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Review Article

3D Printing in Dentistry – An Overview

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Abstract

3D Printing technique is an innovative technique based on an additive process. It has revolutionized dentistry, proving beneficial in surgical and restorative dentistry; and continues to expand its applications in research and dental education. The key to its success lies in the fact that various materials such as, metal, resin, plastic etc. can be used in this technique; thereby, enabling its usage in most fields of dentistry.

The desired object is either scanned by a 3D Scanner or built using a CAD software. Depending on the material of choice various printing methods are available; such as, stereolithography, DMLS etc. Although it requires investment and skills, the advantage of 3D printing lies in its reproducibility, accuracy and ability to create complex parts with ease. It enables to provide a holistic approach to improve health and wellbeing of patients.

Keywords: Digital Dentistry; 3D Printing

Abbreviations

CAD/CAM: Computer-Aided Design and Computer-Aided Manufacturing; 3D: 3-Dimesnsional; DLP: Digital Light Processing; UV: Ultraviolet; SLS: Selective Laser Sintering; BMP: Bone Morphogenic Protein; CT: Computed Tomography; TMJ: Temporomandibular Joint.

Introduction

The origin of dentistry, which is one of the oldest known medical professions, dates back to 5000BC [1], where dental decay was described as "tooth worms". Over the years and centuries, dentistry has evolved and developed; thereby, greatly influencing the health and personal wellbeing for patients; be it for cosmetic or functional reasons.

Since evolution is a constant process, even modern dentistry continues to grow and evolve with the introduction of digital dentistry about few decades ago. The first 3D object was printed by Charles Hull in 1983 using stereolithography [2]. Although digital dentistry was introduced by Francois Duret in 1970s [3], it was not easily welcomed and took it's time to integrate into the current practices [4].

3D Printing is an additive process, also referred to as rapid prototyping; where a lot of thin layers of a given material are added in order to build a three-dimensional object [5]. In contrast, traditional processes remove material in order to achieve the same.

The descriptive data required for printing has to be obtained from a 3D file; which can be created by using a 3D Modelling Software, or by scanning an object that already exists. A large variety of softwares are available for the same, depending on the requirement of use, such as: individual or industrial [5]. For example, most surgical dental procedures require 3D Cone Beam Imaging to gather data and allow printing of desired information. However, small restorations and removable prosthodontics require just a 3D Scan of the mouth to allow for printing of desired models, restorations etc.

There are 3 basic steps in 3D printing technique [5].

The first step is to design a 3D file of the object by using a CAD software, with a 3D scanner.

The second step is the actual printing process. The material that will be used for printing is chosen according to requirement. A variety of materials used in dentistry include plastics, ceramics, resins and metals [5]. Most of these materials allow for plenty of finishing options, thus enabling achievement of a precise design. However, certain materials are still under development.

The third and final finishing process requires specific skills and materials.

Materials used

According to the material chosen, the printing methods are decided. The most commonly used techniques for each group of materials are described in brief.

Plastic or Alumide

- **Fused Deposition Modeling (FDM):** It is probably the most popular and affordable printing method. In this process the material is melted and extruded through a nozzle to 3D print a cross section of an object each layer at a time, building them from bottom to top [2,5].
- **Selective Laser Sintering (SLS):** It fabricates an object by melting successive layers of powder together; thereby facilitating creation of complex and interlocking forms [5].

Resin or Wax

The main principle in using resin or wax material is photopolymerisation, where photo-sensitive resin is solidified by means of a light source. It is used by different 3D printing processes such as:

- **Stereolithography (SLA):** Uses a vat of UV light curable photopolymer resin or photosensitive monomer resin [2,5]. It was the first commercially available printer for rapid prototyping, developed by Charles Hull in 1983 [2]. It is one of the most popular rapid prototyping method used.
- Digital Light Processing (DLP) uses a safelight (light bulb) projector to cure photopolymer resin. The layer is created upside down [2,5]. After construction of the desired object, the residual liquid polymer is drained [2]. DLP along with lost-wax casting technique is used to melt the wax and create the object in desired material of choice [5].
- **Continuous Liquid Interface Production (CLIP):** Projects a continuous sequence of UV images, generated by a digital light projector, through an oxygen-permeable, UV-transparent window below a liquid resin bath [5]. The dead zone created above the window maintains a liquid interface below the part. Above the dead zone, the curing part is drawn out of the resin bath [5].
- **MultiJet printers:** Are similar to Stereolithography. Polyjet and Multijet 3D Printing use a UV light to crosslink a photopolymer. A printer jet sprays tiny droplets of the photopolymer in the shape of the first layer. The UV lamp attached to the printer head crosslinks the polymer [5]. The build platform then descends by one layer thickness, and more material is deposited directly onto the previous layer [5].

Metal

- **DLP** combined with the lost-wax casting technique allows objects to be printed in metal of choice [2].
- **Direct Metal Laser Sintering (DMLS)** was developed by German company EOS [5]. It is similar to SLS and uses a laser as a power source to sinter metal powder by aiming a laser and tracing a cross section of the object layer by layer. The major difference is the sintering temperature. Polyamide in SLS needs to be sintered at a temperature of 160°C to 200°C, whereas more high-wattage laser is needed for metal as it melts at a temperature between 1510°C and 1600°C; [5]. Various metals, like stainless steel, Titanium, Chrome-Cobalt use this technique in dentistry for fabrication [5].
- **Electron Beam Melting (EBM)** uses an electron beam as the power source instead of a laser to melt metal powder layer by layer within a high vacuum; thus producing high-density metal parts and retaining the material's properties [5]. It can achieve full melting of the metal powder [5].

Applications in dentistry

3D printing is an innovative technology, with limitless applications. Its uniqueness lies in its ability to be adapted for usage in various fields of life, be it: education, construction, aeronautics, drones, food industry, healthcare, automotive, textile industry, robotics, electronics, entertainment, to name a few [5].

The application of 3D Printing in dentistry too is very vast and not restricted to a single procedure.

3D Printer	Materials	Potential dental application
Fused Deposition Modeling (FDM)	Thermoplastic polymers such as polylactic acid (PLA), acrylonitrile butadiene styrene (ABS), polycarbonate (PC), polyether ether ketone (PEEK), etc.	In-house production of basic proof-of-concept models, low-cost prototyping of simple anatomical parts
Stereolithography (SLA)	A variety of resins for photopolymerization, ceramic filled resins, etc.	Dental models, surgical guides and splints, orthodontic devices (aligners and retainers), castable crowns, and bridges.
Selective Laser Sintering (SLS)	Powder such as alumide, polyamide, glass-particle filled polyamide, rubber-like polyurethane, etc.	Metal Crowns, copings and bridges, metal or resin partial denture frameworks
Polyjet printing	A variety of photopolymers	Manufacturing of craniomaxillofacial implants, sophisticated anatomical models, drilling and cutting guides, facial prosthesis
Bioprinter	Cell-loaded gels and inks based on collagen, photopolymer resins, agarose, alginate, hyaluronan, chitosan, etc.	Cell-laden scaffolds for hard and soft tissue printing

Table 1: Different 3D printers and their dental applications [6].

A brief mention of the various applications of 3D printing in Dentistry is given below.

Oral and maxillofacial surgery and implantology

3D Imaging using computed tomography (CT) scans enable us to fabricate a 3D anatomical model by rapid prototyping, aiding in diagnosis and treatment planning [2,6,7]. The 3D printed model enables the surgeons to view, acquaint as well as feel the concerned area before surgery; thereby providing a "touch to comprehend" for surgeons [2,8].

The anatomical models printed also aid in designing of surgical guides and templates during craniofacial surgeries [2,6]. The CT image obtained with the help of commercial softwares enable fabrication of digitally planned and printed surgical guides with less defects and precise margins. It helps in transfer of planned procedure with more precision and efficiency.

Congenital or acquired maxillofacial defects can be restored more efficiently using 3D printing [2,6,13-15]. A simulated model of final treatment outcome can also be printed to help enable patients understand and visualize the expected treatment outcome, providing better information and realistic expectations for the patients undergoing maxillofacial reconstructions [6].

Orthognathic surgeries also benefit by fabrication of personalized orthognathic surgical guide (POSG) system [6,16]. This system uses a computer software to predetermine positioning of bone elements, drill holes for screws and surgical aids. The custom titanium plates can be placed if the bone segments are in the exact position; thereby eliminating error of autorotation of temporomandibular joint that normally occurs in orthognathic surgeries.

3D Printed allogenic bone graft blocks can be used to augment bone defects in reconstructive surgeries. The advantage of these grafts are that they are patient specific and lack ethical, cross contamination and donor site morbidity issues [6]. However, they lack osteogenic and osteoinductive potential. With current advances, it is possible to print patient specific bone tissue, which can act as biomimetic scaffold for bone cell growth and differentiation [2,6,9]. Calcium phosphate powders can be mixed with calcium sulphate based 3D printing powders and these scaffolds can be used as bone augmentation material [2,6,10,11]. Currently there is capability to add osteoinductive factors like BMPs to stimulate osteogenic differentiation; thereby enhancing osseointegration by better cell adhesion, proliferation, and vascularization [6,12]. Research has allowed even printing of cartilages and blood cells [2,10,17]. However, these researches have no documented long term follow-up studies to evaluate healing process, osseointegration and viability.

3D printed models also help in fabrication of customized surgical guides that help in implant placement. Currently there are commercial systems available that use a 3D CT Scan of patient to help in placement of implants for full mouth rehabilitation. These systems enable fabrication of surgical guides aiding in providing the exact location, size and angulation of implants [18]. Fabrication of customized implants and abutments is also possible using rapid prototyping [2,6,19,20,21].

3D printed models of jaws and other structures also aid as an educational tool for students in the field of oral surgery [2,6]. It enables ability to visualize anatomy and provides for a 3D spatial orientation of the various anatomical structures.

Restorative dentistry

Restorative dentistry is another branch of dentistry that has greatly benefitted from 3D printing technology. The use of 3D printing is as widespread as the techniques and steps involved in restorative dentistry. From fabrication of impression trays to final restoration, 3D printing offers an opportunity for its usage.

3D scanning of the mouth can be done to obtain the desired information. Various softwares are currently available in the market that enables the same. This data is then utilized for the required procedure.

3d printed custom trays can be made easily available which reduce errors and provide better fit and even space enhancing the quality of the final impression. Use of 3D scanners to record oral mucosa, teeth and adjacent structures is also beneficial in patients who suffer from severe gag reflex, have TMJ disorders, limited mouth opening or oral defects; especially with surgically resected oral structures; as more time, effort and skill is required in order to obtain accurate impressions [6]. 3D printed models can also be made from 3D scans, which aid in fabrication of conventional prostheses for such patients. Current softwares enable fabrication of the prostheses from the 3D scanned data itself, thereby eliminating human error and producing more accurate final results.

Rapid prototyping can thus be used in fabrication of both fixed and removable prostheses. Fabrication of complete and partial acrylic dentures can be done in desired material of choice, be it acrylic resin or metal frameworks [22,23]. Prepolymerized acrylic resin with denture teeth blocks can be used for fabrication of complete dentures, with an advantage of reduction in polymerization shrinkage and tooth fractures [22]. CAD/CAM manufactured prostheses also provide a better adaptation to the tissue surfaces; enhancing the stability, support and retention of the prostheses. The drawback is the difficulty in jaw relations, lip support assessment and limited occlusion schemes with the systems; which can be overcome by using a combination of conventional and digital procedures [22].

Fabrication of chrome-cobalt dentures can also be done using rapid prototyping [24]. The dentures fabricated thus are better fitting with more accuracy as mentioned before. It is especially useful in hybrid dentures with precision attachments, where parallelism of male and female components can be achieved with ease, greater precision and reduction of errors.

Usage of 3D printing in fixed prosthodontics has also been explored, be it in the fabrication of interim or final restorations. Interim restorations can be fabricated using PEEK material. However, final restorations can be made using metal or ceramics. Fabrication of Inlays [25], Onlays [25], Crowns [25], Copings, Bridges, Bridge Frameworks, Implant retained prosthesis has been done using rapid prototyping. The restorations can either be milled from the 3D scan taken from the patient's mouth, or they can be conventionally fabricated with the data by making of a 3D fabricated model. The restorations fabricated using rapid prototyping have the advantage of reduction in patient chairside appointments and accuracy and precision of fit. However, CAD/CAM ceramic restorations still need to improve in strength and fracture toughness, and research is still underway to improve the strength of these materials.

CAD/CAM Zirconia blocks come in a partially sintered state, which are milled to custom fit the patients and then further sintered to achieve more density, thereby enhancing their physical properties. This process of sintering is time consuming, and current speed fire furnaces are available that help in reduction of time required to achieve the same. Another drawback of zirconia blocks is the lack of esthetics that glass and feldspathic ceramics provide. Research is also undergoing to fabricate newer blocks with a mix of both zirconia and glass ceramics; in order to profit from the advantages of both materials; strength and esthetics to restore anterior teeth.

Orthodontics

Normando., *et al*. in 2014 introduced 3D Face Scans and printing to make anatomically correct and precise dental arches and orthodontic brackets [26]. With the help of these scans and softwares, it is possible to make models to show patient changes anticipated post treatment in advance [6,27].

Orthodontics mainly benefits from 3D printing by production of orthodontic aligners. Unlike conventional fixed orthodontic treatment, these aligners are removable; where patient compliance plays a major role in treatment outcome and predictability. Another limitation of these aligners is their inability to correct major malaligned teeth. Their main advantage lies in reduction of clinical visits and reduction in chairside appointments. 3D printed aligners mainly find application in minor malalignments or for post-orthodontic treatment. Indirect bonding and clear aligners {Invisalign®, 3Shape} are based of this technology [6,28,29].

Splint therapy in TMJ disorders also benefits from rapid prototyping by manufacturing of customized splints [6,30,31]. These splints save time required for laboratory work, are more precise and reduce manual errors in fabrication.

Another aspect of orthodontics that benefits from 3D printing is the fabrication of 3D printed brackets. These brackets are custom built and tailored to individual tooth surfaces. They can be accurately positioned using 3D printed guides [6,27].

Rapid prototyping also enables fabrication of various orthodontic devices such as mouth guards, retainers, expanders, sleep apnoea appliances etc.; thereby providing a better intraoral adaptation [6,32,33].

Endodontics

Endodontics too benefits from 3D printing technology; in the fabrication of precise guides for application in surgical as well as nonsurgical endodontic procedures. 3D printed surgical guides help in a guided apicoectomy procedure. Guides in nonsurgical endodontic procedures are especially beneficial for access cavity preparation in cases of calcified canals [6,34,35,36].

Use of 3D printing enables creation of tooth models with realistic anatomical root canal structures by using CT Images; thereby providing dental students an opportunity to deal with realistic procedures, rather than usage of ideal typhodont teeth [6].

Periodontics

3D printed guides are more commonly used in periodontology for esthetic gingival reconstruction [6]. Patient specific surgical guides are utilized for gingivectomy and smile designing enabling a precise and customized approach [6].

The use of 3D printing technology in Regenerative periodontology is still under research [6]. Studies are being done to evaluate the use of 3D printed biphasic scaffolds to help in tissue regeneration of defects and in healing process [6,37]. This technique is called as additive biomanufacturing [6,38]. A CT scan of the defect helps in fabrication of a wax mould; which is designed to make a scaffold that will aid in guided tissue regeneration [6,39].

Advantages

1. Time saving
2. Accurate details and reproduction of scan providing good quality of work and consistent results
3. It is possible to print complex geometric shapes and interlocking parts that require no assembly
4. Reduction of production-related material loss
5. It is possible to produce single objects, in small quantities, at low cost and fast delivery

Disadvantages

1. High investment cost
2. Likely the largest limitation of 3D printing is the final part quality. Due to the way each successive layer is deposited on top of the last in typical 3D printing methods, an inherent weakness is literally built into the design [40].
3. Finishing of final product is time consuming and requires skill [40].
4. Depending on the material, it may still need additional treatment to reach full strength. For example, Zirconia and E-max blocks used in restorative procedures require further sintering to attain high strength after the milling procedure [40].
5. Stereolithography can be done only using light curable liquid polymers [2].
6. Resin used is messy and can cause inflammation and irritation on contact and inhalation [2].
7. Resin cannot be heat sterilized [2].

Conclusion

The introduction of digital dentistry has not only made procedures less time consuming, but also simplified the approach to providing a better quality of life to the patients. Although the initial investment is high and requires training in the usage of the same, it helps to reduce the time for actual patient care. The digital technology benefits the patient by providing care from any part of the world by allowing exchange of information; and thereby improving healthcare as a whole. It blends dental and medical treatment for patients; enhancing overall patient satisfaction and life expectancy.

3D Printing provides for a better educational tool in most dental procedures, not only for practitioners, but also for dental students. It has a great potential in further research and treatment modalities. Although it is not a replacement for conventional treatment methods, its scope to improve and develop is what the future of dentistry holds.

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