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3D Printing - Revolutionizing Prosthodontics: A Review

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Abstract

With the evolution of technology, three-dimensional (3D) printing has revolutionized the process of manufacturing leading to a future comprising of absolute digitalization. Three-dimensional (3D) printing has become the latest innovation with its modern technology giving an insight to a bright future ahead. Digital technology and 3D printing have significantly elevated the rate of success in today’s dental practice by improving the quality and accuracy of dental work. 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. Therefore, this article will give an insight on how 3D printing works and its applications in prosthodontics with its future vision.

Keywords: 3D Printing, CAD/CAM, rapid prototyping, applications, prosthodontics, advances.

Introduction

Over the years dentistry has evolved and developed thereby, greatly influencing the health and personal well-being for patients; be it for cosmetic or functional reasons.[1] As evolution is a constant process, even modern dentistry continues to grow and evolve with the introduction of digital dentistry. Although Digital dentistry was introduced by Francois Duret in 1970s [2],it was not easily welcomed and took it’s time to integrate into the current practices.[3] In 1983, Charles Hull printed for the first time a three-dimensional object and also created the first 3D printer that used the technique of stereolithography as well as the first program for virtualization.[4]

The term 3D printing is used to describe a manufacturing approach that builds an object by incremental deposition of material layer over layer.[5] This process is correctly described as additive manufacturing and also referred to as Rapid Prototyping.[6] It's an innovative method over the other manufacturing technologies as it doesnot waste the material out to form an object.[7]

Initially, the technique received high attention in fields of architecture & aeronautics due to the increased potential in the direct construction of structures and various small parts used in spacecraft construction and telecommunications domain.[8] But later incorporation of 3D printing in clinical dentistry has expanded the possibilities of treatments in different branches of dentistry such as in oral surgeries, maxillofacial prosthesis, prosthodontics and dental implantology.[9,10] Moreover, 3D printing is also used in dental research through the fabrication of low-volume molds and adapters using different materials with precise dimensions.[11] Most surgical dental procedures require 3D Cone Beam Imaging to gather data and allow printing of desired information. However, in prosthetic treatments computerized scanning systems and 3D printing systems have come largely to replace traditional techniques for producing prosthetic works.[12,13].

3D modeling technologies are developing due to the increased popularity of 3D printers.[14] These manufacturing techniques provides dimensional printing that offers the possibility to produce a variety of geometrical pieces using various materials in the form of powder and binder.[15] Thus, this article sets out to explore various 3D-printing technologies and all of their possible applications in contemporary dental practice.

3D Printing Technology: The Process

3D printing technology firstly uses an optical camera to record a virtual impression of object by creating a three dimensional image which is forwarded to a software program. Then, a digital image of the object is sliced in the Computer Aided design (CAD) unit by a special software. The manufacturing of the 3D object/prosthesis continues with a process almost similar to printing on paper – one layer on top of another. A digital prototype of the real object is constructed and processed to the Computer Aided Manufacturing (CAM) unit ie by using a 3D Printer. This whole process is the so-called "3D-printing" (Figure 1).The data for the Computer Aided design (CAD) unit is obtained either through indirect scanning of a plaster model or through direct intraoral scanning of the prosthetic field.[16] Synonymous terms that are often used in different sources are: "layered manufacturing", "freeform fabrication","rapid-prototyping","rapid-manufacturing".[17-20]

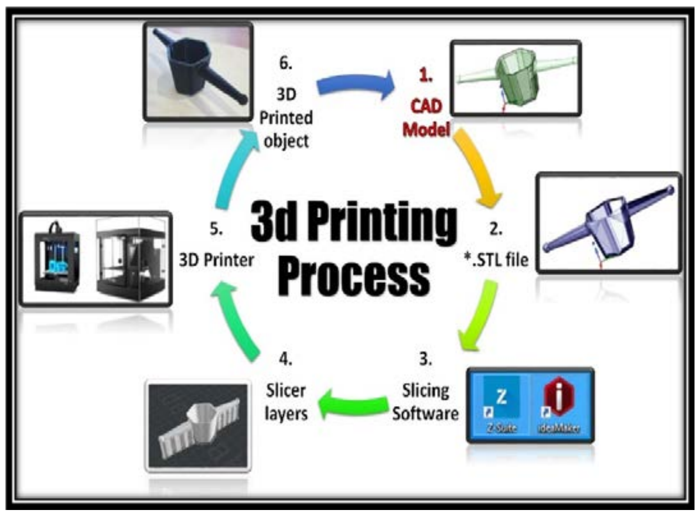

Figure 1: Diagrammatic representation showing process of 3D printing

There are two possibilities for the manufacturing of a 3D object/prosthesis in this stage – subtractive and additive technologies (Figure 2). Dentistry has a long association with subtractive manufacturing technology[21] commonly known as 'milling'. Subtractive manufacturing is the removal of material to form an object. CAD/CAM for the milling of crown copings and bridge frameworks is now synonymous with modern dental technology [22]. However, subtractive manufacturing brings with its disadvantage such as fit problems, wastage of considerable amount of raw material, excessive abrasion of milling tools, microscopic cracks into the ceramic, limitations of the precision fit of the inside contour which depends on the smallest tool of increased wastage with removal of excess material and inability of mass production.[19,23-25] On the contrary, the process of additive manufacturing works on the principle of minimal wastage. Each slice is printed one on top of the other to create the three dimensional objects. The term "additive manufacturing" is defined by the American Society for Testing and Materials (ASTM) as: "the process of joining materials to make objects from 3D model data, usually layer upon layer.[13]

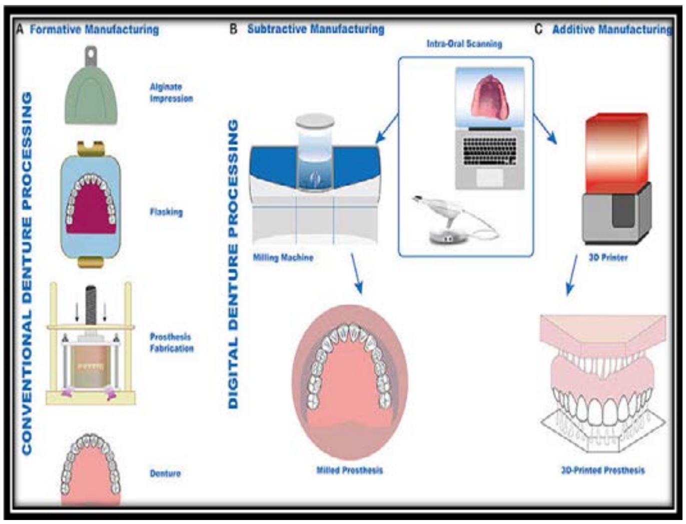

Figure 2: Figure showing difference between- Conventional and Digital prosthesis fabrication approaches.

A. Formative manufacturing: Conventional approach for denture fabrication by alginate impression and flasking method
B. Subtractive manufacturing: Digital approach with intra-oral scanning-based impression; manufacturing of denture either by CAD/CAM
C. Additive manufacturing: 3D printer

3D Printing Materials And Their Applications: An **Overview**

Currently the most frequently applied additive technologies in dentistry are Stereolithography (SLA), Inkjet-based system (3DP), Selective laser sintering (SLS) and Fused Deposition Modelling (FDM), Bioprinter mainly with different materials like wax, metal alloys, resin materials and ceramics.[20,22] Various materials used for 3DPrinting include acrylonitrile-butadiene-styrene (ABS) plastic, stereolithography materials (epoxy resins), polylactic acid (PLA),polyamide (nylon), glass-filled polyamide, silver, steel, titanium, photopolymers, wax, and polycarbonate[26]. These materials exhibit highly beneficial mechanical properties while delivering complex designs which are impossible to achieve using conventional manufacturing.3D printing technologies along with the materials they utilize in printing as well as their applications are summarized in the following table:

Table 1: Different 3D printers and their applications in dentistry[1]

S.N	3D Printing Technology	Material used	Dental application

1	Fused Deposition Modeling (FDM)	Thermoplastic polymers such as: • Polylacticacid (PLA), • Acrylonitrile butadiene styrene(ABS), • Polycarbonate (PC) • Polyether ether ketone (PEEK).	• In-house production of Models • Low cost prototyping of simple anatomical parts
2	Stereolithography (SLA)	• Resins forphotopolymerization, • ceramic filled resins, • waxes	• Dental models • Surgical guides and splints • Orthodontic devices(aligners and retainers) • Castablecrowns, and bridges.
3	Selective Laser Sintering (SLS)	Powder such as • Alumide, • Polyamide • Glass-particle filledpolyamide • Rubber-like Polyurethane	• Metal Crowns, copings and bridges • Metal or resin partialdenture frameworks
4	Polyjet printing	A variety of photopolymers	• Craniomaxillofacial implants • Anatomical models • Drilling and cutting guides • Facialprosthesis
5	Bioprinter	Cell-loaded gels and inks based on collagen,photopolymer resins.	• Scaffolds for hard and soft tissue printing

3D Printing Technologies Used In Dentistry

Stereolithography (SLA): It was the first commercially available printer for rapid prototyping developed by Charles Hull in 1983.[27] It is one of the most popular rapid prototyping method used.The principle of this technology is based on a photosensitive monomer resin which forms a polymer and solidifies when exposed to ultraviolet (UV) light.[28] The reaction created by UV light takes place only on the surface of the material.[29]The ultra violet light draws the object and cures it with the input as digital CAD..Because of the high mechanical strength of polymer resin, it is used to make implant surgical guides, obturators, surgical stents, duplication of prosthesis and burn stents. Moreover, SLA has the ability to create complex shapes of high feature resolution with lower cost materials if used in bulk.[6] Curing is affected by the power of the light source, the scanning speed, chemistry and amount of the monomer and photo initiators. The main disadvantages of SLA are the scarcity of biocompatible resins with proper SLA processing properties and its an expensive process.[30]

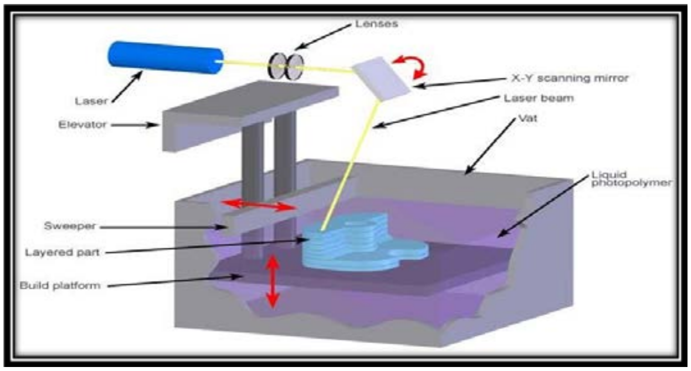

Figure 3: Process of Stereolithography (SLA)

Fused Deposition Modeling (FDM): It is probably the most popular and affordable printing method developed by Schott Crump. These printers are the most common to begin within a medical or dental set-up due to its wide availability, moderately reliable printing quality, ease of installation and most importantly economic affordability.[31] In this technology, a thermoplastic filament material is extruded through a nozzle which is controlled by temperature and the material hardens immediately (within.1 sec) after extrusion. A processor controls the nozzle head and helps in the uniform distribution of material on a platform. Its accuracy will depend upon the speed of travel of the extruder, as well as the flow of material and the size of each 'step'. Each time the melted material is extruded through a nozzle a 3D print of an object is built from bottom to top [30] (Figure 3).The 3D printers adopting this technique find the highest penetration at the domestic level; often nicknamed 'home-printers'.[6,32] But still, this technology comes with its own technical limitations which are high printing time, limited color selection, moderate printing resolution and complete removal of support material.[30]

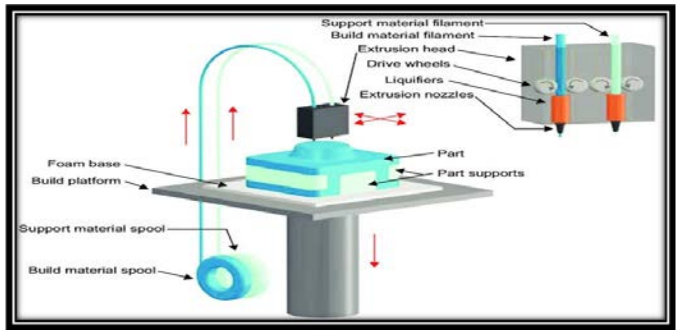

Figure 4: Process of Fused deposition modelling (FDM)

Selective Laser Sintering (SLS): As various problems were encountered during casting of alloys a new technique ie Selective laser sintering was introduced by University of Texas for fabrication of metallic frameworks.[33] This technique involves layer by layer addition of fine powder material fused by scanning laser that generates 3D pieces by strengthening selective and successive layers of powder material using heat generated by a computer-controlled laser radiation (Figure 4). As a powder bed drops down, a new fine layer of material is spread uniformly over the surface.[34-36] SLS was used for the production of facial prosthesis using polymers scaffolds (poly amide or poly caprolactone), use of steel, titanium, cobalt chromium porous mesh or dental implant.[37] The advantages of this technique includes- a high level of resolution (60μm) obtained and as the structures that are printed doesnot require a support material as it is supported by the surrounding powder. Polymers used in this process have high melting points and have excellent material properties.[38,39] Drawbacks of this technique- its expensive due to its high maintenance cost. Moreover, it also poses a health risk due to dust inhalation or accidental explosion.[40]

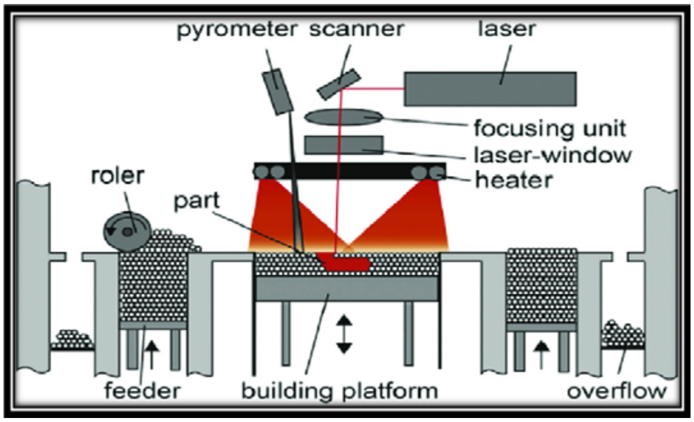

Figure 5: Process of Selective Laser Sintering (SLS)

Polyjet printing: It works on the principle of ejecting small ink drops propelled with pressure, heat and vibration towards a substrate as shown in Figure 6. Liquid droplets change their phase on deposition on a substrate by which dental models, surgical guides, try in veneers and mouth guard can be fabricated. The ink used could be a suspension of ceramic powders that is forced to pass through the nozzle. Ceramic inkjet printing has a number of advantage with minimum tooling and gives great design and fabrication flexibility.[41] Although this technique is cost-effective, it falls short on the resolution output, easiness to operate and heat sterilization.[42]

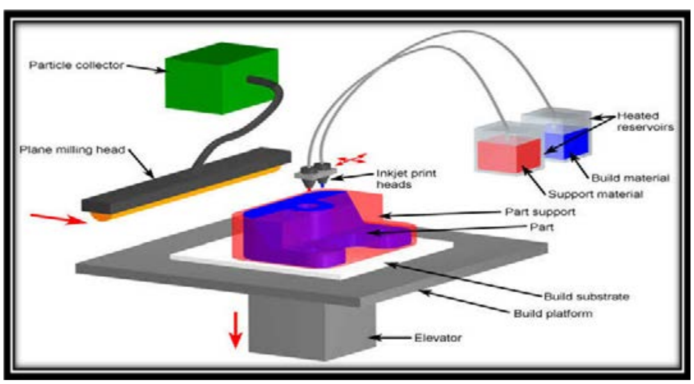

Figure 6: Process of Polyjet Printing

Applications of 3D Printing In Prosthetic Dentistry

1. **Wax Patterns**: The manufacturing of wax pattern is the first step in the process of fabrication of a dental prosthesis. Rapid prototyping technologies had made possible automatic build-up of numbers of wax patterns for different dental constructions by structuring them up layer by layer.[16] The next step remains the traditional lost wax procedure.

   3D Molds for Metal Casting: Ceramic casting molds are fabricated through an incremental printing method[43] without the need of manufacturing wax pattern and all of the following steps in the wax-eliminating process.[44]

2. **3D Molds for Facial Prosthesis**: 3D Printing aided in manufacturing of facial prosthesis molds which is an alternative to the conventional flasking and investment procedures. This fabrication of facial prosthesis shortens the fabrication process and allows multiple pourings from a single mold.[45]
3. **3D Molds for Complete Dentures**: Advanced manufacturing technologies are used in the field of removables mainly to fabricate a physical mold through a CAD process. 3D graphic records of the artificial teeth as well as 3D data of the edentulous rims and centric relation are needed for the software. Since the mold is ready, the complete denture undergoes the traditional manufacturing process to be ready for the dental office. [41,43,46]
4. **All-Ceramic Restorations**: The direct inkjet technology can be implemented for fabrication of zirconia all ceramic restorations.[9] Although all ceramic restoration is still an object of researches and experiments.
5. **Occlusal Splints**: Customized occlusal splints which are used to correct TMJ disorders also benefits from rapid prototyping. These splints requires less time for laboratory work, with more precision and reduce manual errors in fabrication.[47,48]
6. **Implant retained prosthesis**: 3D printing technology to create dental implants have been used by manufacturers widely.[6] 3D printing has the ability to reproduce the minute details of the anatomical

structure along with the surrounding structures associated with it, such as a bone-like morphology, which may not be produced by milling alone – although milling/machining may also be used to refine the printed form.[49]

7. **Surgical Stent**: In implantology, the use of surgical guides has been strongly recommended to facilitate better planning and reduce the risk of operative complications.[9] SLA enables fabrication of surgical guides aiding in providing the exact location, size and angulation of implants.[50]

8. **3D printed models**: Plaster models serve as an educational tool for students and can also be used for treatment planning, record keeping, assessing potential management difficulties.3D printed models reproduce the exact details of the anatomical structures and also overcomes the limitations of plaster models which are burden of their storage, risk of damage/breakage & difficulty in sharing data with other professionals/technicians. The data of the 3d model can be stored and also exchanged electronically.[51]

9. **Regenerative Dentistry:** 3D printer can print bone tissue tailored to requirement of patients act as biomimetic scaffold. These days there are 3D printed alginate peptide hybrid scaffold, which act as a stable medium for the optimal growth of stem cells. Calcium sulphate, calcium phosphate and composite powders can be printed which act as augmentation material.[27,52-54]

Figure 7: Overview of Applications of 3D Printing in Prosthodontics

Table 2: Advantages And Disadvantages Of 3D Printing[9,40]

S.N.	Advantages	Disadvantages
1.	Time saving	Finishing of final product is time consuming and requires expertise.[55]
2.	Accurate details and reproduction of scan providing good quality of work and consistent results.	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.[55]
3.	It is possible to print complex geometric shapes and interlocking parts that require no assembly.	High investment cost.
4.	Reduction of production-related material loss.[55]	Depending on the material, it may still need additional treatment to reach full strength. Eg. Zirconia and E-max blocks.[55]

5.		Stereolithography can be done only using light curable liquid polymers.[28]
6.		Resin used is messy, can cause inflammation and irritation on contact and inhalation and cannot be heat sterilized.[28]

Studies for different 3D printing technologies and materials

Various studies are already being done regarding 3D printing technologies and materials, still an ample of research can be carried out detailing its applications. Xu et al[56] and Quante[57] found improved and comparable marginal fit of laser sintered chrome cobalt crowns compared to traditional techniques. Eswaran et al found favourable results with direct metal laser sintered crowns compared to casting technique using 3D printed resin patterns and wax patterns. However, studies by Ortopa, Kim, Akova, Park[58-61] show increased marginal gap after porcelain firing compared to the traditional casting technique. A permitted value of marginal gap of at least 120 um is required for clinical application. In implantology, mechanical properties, grind ability and corrosion of dental implants manufactured by electron beam melting were found to be comparable to the precious and non-precious metal alloys.[62] Computer technology in guided implant surgery uses the DICOM data conversion to CAD-CAM technology to produce surgical guides. Systematic review by Schneider et al shows a survival rate of 96% after a year of clinical observation in different clinical conditions with variable levels of evidence with 4.6% of post-operative complications. But there is still no strong evidence to recommend computer assisted surgeries based on safety, morbidity, efficiency or cost factors.[63] Moreover, particle analysis of the powders is necessary to determine ceramic powder particle size which is important for particle distribution to prevent agglomeration in the nozzles. As irregular particle size could possibly increase the chances of agglomeration.[64] In maxillofacial prosthodontuics, ear prosthesis have been fabricated using semi-automated technology of CAD modelling and rapid prototyping. Subtractive method of combining the mirror image of the contralateral ear with the scan of the defective side is used to print the mold models with-Fused Deposition Modelling (FDM). The molds were finally then made in silicone fetching better accuracy and less time.[65] Integrated manufacturing systems with a laser digitising scanner, rapid prototyping and a vaccum casting machine were used to fabricate a facial prosthesis.[66]

Conclusion

With the introduction of digital dentistry not only the procedures have become less time consuming, but has also simplified the approach of 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. Additive manufacturing technology is in its experimental phase, but there’s no doubt that it has potential in terms of cost, productivity and time. 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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