International Journal of Dental Sciences
www.dentaljournal.in
E-ISSN: 2663-4708, P-ISSN: 2663-4694
Received: 17-11-2023; Accepted: 03-12-2023; Published: 19-12-2023
Volume 5, Issue 2, 2023, Page No. 45-49

3D Printing in digital dentistry: An overview

Sarmistha Sritam
Department of Periodontology, Shree Siddharth Dental College, Tumkur, Karnataka, India

Abstract
3D printing technologies are advanced manufacturing technologies based on computer-aided design and digital models to create personalized 3D objects automatically. It is the newest technology and has become a fixture in dental practices all over the world. 3D printing in dentistry creates dental parts for use of patients. These parts range from models of teeth to dental aligners to full sets of dentures also. The 3D printing technologies have the advantages of manufacturing a single complex geometry. Dental 3D printing makes use of all types of additive manufacturing technology, including stereolithography (SLA), digital-light processing (DLP), and selective laser sintering (SLS). It not only makes the process easier for dental providers but also gives significant benefits to patients in affordable dental solutions. This article covers the basic history of 3D printing, its benefits and applications.

Keywords: 3D Printing, dentistry, implant

Introduction

The term 3D printing is used to describe a manufacturing approach that builds objects one layer at a time and adding multiple layers to form an object. This process is more correctly described as manufacturing additive (MA), and is also referred to as rapid prototyping. [1, 2].

Charles Hull introduced the first three-dimensional (3D) printing technology in 1986, and it has been further developed many different manufacturing technologies, which have been applied to variuos fields [3-6]. Hull patented stereolithography (SLA) in 1986 and developed a 3D printing system. In 1990, Scott Crump received a patent for Fused Deposition Modelling (FDM) [7]. It is based on computer-aided design (CAD) digital models, using standardized materials to create personalized 3D objects through specific automatic processes [4, 9, 10]. It is used for rapid prototyping, which has been widely used in industry, design, engineering, and manufacturing fields for nearly 30 years. In the field of dentistry, its applications range from prosthodontics, oral and maxillofacial surgery, oral implantology to orthodontics, endodontics, and periodontology [12, 13]. Compared with traditional wax loss technology and subtraction computer numerical control methods, 3D printing has advantages in process engineering [14]. Owing to its rapid production, high precision, and personal customization, complete dentures, and implant teeth are easier to obtain [15].

3D printing has been hailed as a disruptive technology which will change manufacturing. Used in aerospace, defence, art and design. 3D printing is becoming a subject of great interest in surgery. This technology has a particular resonance with dentistry, and with advances in 3D imaging and modelling technologies such as cone beam computed tomography and intraoral scanning, and with the relatively long history of the use of CAD CAM technologies in dentistry, it will become an increasing importance. Uses of 3D printing include the production of drill guides for dental implants, the production of physical models for prosthodontics, orthodontics and surgery, the manufacture of dental, cranio-maxillofacial and orthopaedic implants, and the fabrication of copings and frameworks for implant and dental restorations.

In last decade, 3D printing technology has become more attainable for clinical practitioners and has allowed them to deliver more accurate, cost effective and efficient treatments in particular time to the patients [16-18]. This revolutionary modality of 3D printing allow to fabricate the working models, surgical guides for implant, prosthodontic restorations, maxillofacial prostheses and orthodontic appliances [19-21]. The foundation to 3D printing technology is the data acquired from intraoral optical scanners (IOS) and cone beam computed tomography (CBCT) images [22]. These data is then converted into standard tessellation language (STL) where it can be uploaded to 3D modelling software to be manipulated to meet the clinical practitioners' manufacturing needs. The most common types of 3D printing technology in dentistry are stereolithography (SLA), digital light processing (DLP), and material jetting (MJ) [23-24]. These machines use additive manufacturing techniques to generate a product on top of the printer's build platform. The capabilities to produce various material types such as ceramic, metal, or thermoplastic resin. Once manufacturing is complete, post-manufacturing procedures are conducted to ensure the product is free of imperfections and properly cured. It may be noted that the accuracy and precision of each printer type depends highly on 3D printer quality, technology, the materials used, software settings, and the post manufacturing refinement process.

3D Printing in Dentistry

To create dental parts such as aligners, dentures, and crowns, 3D printing is used as additive manufacturing. Customized parts being created that match a patient's anatomy. A tool called as intraoral scanner is being used by the dental practitioners. This creates images of a patient's teeth and records them in the form of a CAD file. Dentists then use this CAD file to create implants or dental moulds through 3D printing. 3D printing has significantly simplified and improved the treatment of patients.

Common uses of 3D printing in dentistry

1. **Implants**: 3D printers with high resolutions and printing accuracy (e.g., SLA and DLP printers) are exceptional at printing complex geometries like those associated with teeth. 3D-printed implants are biocompatible and have similar mechanical properties to human teeth. Additionally, maxillofacial dental implants can be 3D-printed as well. Maxillofacial dentistry is a specialized branch of oral surgery performed to correct injuries and defects of the jaws and mouth.

2. **Crowns and Bridges:** Dental 3D printers can create precise crowns and bridges of both fixed and removable varieties. Burn-out resins can be printed to complete a lost-wax casting of a tooth. Patterns and geometries for casting are printed based on the results of an intraoral scanner. Dentists can then use these 3D printed patterns, burn them away, and be left with a cavity to be filled with resin. 3D printing has significantly improved the process to make crowns and bridges.

3. **Surgical Guides:** Dentists can use 3D printers to create surgical guides for drilling and cutting. These guides assist dentists to make surgery easier.

4. **Anatomical Replicas and Models:** Accurate anatomical replicas of a patient's mouth and jaws can be made with 3D printing. This gives the dentist a tangible model that can be seen and touched to better understand a patient's anatomy before beginning treatment.

Different types of 3D printing techniques

Stereolithography (SLA): The most widely utilized and oldest 3D printing technique in dentistry is SLA. These printers use an ultraviolet (UV) laser to cure a liquid photopolymer resin into layers. Liquid resin is held in a vat while the laser polymerizes each layer of the resin it contacts. Following the curing of a single layer, the build platform descends, and subsequent layers of resin are cured on top of each other. After fabrication is complete, the product must be refined of excess resin, support struts, then hardened in an UV oven or solvent bath. Advantages to SLA printing include its production speed, high resolution, relatively low cost to other 3D printer types, and ability to construct intricate designs. High end SLA printers have the ability to produce orthodontic aligners, surgical guides, splints, occlusal guards, complete dentures, temporary and permanent crowns. The ability of SLA printers is to produce a wide array of products with highly accurate results makes them the most popular 3D printer in the field of dentistry.

Digital Light Projector (DLP): Another printing method is DLP technology which shares the same curing, polymerization, and build-up techniques but varies in light source; DLP printers use a digital projector. Digital projectors allow for a complete polymerization of a material layer in the x-y axis at once making this a significantly faster fabrication method when printing on a large scale. The speed experienced on DLP large scale printing jobs is traded for a decrease in resolution and surface detailing, but when build volume is reduced resolution and surface detailing is restored. However, digital projector light sources are prone to creating voxel lines on products. These lines produce small rectangular steps and affect the formation of curved edges. Refinement of voxels in needed by post-manufacturing modification or fusing/ detailing agents to get well defined surface details. Post manufacturing modification is mainly carried out by sandblasting while fusing/detailing agents are specific liquids used to fuse/melt voxels together, both result in a more desired surface finish. Even with this drawback, very good feature resolution down to several micrometers can be attained on small-scale DLP printing jobs making them ideal for products that require extreme accuracy. DLP printers have the capability to achieving this accuracy on complete and partial dentures, thermoform models, surgical guides, single and multi-unit wax-ups. This accuracy, volume, and speed come at a cost, generally DLP printers are more costly than their SLA counterparts.

Material Jetting (MJ): A new method of 3D printing i.e.; material jetting (MJ) has been growing in popularity for its superior production capabilities. MJ is a process similar to the one found in household ink printers. Light sensitive polymer is jetted onto the printers build platform through the printer's nozzle and then cured via UV light one layer at a time. MJ printers are able to construct products with equal accuracy to SLA and small batch DLP printers without the need of post manufacturing modifications. Another unique feature to these printers is their ability to print multiple materials during a single print cycle. These materials can vary in color, biomechanical properties, and textures making them highly versatile and particularly attractive for their potential application in esthetically complex cases. This makes MJ printing favored for the production of crown, multi-unit prostheses, implant models, surgical guides, removable partial dentures and various orthodontic appliances. These printers tend to be large in size and utilize proprietary blends of materials making them less optimal to fabricate a wide range of products and increase production costs. It can be expected that as the field of 3D printing and material jetting advances that more materials will be available for practitioners, strengthening this techniques appeal to the dental marketplace.

Applications of 3D Printing in Dentistry

There are many applications of 3D printing in the field of dentistry. 3D printing in dentistry is gaining popularity now a days as a new technology which brings wide-range of benefits to dentistry. The major application of 3D printing in dentistry are:

1. 3D scanning used in 3D printing

It is the first step in the digital workflow. With the help of a 3D scanner, the inside of the patient's mouth is scanned, so that a digital model file is created, and finally exported in STL and other formats for 3D printing.

2. Crowns and bridges used in 3D printing

Crowns and bridges are the most common products in dental treatment because they are used to replace missing teeth. Crowns are used to cover damaged or decayed teeth, and bridges are used to replace missing teeth and consist of two crowns (one at each end) and some false bridges. Resin 3D printing can be used to make temporary, high-precision, and beautiful 3D printed crowns and bridges.

3. 3D printing is used in aligners and retainers
3D printing is producing highly customized and printed retainers or aligners that can be used to move a patient's teeth.

4. 3D printing is used in implants
Whenever we lose a tooth, it needs to be treated quickly with implants, otherwise the area around the missing tooth will regress from insufficient pressure. With the help of 3D printing, implants in the dental field can not only be produced on demand, faster, but also can be personalized, which is especially important in dental care.

5. 3D printing is used in anatomical replicas and models
The anatomical model of the jaw or mouth which are used in planning and discussing surgical procedures can be provided with detailed images of the desired area and are ideal for presentations and training with a low risk of operator error when 3D printing is used.

6. 3D printing in dental is used in dentures
Dentures are traditionally made by milling through a resin base, which is complex, time-consuming and requires multiple visits to the dentist. With the use of 3D printing to produce dentures is an emerging technology that has the advantage of streamlining the process with faster and cheaper.

7. 3D printing in dental is used in casting models
Dental cast models are exact 3D replicas of a patient's teeth and are used not only to study the mouth, but also to make crowns, fixed bridges and dentures. With 3D scanning and printing, the process is simplified to create a high-precision mould by printing, cleaning, removing supports, sintering, etc. to get the final product.

Advantages of 3D printing adoption in dentistry
1. Cost efficiency
3D printers simplify workflows, reduce room for error, as well as the amount of labour required, which provides time and cost savings for the dental practitioners, laboratory technicians and patients. A 3D printer does not require specialist staff involvement or additional training which makes it a more cost-efficient way to produce dental appliances. Also 3D printers can allow a better quality of production than manual methods.

2. Speed
A 3D printer allows to create appliances such as surgical guides and splints in house without the need to send impressions off to a laboratory and wait for them to be produced and delivered. In addition, with 3D printers, the appliances are much quicker to produce, and more than one can be produced at a time, which means less waiting time for patients. With 3D printing workflows in place, the scan of the patient's mouth can be sent to the laboratory within minutes, making production much quicker.

3. Usability
3D printing technology has now developed with more automation making the printers easy to use with no requirement of specialized training. Present 3D printing with end to end solution provides automated post-processing which reduces handling time, allows delegation and maximizes productivity. All of these features facilitate for an easy-to-use system which can help to streamline workflows.

4. Accessibility and integration
3D printers can be utilized for a wide range of purposes within dentistry. An increasing elderly generation and more patients are taking care of their dental health. The cosmetic treatments are rising in popularity too. The dentists who can provide a better service with more accurate and less chair time will sit ahead of their competitors in the future. Dentists and lab technicians, who implement digital workflows are better equipped to meet patient expectations and attract new patients in the future.

5. Material innovations and new applications
The number of advanced materials available for 3D printing is growing and, thus, the range of printable dental appliances is also growing. 3D printing in dentistry can already be used to create models, guides and splints but, as materials develop, so will the range of appliances that can be 3D printed with more services offering in the future. Alongwith the materials, 3D printing is being developed with new features and applications by adding the software and hardware. 3D printing is a market that is continually developing and can be easily integrated into the workflows of any dental practice or laboratory.

6. Digital workflows
3D printers are having features within digital dentistry. It is a part of a digital workflow that takes advantage of other pieces of hardware and software. 3D printing allows more to incorporate digital workflows and provide a faster, more accurate and more efficient patient service.

7. Chairside 3D Printing
Chairside 3D printing has now become a viable alternative in dental clinics as opposed to outsourcing work to a dental lab. As options for 3D printers range from large-scale industrial printers to smaller desktop printers, chairside 3D printing allows for same-day production of dental restorations thus eliminating the need for multiple appointments and reducing patient wait times.

8. Customized Dental Implants
Using patient-specific data, 3D printers allow for the creation of highly customized implants. The production of these dental implants means that they perfectly fit a patient's anatomy, can accurately replicate the patient's teeth, and improve implant placement and better patient comfort and clinical outcomes.

9. Surgical Guides
3D Printer can be a surgical guides during implant placements, jaw surgeries and other complex dental procedures. Much like customized dental implants, these surgical guides are designed using patient-specific data and allow for precise and minimally invasive surgical procedures, reducing risks and improving outcomes.

10. Digital Dentures
Advancements in 3D printing have led to create dentures digitally. Digital dentures are created using scans of a patient's mouth, where this data is used to design the

denture and then 3D printed. As a more accurate, comfortable and efficient alternative compared to conventional dentures, improvements to patient care and comfort, faster turn-around times and improved clinical outcomes are the benefits to this custom development.

11. Digital Wax-Ups

The usual method of traditional wax-up restorations used for prosthodontic treatments can be done digitally. Digital wax-ups can now replace traditional wax-ups using 3D printing to be more accurate, faster and cost-effective, allowing for better communication between dental laboratories and clinicians.

12. Dental Education and Training

Dental colleges and training institutes have started to incorporate 3D printing into their curriculum to prepare future dental professionals for the future of digital dentistry.

Following table can give basic idea of application and advantage of 3D printing.

Table 1

Field	Application	Advantage
Prosthodontics	Crown and bridge dentures	Reducing time consumption
		Good fit
	Complete dentures	Good detail reproducible properties
		Low costs
		Convenient and fast
	Removable partial denture frameworks	Accurate
		Close adaptability
		Uniform contact pressure
		Good mechanical properties
Oral and maxillofacial surgery	Occlusal splints	Saving time and cost
		High mechanical strength
	Surgical implants	Adjustable porosity
		Convenient and fast
	Prostheses	Accurate
		Improving integrity and aesthetics
	Working models	Reducing operative time and risk
Oral implantology	Surgical guides	Reducing operation errors
		Simple operation
	Custom trays	High efficiency
		High accuracy
Orthodontics	Working models	Good surface quality
		Light
		High wear resistance

Conclusion

The possibilities with 3D printing in dentistry are endless. Dental practitioners now have only realized the true potential that 3D printing provides the field of dentistry. In the coming years it can be expected that there will be a shift from the long-standing subtractive manufacturing methods of product milling to additive 3D printing techniques. New techniques and materials of 3D printing are entering the dental manufacturing market regularly. Although equipment, materials and services differ with 3D printing technologies, new and innovative applications of 3D printing in dentistry still have room for further exploration. Practitioners should be aware of the limitations of this technology to models, provisional restorations, and basic orthodontic appliances etc. In future, 3D printing technology will be used for a wide array of dental restorations. The development of new materials and technologies will be the future trend of 3D printing in dentistry, and there is no denying that 3D printing will have a bright future.

References

1. AndonoviĆ V, Vrtanoski G. Growing rapid prototyping as a technology in dental medicine. Mech Eng Sci J,2010:29: 31–39.
2. Liu Q, Leu MC, Schmitt SM. Rapid prototyping in dentistry: technology and application. Int J Adv Manuf Technol,2006:29:317–335.
3. Barazanchi A, Li KC, Al-Amleh B, Lyons K, Waddell JN. Additive technology: update on current materials and applications in dentistry, Journal of Prosthodontics,2017:26(2):156–163.
4. Vukicevic M, Mosadegh B, Min JK, Little SH, Cardiac 3D printing and its future directions," JACC: Cardiovascular Imaging,2017:10(2):171–184.
5. Farooqi KM, Sengupta PP. Echocardiography and three-dimensional printing: sound ideas to touch a heart," Journal of the American Society of Echocardiography,2015:28(4):398–403.
6. Mai HN, KB Lee, Lee DH. Fit of interim crowns fabricated using photopolymer-jetting 3D printing," The Journal of Prosthetic Dentistry,2017:118(2):208–215.
7. Gross BC, Erkal JL, Lockwood SY, Chen C, Spence MD. Evaluation of 3D printing and its potential impact on biotechnology and the chemical sciences," Analytical Chemistry,2014:86(7):3240–3253.
8. Lukić M, Clarke J, Tuck C, Whittow W, Wells G. Printability of elastomer latex for additive manufacturing or 3D printing," Journal of Applied Polymer Science,2016:133(4):42931.
9. Lin L, Fang Y, Liao Y, Chen G, Gao C, Zhu P. 3D printing and digital processing techniques in dentistry: a review of literature," Advanced Engineering Materials,2019:21(6):1801013.
10. Alharbi N, Alharbi S, Cuijpers V, Osman RB, Wismeijer D. Three-dimensional evaluation of marginal and internal fit of 3D-printed interim restorations fabricated on different finish line designs," Journal of Prosthodontic Research,2018:62(2):218–226.
11. Lin HH, Lonic D, Lo LJ. 3D printing in orthognathic surgery − a literature review," Journal of the Formosan Medical Association,2018:117(7):547–558.
12. Oberoi G, Nitsch S, Edelmayer M, Janjić K, Müller AS, Agis H. 3D printing-encompassing the facets of dentistry," Frontiers in bioengineering and biotechnology,2018:6:172.
13. Prechtel A, Reymus M, Edelhoff D, Hickel R, Stawarczyk B. Comparison of various 3D printed and milled PAEK materials: effect of printing direction and artificial aging on Martens parameters, Dental Materials,2020:36(2):197–209.

14. Revilla-Leon M, Sadeghpour M, Ozcan M. An update on applications of 3D printing technologies used for processing polymers used in implant dentistry," Odontology,2020:108(3):331–338.
15. Zanetti EM, Aldieri A, Terzini M, Calì M, Franceschini G, Bignardi C. Additively manufactured custom loadbearing implantable devices," Australasian Medical Journal,2017:10(8):694–700.
16. Kessler A, Hickel R, Reymus M. 3D printing in dentistry-state of the art. Operat Dent,2020:45:30e40.
17. Cousley RR. Introducing 3D printing in your orthodontic practice. J Orthod,2020:47:265e72.
18. Unsal GS, Turkyilmaz I. Improved reconstruction of an implantretained auricular prosthesis using CAD/CAM technology. J Dent Sci,2019:14:328e9.
19. Yoo SY, Kim SK, Heo SJ, Koak JY, Kim JG. Dimensional accuracy of dental models for three-unit prostheses fabricated by various 3D printing technologies. Materials (Basel),2021:14:1550.
20. Sherwood RG, Murphy N, Kearns G, Barry C. The use of 3D printing technology in the creation of patient-specific facial prostheses. Ir J Med Sci,2020:189:1215e21.
21. McCarty MC, Chen SJ, English JD, Kasper F. Effect of print orientation and duration of ultraviolet curing on the dimensional accuracy of a 3-dimensionally printed orthodontic clear aligner design. Am J Orthod Dentofacial Orthop,2020:158: 889e97.
22. Turkyilmaz I, Lakhia S, Tarrida LG, Varvara G. The battle of file formats from intraoral optical scanners. Int J Prosthodont,2020:33:369e71.
23. Unkovskiy A, Schmidt F, Beuer F, Li P, Spintzyk S, Kraemer Fernandez P. Stereolithography vs. direct light processing for rapid manufacturing of complete denture bases: an *In vitro* accuracy analysis. J Clin Med,2021:10:1070.
24. Turkyilmaz I. Restoring edentulous mandible with an implantretained overdenture in a day by means of flapless surgery and stereolithographic surgical guide: a case report. J Oral Maxillofac Res,2019:10:e5.