating the entire sheet.

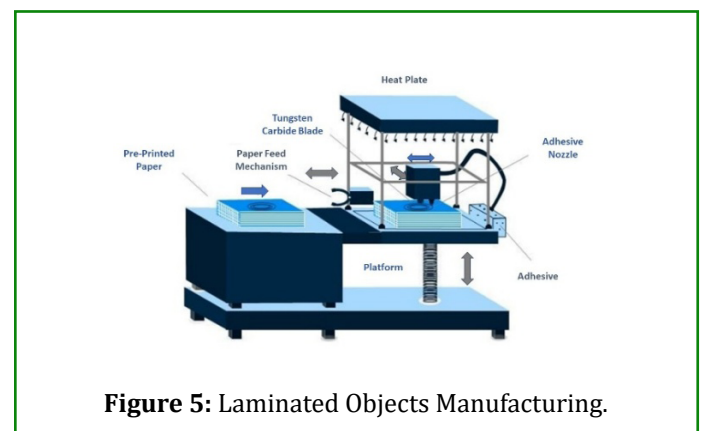
**Lamination:** This involves stacking overlapping sheets, resulting in components that are strong, durable, and long-lasting [14] (Figure 4).



**Figure 4:** Selective Deposition Lamination.

**Laser Bioprinting (LAB):** By combining additive manufacturing with biotechnology, Laser-Assisted Bioprinting (LAB) shows significant potential in dental regenerative treatments. Through the precise layering of living cells and biomaterials using lasers, LAB enables the fabrication of tissue-engineered constructs for oral mucosa repair and periodontal regeneration, providing innovative solutions to complex dental challenges and improving patient outcomes [15].

**Laminated Objects Manufacturing (LOM):** Laminated Object Manufacturing (LOM) is an additive manufacturing method for producing 3D objects from materials like paper, plastic, or metal. The technique involves stacking and laminating sheets, which are then precisely cut into shape using a laser. Each sheet is first adhered to a substrate with a heated roller, after which the laser outlines the design, removing unwanted areas. Once a layer is complete, the platform lowers, a new sheet is applied, and the process repeats until the full object is formed [16-18] (Figure 5).



**Figure 5:** Laminated Objects Manufacturing.

The advancement of dental 3D printing materials is largely directed toward improving mechanical strength and biocompatibility, comparable to conventional dental resins. These materials are further optimized through processes such as curing and washing, enhancing their suitability for clinical dental applications.

### Manufacturing Of 3d Printing Biomaterials

High-quality materials are essential in 3D printing to meet strict standards and ensure the consistent production of reliable components. Similar to conventional manufacturing, protocols, specifications, and material control agreements are established among suppliers, buyers, and end users to maintain quality. 3D printing allows the fabrication of fully functional parts from a wide range of materials, including polymers, metals, and ceramics, as well as combinations that form hybrids, functionally graded materials (FGMs), or composites [19]. The rapid advancement of dental 3D printing materials has primarily targeted improvements

in mechanical performance and biocompatibility, similar to conventional dental resins. These materials undergo processes such as curing and washing, further enhancing their suitability for dental applications.

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**Metals:** Metal 3D printing is gaining significant attention across sectors such as manufacturing, automotive, aerospace, and healthcare due to its versatile properties. Commonly used metals include aluminum [20], stainless steel [21], cobalt-based alloys [22], titanium [23,24], and nickel-based alloys [25]. Cobalt-based alloys are particularly suited for dental applications because of their high elongation, specific stiffness, resilience, and heat-treated properties [22]. Nickel-based alloys are beneficial in aerospace for withstanding temperatures up to 1200 °C and high corrosion resistance [25]. Titanium alloys are widely employed due to their low density, excellent corrosion resistance, oxidation resistance, and ductility, making them ideal for high-stress and high-temperature applications [23].

**Polymers:** Polymers are extensively used in 3D printing for functional structures and complex prototypes [26]. Fused Deposition Modeling (FDM) constructs objects by depositing successive layers of thermoplastic filaments, such as polyethylene (PE) [26], polylactic acid (PLA), polypropylene (PP), and acrylonitrile butadiene styrene (ABS). High-melting-point polymers like PMMA and PEEK have also been adopted [27]. Liquid or low-melting-point polymers are widely preferred due to their affordability, light weight, and ease of processing [28]. In medical applications, polymers act as inert materials providing mechanical support in orthopedic implants [22].

**Ceramics:** Modern 3D printing can produce ceramic and concrete structures with minimal porosity or cracks by optimizing mechanical parameters [29]. Ceramics are durable, fire-resistant, and can be molded into complex shapes before setting, making them ideal for dental and aerospace applications [30], including zirconia [31], bioactive glasses [32], and alumina [33]. For instance, alumina powder can be processed using 3D printing, enabling high-density structures post-sintering despite its challenging curing

requirements [30,33,34]. Glass-ceramics and bioactive glass processed via SLA demonstrate enhanced bending strength, allowing applications such as bone scaffolds [32]. Stereolithographic Ceramic Manufacturing (SLCM) can yield dense, homogeneous microstructures with high mechanical strength. Zirconia is also used in the nuclear industry for element tubing due to low thermal neutron absorption and radiation resistance [31].

**Composites:** Composite materials offer lightweight, customizable, and high-performance properties, transforming industries such as aerospace. Carbon fiber-reinforced polymer composites are utilized for their exceptional fatigue resistance, strength, stiffness, and corrosion resistance [35,36]. Glass fiber-reinforced polymer composites are employed in 3D printing for their affordability and performance, with favorable thermal conductivity, low expansion, and flame resistance enhancing their suitability [35,37].

**Smart Materials:** Smart materials can alter shape or geometry in response to external stimuli such as heat or water [38]. Examples in 3D printing include soft robotics and self-evolving structures. Shape memory polymers (SMPs) [39] and nickel-titanium shape memory alloys [40] are notable, used in devices ranging from microelectromechanical systems to biomedical implants. Nickel-titanium 3D-printed parts require control over microstructure, density, and transformation temperatures [29]. SMPs respond to stimuli like heat, light, electricity, or chemicals, and 3D printing allows for fabrication of complex geometries with high part density, surface quality, and dimensional accuracy [39].

**Food and Specialty Materials:** 3D printing is applied to food, including chocolate, meat, sweets, pizza, spaghetti, and sauces, allowing precise shaping while maintaining nutritional value [41]. Lunar dust printing technology could support moon colonization by producing layered parts directly from regolith [42]. In jewelry and apparel, 3D textile printing reduces processing time, packaging costs, and supply chain expenses [43].

**Bioink Materials:** Bioinks are essential for tissue and organ fabrication in 3D bioprinting, serving as scaffolds for living cells. Materials include hydrogels such as gelatin and alginate, and synthetic polymers like PLA and PCL. Cells can be embedded in hydrogels or used as aggregates to form cell-laden bioinks. Bioinks are valuable in tailored therapeutics for drug release management, cancer treatment screening, side effect studies, and tumor cell behavior analysis [44]. Hydrogel-based bioinks mimic the extracellular matrix (ECM), and using biocompatible, biodegradable materials allows printing of customized tissues with minimal immune response and accelerated healing. Current 3D bioprinting applications

include skin, cartilage, bone, lung, and heart tissues [44].

## Applications Of 3d Printing In Dentistry

### Prosthodontics

*Crown and Fixed Partial Dentures (FPDs)* 3D printing technologies, particularly SLA and DLP, are increasingly used to fabricate definitive or provisional crowns and FPDs. Intraoral scanning allows precise virtual models for prosthesis design using CAD software (e.g., 3Shape Dental System 2022, 3Shape A/S, Copenhagen, Denmark). 3D printing offers advantages in cost, speed, and resource efficiency compared to milling [45,46], with studies demonstrating superior edge and internal fit of 3D-printed provisional crowns [47-49].

### Complete and Removable Partial Dentures

Denture fabrication remains challenging in patients with severe gag reflex, TMJ disorders, tumor excisions, or oral abnormalities. Integration of intraoral scanning and 3D printing streamlines production, reduces errors, and enhances flexibility [50]. Traditional wax and cast methods are time-consuming and prone to errors, such as misalignment, mucosal ulcers, and ridge resorption [51]. RPD frameworks fabricated via selective laser melting (SLM) show superior fit and homogeneous contact pressure compared to conventional methods [52,53].

### Implantology

3D printing simplifies implant surgeries by enhancing predictability, accuracy, and efficiency while reducing risks. Traditional 2D radiograph-based guides are less accurate due to low resolution. CAD-based guides derived from CBCT and intraoral scans improve surgical precision [54], while also offering cost, speed, and customization advantages [55,56].

*Dental/Maxillofacial Surgical Templates and Guides* For three decades, additive manufacturing has been employed in oral and maxillofacial surgery for model construction, planning, surgical guides, and custom implants [57,58]. CT imaging and CAD analysis generate patient-specific templates, improving precision, margin control, and bone preservation [59].

### Custom Implants

3D printing enables implants with complex geometries using SLS and SLM to print titanium or polymers such as PEEK, offering adjustable porosity and mechanical properties [58,60].

### Maxillofacial Prostheses

3D printing allows fabrication of intricate prostheses tailored to defects, reducing production time and enhancing

reproducibility [57,61,62].

### Orthodontics

3D printing is widely used for aligners, improving clarity, removability, hygiene, and aesthetics [63]. Direct 3D-printed aligners offer better fit, function, and stability than thermoformed ones [64,65]. 3D printing also supports Gnathology in managing TMDs, enabling digital planning and fabrication of customized intraoral appliances [66].

### Endodontics

Applications include access cavity preparation and training [67]. 3D-printed access guides enhance precision [68-70], and guided apicoectomy benefits from improved accuracy over freehand methods [71,72].

### Periodontics

- **Regenerative Hard and Soft Tissue Scaffolds:** 3D-printed scaffolds support bone and periodontal tissue regeneration, offering customized solutions with improved healing and aesthetics [73,57]. Soft tissue grafts for keratinized tissue augmentation address larger defects without donor site limitations [74].
- **Gingivectomy Surgery Guides:** 3D-printed, patient-specific surgical guides for gingivectomy enhance precision and aesthetics by utilizing intraoral scans and CAD software [57].

## Conclusion

This review provides a comprehensive overview of 3D printing technologies, their mechanics, classification, and applications in dentistry. 3D printing simplifies complex 3D manufacturing into a 2D layering process, though challenges remain. Anisotropy affects long-term intraoral device performance, and layer thickness can reduce surface smoothness in equipment like ceramic restorations. Future research should address these limitations, alongside high equipment costs, material expenses, post-processing time, and reliance on skilled operators.

Integration of new dental-specific materials, such as Co-Cr alloys in DMLS, and technologies like 3D scanners, CBCT, and conventional CT, will enhance accuracy, reduce labor costs, and improve clinical outcomes [75,76]. 3D bioprinting has expanded to soft tissue biomaterials, including periodontal tissue regeneration using stem cells, gene therapy, and multilayer bionic technology [77,78]. Machine learning improves CAD/CAM processes, optimizing design and manufacturing quality [79]. Virtual reality integration enables precise evaluation of 3D restoration designs, reducing waste and enhancing accuracy.

## Future Directions

Advances in precision, efficiency, and accessibility will drive personalized prostheses and biomaterials. 4D printing could enable shape-changing materials for endodontic devices and dental implants. Computed axial lithography promises rapid production with low-viscosity materials. Continued development of materials and technologies will further shape 3D printing's impact on dentistry.

## Declaration of Competing Interest

The author declares that he has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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