# 3D Printing: Techniques and Application in Dentistry - A Review.

Ankur Singh[1], Dhaval Mehta[2], Vishwa Shah[3]

[1]Professor, [2]Professor and Head, [3]PG student, Department of Oral Medicine and Radiology, Narsinhbhai Patel Dental College and Hospital, Sankalchand Patel University, Gujarat, India.

## Abstract

Three-dimensional (3D) printing technologies are advanced manufacturing techniques that use computer-aided design digital models for the automated manufacture of customized 3D products. With a history spanning over three decades, these technologies have found widespread applications across various industries, including design, engineering, and manufacturing. Within the realm of process engineering, 3D printing brings numerous advantages and finds applications in diverse fields such as prosthodontics, oral and maxillofacial surgery, oral implantology, orthodontics, endodontics, and periodontology. The purpose of this paper is to provide a practical and technical overview of 3D printing technology by introducing modern 3D printing processes such as powder bed fusion, photopolymerization molding, and fused deposition modeling. Furthermore, it delves into the clinical applications of 3D printing in dentistry, including the creation of functional models and primary applications in prosthodontics, oral and maxillofacial surgery, and oral implantology. The benefits of 3D printing technologies encompass efficient material utilization and the capability to fabricate intricate geometries, but they come with drawbacks such as high costs and time-intensive post-processing. Looking ahead, the future trajectory of 3D printing in dentistry points toward the evolution of new materials and technologies, leaving no doubt that 3D printing holds a promising and vibrant future within the field.

**Key words**: *3D printing, applications in dentistry, techniques*

Corresponding Author: Dr. Ankur Singh, Professor, Department of Oral Medicine and Radiology, Narsinhbhai Patel Dental College and Hospital, Sankalchand Patel University, Gujarat, India

Date of Submission: 28 January 2024
Date of Revision: 18 March 2024
Date of Acceptance: 29 April 2024

## Introduction

Recent years have seen technology play a crucial role in dentistry, transforming treatment procedures and educational tools across various dental specialties. Dentistry now embraces a digital workflow consisting of three main elements: scanning for data capture, CAD software for data processing, and CAM for producing dental products. Traditional subtractive manufacturing methods were slow, wasteful, and unsuitable for complex anatomical structures. To address these issues, 3D printing technology was introduced to revolutionize dentistry.[1]

Evidence indicates that the inaugural 3D printing technique was introduced by Charles Hull in 1986. Subsequently, a multitude of advancements spanning various fields and encompassing numerous therapeutic applications have been documented. Hull was a trailblazer in the realm of stereolithography (SLA), having conceptualized and refined a 3D printing approach in the year 1986.[2-5] Additionally, Scott Crump secured a patent for fused deposition modeling (FDM) in 1990. Subsequent to these pioneering efforts, 3D printing has undergone substantial evolution and progress.[6]

The term "3D printing" typically describes a manufacturing process in which objects are built by adding material layer upon layer. This process is more precisely known as additive manufacturing or rapid prototyping. It is often referred to as desktop fabrication, involving the synthesis of a structure from a 3D model.[7] The 3D design is typically stored in STL (surface tessellation language or Stereolithography) format and then sent to a 3D printer. Various materials like ABS (Acrylonitrile butadiene styrene), PLA (Polylactic Acid), and composites can be used in this process.[8]

The development of RP (Rapid Prototyping) technology unfolded in three distinct phases:[9]

- In the initial phase, skilled craftsmen manually crafted prototypes.
- The second phase, in the mid-1970s, a development emerged that introduced the idea of applying precise materials to soft prototype models in a virtual manner, utilizing 3D curves.
- The third phase, which began in the 1980s, embraced a layer-by-layer approach to prototype creation.

This summary focuses on three primary 3D printing methods: powder bed fusion (PBF), light curing, and FDM. It also explores the diverse applications of 3D printing in the field of dentistry, which encompass creating functional models and its significant contributions to various aspects of oral healthcare, including oral medicine and radiology, endodontics, orthodontics, periodontology, prosthodontics, oral and maxillofacial surgery, and oral implantology.

**3-D Printing Techniques**

Three primary 3D printing technologies, namely PBF, light curing, and FDM, can be further categorized into specific methods, each offering its unique advantages. [7] These methods include SLA, FDM, Selective Laser Sintering (SLS), Selective Heat Sintering (SHS), Selective Laser Melting (SLM), Electron Beam Melting (EBM), Binder Jetting (BJG), Photo polymerization, DLP projecting, and Laminated Object Manufacturing (LOM).[10]

The table, summarizes the three main 3D printing technologies, their classifications, materials used, and their key advantages:[2-6]

Powder Bed Fusion
- Classifications: SLM, SLS, EBM, DMLS
- Materials: Metal materials
- Advantages: No binding process required, suitable for metal, and offers high strength.

Light Curing
- Classifications: SLA, DLP, PJ
- Materials: Resin, Ceramic [11]
- Advantages: Good mechanical resistance, reduced construction time, and high surface quality of printed objects.

Fused Deposition Modelling:
- Materials: Thermoplastic materials
- Advantages: Biocompatible, high mechanical strength of fabricated scaffolds.[12]

In short, these 3D printing technologies offer various advantages such as strength, speed, and quality, depending on the materials and methods used.[12]

1. Powder Bed Fusion (PBF) - Versatile 3D printing technology that uses laser or

electron beam radiation to sinter or fuse powdered materials, solidifying them upon cooling.[14] PBF includes methods like Selective Laser Melting (SLM), Selective Laser Sintering (SLS), Electron Beam Melting (EBM), and Direct Metal Laser Sintering (DMLS), all relying on heat to melt powders. In dentistry, PBF is employed to create various metal products, such as titanium (Ti) dental implants, custom Ti implants, cobalt-chromium (Co-Cr) frames, and even ceramic restorations like frame crowns and model casting abutments.[15,16]

It's important to note that the terms "laser sintering" and "selective laser melting" can be ambiguous. SLS and DMLS operate below materials' melting points, resulting in partial melting, porosity, and rough surfaces.[17] In contrast, SLM and EBM directly melt the powder at the material's melting point in an inert environment. Powder Bed Fusion involves applying powdered material onto a build platform and selectively fusing particles based on a CAD file's design. The build platform descends layer by layer until the object is complete.[16]

Titanium and its alloys, particularly when processed with SLS, exhibit impressive strength and ductility. Ceramics can also be used in SLS for dental applications, usually involving polymer bonding and sintering.[18] SLM eliminates the need for debinding, resulting in shorter fabrication times compared to other 3D printing methods. However, rapid heating and cooling can induce thermal stress, which can be mitigated by preheating the powder. SLS-based products may exhibit weaknesses and porosity, requiring complex post-processing, whereas DMLS products tend to be denser. An innovative use of DMLS involves creating custom Ti meshes for bone regeneration in atrophied maxillary dental arches, as demonstrated by Ciocca et al.[19]

2. Light Curing - Subset of 3D printing methods that utilize photosensitive resin materials solidified by exposure to light.[20] This category includes Stereolithography (SLA), Digital Light Processing (DLP), and Photo Jet (PJ). The process in SLA and DLP involves three main steps: light exposure, platform movement, and resin replenishment.[19]

SLA, one of the earliest 3D printing technologies, employs a UV laser to solidify a liquid resin.[21] In SLA, the build platform can move either from the top-down or bottom-up, with the bottom-up approach being preferred in most cases due to advantages like reduced oxygen interference, operator safety, and automatic resin replenishment via gravity.[20]

In ceramics applications, SLA combines ceramic particles with a curing resin, selectively curing a ceramic slurry. Achieving the right balance between ceramic powder content and resin viscosity is crucial for mechanical properties. Ceramics like alumina and zirconia, known for their mechanical resistance, are commonly used in applications such as polycrystalline ceramic crowns (Fig 1).[20-22]

In contrast, Photo Jet (PJ) employs a photopolymerizable inkjet system in which the printhead moves along the X/Y-axis, spraying photopolymer onto the table. Simultaneously, an ultraviolet lamp emits light in the same direction as the printhead's movement to cure the photopolymer, completing one layer of printing. The table then descends along the Z-axis, and this process repeats until the object is fully printed. PJ is distinguished by its material versatility, accommodating a wide range of materials from thermoplastics to resins and ceramics, including zirconia paste. It has the capability to blend materials, allowing for objects with diverse properties.[21] PJ also produces high-quality surfaces and print resolutions, eliminating the need for extensive post-printing polishing.[22]

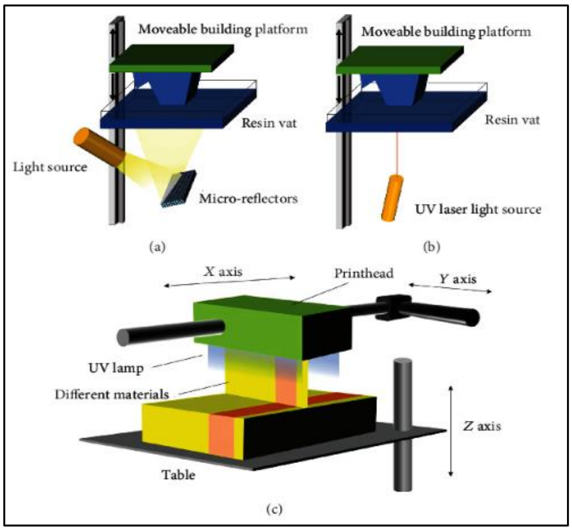


Fig 1: Schematic diagram of three-dimensional (3D) technologies. (a) Digital light processing. (b) Stereolithography. (c) Fused deposition modelling

Light-curing technology encompasses SLA, DLP, and PJ, each with its unique approach to 3D printing using photosensitive resins. These methods offer a variety of material options and distinct advantages, making them suitable for diverse applications and industries.[20]

3. Fused Deposition Modelling (FDM) - Widely utilized and cost-effective 3D printing technology in dentistry. It involves heating and melting a filamentous thermoplastic material through a nozzle.[21] The nozzle and worktable are operated by a computer, causing them to move in the horizontal (X-axis) and vertical (Y-axis) directions. As they move, they extrude the molten material onto the worktable in layers, which then solidify to form the desired end product.[22] FDM is favored in dentistry for its versatility and affordability, capable of using various engineering thermoplastics.[21] PLA, for instance, is suitable for oral applications, and FDM has shown promise in producing biocompatible dental scaffolds and custom dental devices.[22]

## Application in dentistry

3D printing's digitalization has ushered in substantial progress in dentistry, delivering precision and versatility across various applications. This emerging technology has enhanced diagnostic precision, simplified treatment processes, and minimized chair-side time, empowering dentists to offer effective and accurate treatments. Today, 3D printing stands as a preferred method in dental care, ensuring both quality and quantity in patient treatment.[23]

3D printing technology is widely applied in various dental procedures, with factors like printer type, materials, and build thickness influencing the precision of printed models. These applications include bioprinting tissues and organs, 3D printed teeth, implant-supported restorations, aesthetic inlays, guided endodontic procedures, custom myofunctional appliances, maxillofacial prostheses, obturators, full dentures, digital impressions, Invisalign, and customized 3D printed drug delivery systems.[24]

The advent of 3D printing has transformed dentistry, allowing for the creation of top-notch dental prosthetics characterized by outstanding precision. This innovation has significantly improved patient care and treatment results.[23]

Oral Medicine and Radiology: 3D printing has found early and frequent use in evaluating head and neck pathologies, particularly in dentistry and craniofacial diagnosis over the last decade. These technologies are employed to create detailed maxillofacial models, offering precise information about lesion extent and boundaries. This assists diagnosticians in devising more effective treatment strategies and gaining insights into prognosis.[25] Experienced radiologists frequently contribute their knowledge to the manufacturing process to ensure the precision of these 3D-printed models.[24]

In radiation oncology, achieving the best treatment plan must consider the impact of tumor distortion on normal anatomy and irregular tissue surfaces. Three-dimensional printing offers a potential solution to address these challenges. Sun and Wu utilized 3D printing to create a patient-specific cranium based on CT images, allowing for the testing of different treatment options. Similarly, Zemnick et al introduced a patient-specific extraoral radiation shield using 3D printing technology, ensuring patient comfort and homogeneous radiation delivery for skin cancer treatment, even in cases of uneven superficial tissue topography.[25]

Endodontics: Recent advancements in digital technology, including the use of 3D printed objects in dentistry, have significantly impacted the teaching and management of case related to implant, craniofacial, maxillofacial, orthognathic, and periodontal treatments. These 3D printed models and guides have proven beneficial in planning and addressing complex non-surgical and surgical endodontic procedures, as well as facilitating skill development.[27] Furthermore, 3D printing technology has enhanced the management of endodontic procedures by enabling the duplication and maintenance of accurate records, educating patients, aiding treatment planning through improved visualization, identifying crucial anatomical landmarks and pathologies such as root resorption, and facilitating the production of laboratory-made directional or surgical guides. Specifically, 3D printed guides are valuable for guided non-surgical and surgical endodontic interventions.[28]

Oral and Maxillofacial Surgey: The utilization of 3D printing techniques allows for the creation of anatomical models, offering a novel approach to surgical treatment planning and simulation. This technology provides surgeons with a comprehensive view of complex structures before they perform surgery.[29] The surgical correction of a broad midline craniofacial cleft in an 8-month-old patient was made possible by Anderl et al.'s effective use of CT-guided stereolithography to construct an acrylic model in the early 1990s. This acrylic model allowed for preoperative planning and intraoperative care.[25]

When reconstructing maxillofacial defects, it is essential not only to restore anatomical appearance but also tissue functionality.[27] Autologus bone grafts are the current gold standard for this purpose due to their ability to support bone growth. However, they have the drawback of requiring manual shaping to match the defect, prompting the search for less invasive treatments for bone defects.[29]

Orthodontics: Recent advancements in intraoral digital scanning technology have revolutionized orthodontics by eliminating the need for uncomfortable impressions, providing more precise appliances, and shortening treatment durations.[30]

When using the Invisalign System, a patient's teeth are digitally realigned to produce a set of 3D printed models from which aligners are made. Patients receive new aligners every two weeks, gradually repositioning their teeth. This technology saves time, allows for digital storage of patient data, reduces physical storage needs, and integrates bracket production and positioning into a single CAD/CAM process. This approach combines individualization with space efficiency.[29,30]

Periodontology: With numerous uses including the treatment of alveolar bone abnormalities, implant placement guidance, serving as a drug delivery system, and producing human bone and skin grafts in vitro, 3D printing is becoming an increasingly important part of periodontal therapy. The results of treatment could be completely changed by these developments in periodontology.[31]

Bioresorbable scaffolds for periodontal recuperation and regeneration, socket preservation, bone and sinus augmentation operations, guided implant placement, peri-implant maintenance, and implant education are some specific applications of 3D printing in periodontology.[29]

Prosthodontics: 3D printing has rapidly evolved in recent years and has found numerous applications in prosthetic dentistry. This technology offers significant advantages, including time and labor savings and the assurance of a perfect fit for fabricated dental constructions.[15]

The capacity to produce items utilizing a variety of materials, including polymers, composites, metals, and alloys, all with precise structural integrity and predetermined surface roughness, is a key advantage of additive technology in prosthetic dentistry.[32] This adaptability enables the creation of complex shapes without the requirement for specialized CAM unit adjustments and permits the controlled use of various materials in various regions of the same design.[15]

Implants placement: Implant placement is a common procedure in dentistry, known for its reliability in replacing missing teeth.[33] However, it's technically complex and, if not performed correctly, can result in complications like aesthetic issues, harm to vital structures, infections, and implant failure.[28] Utilizing 3D printing to create surgical guides for guided implant placement is a solution to avoid these problems. These guides ensure precise 3D implant placement, minimizing the risk of anatomical damage and saving time during the procedure.[31]

## Conclusion

The influence of 3D imaging, CAD technologies, and 3D printing in dentistry is profound. Digital data allows for the creation of precise and intricate shapes in various materials, either locally or in industrial settings. This technology enhances patient consultations, elevates diagnostic accuracy, improves surgical planning, serves as a surgical guide, and offers templates for surgical procedures. Moreover, as bio-cell printing continues to advance, there is potential for the creation of tissues and organs through 3D printing. Overall, 3D printing has the potential to greatly benefit both patients and doctors providers through personalized and patient-specific medicine.

## References


1. Gul M, Arif A, Ghafoor R. Role of three-dimensional printing in periodontal regeneration and repair: Literature review. Journal of Indian Society of Periodontology. 2019 Nov;23(6):504.
2. Barazanchi A., Li K. C., Al-Amleh B., Lyons K., Waddell J. N. Additive technology: update oncurrent materials andapplications in dentistry. J. Prosthet. Dent. 2017;26(2): 156–163.
3. Vukicevic M., Mosadegh B., Min J. K., Little S. H. Cardiac 3D printing and its future directions. *JACC: Cardiovascular Imaging*. 2017;10(2):171–184.
4. Farooqi K. M., Sengupta P. P. Echocardiography and three-

dimensional printing: sound ideas to touch a heart. JASE. 2015;28(4):398–403.
5. Mai H. N., Lee K. B., Lee D. H. Fit of interim crowns fabricated using photopolymer-jetting 3D printing. J. Prosthet. Dent. 2017;118(2):208–215.
6. Gross B. C., Erkal J. L., Lockwood S. Y., Chen C., Spence M. D. Evaluation of 3D printing and its potential impact on biotechnology and the chemical sciences. Anal. Chem. 2014;86(7):3240–3253.
7. Dawood A, Marti BM, Sauret-Jackson V, Darwood A. 3D printing in dentistry. Br. Dent. J. 2015 Dec;219(11):521.
8. Hota S. Study, Design and Fabrication of a 3D Printer (Doctoral dissertation).
9. Jayaraj A, Jayakrishnan SS, Shetty KP, Nillan K, Shetty RR, Govind SL. 3D printing in dentistry: A new dimension of vision. Int. J. Appl. Dent. Sci. 2019;5(2):165-9.
10. Jasveer S, Jianbin X. Comparison of different types of 3D printing technologies. Int. j. sci. res. 2018 Apr;8(4):1-9.
11. Lukić M., Clarke J., Tuck C., Whittow W., Wells G. Printability of elastomer latex for additive manufacturing or 3D printing. J. Appl. Polym. Sci. 2016;133 (4, article 42931)
12. Lin L., Fang Y., Liao Y., Chen G., Gao C., Zhu P. 3D printing and digital processing techniques in dentistry: a review of literature. Adv. Eng. Mater. 2019 Jun;21(6):1801013.
13. Alharbi N., Alharbi S., Cuijpers V., Osman R. B., Wismeijer D. Three-dimensional evaluation of marginal and internal fit of 3D-printed interim restorations fabricated on different finish line designs. J. Prosthodont. Res. 2018;62(2):218–226.
14. Mazzoli A. Selective laser sintering in biomedical engineering. MBEC. 2013;51(3):245–256.
15. Galante R., Figueiredo-Pina C. G., Serro A. P. Additive manufacturing of ceramics for dental applications: a review. Dent. Mater. J.2019;35(6):825–846.
16. Revilla-Leon M., Sadeghpour M., Ozcan M. A review of the applications of additive manufacturing technologies used to fabricate metals in implant dentistry. J. Prosthodont. 2020;29(7):579–593.
17. Methani M. M., Revilla-Leon M., Zandinejad A. The potential of additive manufacturing technologies and their processing parameters for the fabrication of all-ceramic crowns: a review. J Esthet Restor Dent. 2020;32(2):182–192.
18. Konda Gokuldoss P, Kolla S, Eckert J. Additive manufacturing processes: Selective laser melting, electron beam melting and binder jetting—Selection guidelines. materials. 2017 Jun 19;10(6):672.
19. Ciocca L., Fantini M., De Crescenzio F., Corinaldesi G., Scotti R. Direct metal laser sintering (DMLS) of a customized titanium mesh for prosthetically guided bone regeneration of atrophic maxillary archesMBEC 2011;49(11):1347–1352.
20. Reymus M., Hickel R., Kessler A. 3D printing in dentistry-state of the art. Oper. Dent. 2020;45(1):30–40.
21. Yefang Z., Hutmacher D. W., Varawan S. L., Meng L. T. Comparison of human alveolar osteoblasts cultured on polymer-ceramic composite scaffolds and tissue culture plates. Int. J. Oral Surg.2007;36(2):137–145.
22. Chen H., Yang X., Chen L., Wang Y., Sun Y. Application of FDM three-dimensional printing technology in the digital manufacture of custom edentulous mandible trays. Sci. Rep. 2016 Jan 14;6(1):19207.
23. Vallabhaneni S, Saraf P, Khasnis S. Augmenting realm of 3D printing in restorative dentistry and endodontics-A

review. International Journal of Dental Materials. 2020 Mar 9;2(1):24-9.
24. Katkar RA, Taft RM, Grant GT. 3D volume rendering and 3D printing (additive manufacturing). Dental Clinics. 2018 Jul 1;62(3):393-402.
25. Swennen GR, Pottel L, Haers PE. Custom-made 3D-printed face masks in case of pandemic crisis situations with a lack of commercially available FFP2/3 masks. Int. J. Oral Surg.2020 May 1;49(5):673-7.
26. Vasamsetty P, Pss T, Kukkala D, Singamshetty M, Gajula S. 3D printing in dentistry–Exploring the new horizons. Materials Today: Proceedings. 2020 Jan 1; 26:838-41.
27. Lim G, Choi D, Richardson EB. 3-D printing in organ transplantation. Hanyang Medical Reviews. 2014 Nov 1;34(4):158-64.
28. Shah P, Chong BS. 3D imaging, 3D printing and 3D virtual planning in endodontics. Clinical Oral Investigations. 2018 Mar 1;22(2):641-54.
29. Choi JW, Kim N. Clinical application of three-dimensional printing technology in craniofacial plastic surgery. Archives of plastic surgery. 2015 May;42(3):267.
30. Groth CH, Kravitz ND, Jones PE, Graham JW, Redmond WR. Three-dimensional printing technology. J ClinOrthod. 2014 Aug;48(8):475-85.
31. Bhatnagar A, Bhardwaj A, Verma S. Additive Manufacturing: A 3-Dimensional Approach in Periodontics. Journal of Advances in Medicine and Medical Research. 2020 May 13:105-17.
32. Katreva I, Dikova T, Abadzhiev M, Tonchev T, Dzhendov D, Simov M, Angelova S, Pavlova D, Doychinova M. 3D-printing in contemporary prosthodontic treatment. Scripta Scientifica Medicinae Dentalis. 2016 Mar 15;2(1):7-11.
33. Sun J, Zhang FQ. The application of rapid prototyping in prosthodontics. J Prosthodont: Implant, Esthetic and Reconstructive Dentistry. 2012 Dec;21(8):641-4.

How to cite the article:

Singh A, Mehta D, Shah V. 3D Printing: Techniques and Application in Dentistry: A Review. JIHR 2024;1(2):48-55.