The journal of
PROSTHETIC AND IMPLANT DENTISTRY
Official Publication of Indian Prosthodontic Society
Kerala State Branch
jpid.ipskerala.com

3D PRINTING TECHNOLOGY IN DENTISTRY – AN OVERVIEW

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https://doi.org/10.55231/jpid.2022.v05.i03.04

Abstract

Three Dimensional printing, is the latest addition to dentistry. This technology is considered to be the future that would change the manufacturing processes.

The 3D printing process builds an object which is three dimensional from a computer-aided design (CAD) model. The process involved in 3D printing is called 'additive manufacturing' which successively adds material layer by layer. This technology has created a great impact in the field of dentistry. With advancements in three dimensional imaging and designing technologies in dentistry, it will have more significant effects on faster and improved treatment outcomes. This article reviews the various 3D printing technologies that are available, their advantages and disadvantages and their applications in the various fields of dentistry.

Keywords: 3 Dimensional printing, Additive manufacturing, Computer aided design (CAD), Applications in dentistry

Introduction

Three Dimensional printing also called as additive manufacturing was founded back in the year 1980 but has become mainstream more rapidly in last decade. It all started as Charles Hull used a 3D printer to print, a 3D object. A process by which solid three dimensional objects are made from a digital file (present as a STL file) is called a 3D printing. STL is called as surface tesselation language file or standard triangulation language. This digital file is processed by the 3D printer and it prints by joining it, followed by sintering, bonding and polymerizing elements at a smaller volume.[1]

The term "3D printing" is not new. Excel Jon was the first who treated a person using 3D printing in the year 1999, with the material added together typically layer by layer.[2] This article explains the significance of 3D printing in dentistry, and in-turn how dentistry helps advancements in 3D printing.

3D Printing technology:

3D printers are devices that would not function without computer-aided design (CAD) software that allows objects, and whole assembly units to be designed in a digital environment. CAD

software has been increasingly used and is been seen in industrial sector, engineering, and manufacturing factories, and it has also become a common equipment in the dental laboratory. It has even become a daily order in many of the dental surgeries conducted these days.[3]

Advances in computer and software applications are the main factors that brought advances in 3D printing. We must have ready access to digital data in the form of computed tomography (CT) data, intraoral or laboratory optical surface scan data, cone beam computed tomography (CBCT) data for 3D printing to have full application in dentistry.[4]

The advancements in CBCT and optical scan technology, have brought revolutionary changes in various aspects of dentistry, particularly in restorative and implant dentistry. These technological tools are available to dentists and dental technicians, who have an understanding of technology to use them. Dentistry has a long connection towards subtractive manufacturing which is more commonly called 'milling'. It is the process by which an object is formed by reduction of material.[5]

The CAD CAM used to mill copings and crown-bridge frameworks is now a day-to-day procedure in modern dentistry.[3] Modern day dentistry now uses CAD CAM and has become an alternative to the metal casting alloys.[6] This technology reduces the intensity of labour and permits the use of materials which would be difficult to use, hence it allows the Dental personnel to concentrate more on the creative aspect of the process than on the manufacturing aspect of the process.[7] The Dental personnel will have to have a high level of precision to deal with the complexity of the restoration.[8] But CAD-CAM makes the workflow more simplified and also with increased precision. 3D printing, however, prints and aids in the manufacturing of complex structures in a wide range of materials to have desirable properties in both Dentistry and Surgery.[9, 10]

Types of 3D Printers

Various types of 3D printers utilizing different techniques for 3D printing are available. The choice of 3D printer will depend on the type of application at stake.

1) Stereolithography (SLA)

A stereolithography is based on the use of a scanning laser to build parts in a layer by layer fashion. This technology uses an ultraviolet laser curable polymer resin (liquid) contained in a vat and a laser to build the object's layer one at a time. A complete 3D object can be formed with the supporting structures. These supporting structures are required to hold the object because it floats in the vat (basin) filled with polymer resin, later which the supporting structures can be removed manually. The advantages include rapid fabrication, ability to create complex shapes in high resolutions, lower cost if the material is used in bulk.[11] This technology is only available with light cure polymers and hence it is a limitation. It can cause skin reactions, and may be irritant when contacted or when inhaled. It has a limited shelf life. They cannot be sterilized and it comes at a very high cost.

2) Photojet

A layer by layer curing of the polymer by an inkjet printhead that jets out a light sensitive polymer onto a platform.[12] They are relatively fast, they provide high-resolution, quality and better finish. There are multiple materials that are available in various colours and have a wide range of physical properties with a lowered cost of technology. Elastic materials can also be printed using this technology.[11] The disadvantages include skin irritation caused by a tenacious support material and it is very tough to remove completely. They cannot be heat sterilised and the cost of the

materials is higher.

3) Digital Light Processing (DLP)

A layer by layer curing of the liquid resin is done by a projector light source. The built object is upside down on an incremental platform which is elevated. There are four main components in DLP, namely, Digital light projector (Light source), Digital Micromirror Device (DMD), Vat (basically a tank filled with resin) and a building platform.[11] The advantages are good accuracy, relatively fast processing, smooth surfaces and economical. There are some disadvantages like the support materials must be removed for better outcomes, the resin can be sensitive to the skin and may be a potential irritant to the skin on contact. They have a limited shelf life (one year, if stored properly) and they also have a limited vat life and it cannot be heat sterilised and it comes at a higher cost.

4) Powder Binder

Binder Jetting is also an additive manufacturing process developed in the year 1993 at Massachusetts Institute of Technology. In this type, powder is selectively deposited on the powder bed and then these areas are bonded together forming a layer one at a time. Materials such as sand, ceramics and metals are more often used in Binder jetting. They come in a granular form. It is built on a descending platform in a layer by layer fashion. The advantages are lowered cost of the materials and equipment, and it can be printed in various colours. The un-set material provides good support and the process is relatively faster with safer materials. Limitations include low strength, messy powder, poor resolution and cannot be heat sterilised or soaked.[13]

5) Selective Laser Sintering (SLS)

It was first found in the 1980s by Dr. Carl Deckard.[11] Fine powder material is fused layer by layer to build the structures. A new material is formed as the bed bends down incrementally and an evenly spread new layer is formed over the surface.[14]

The object is built layer by layer on the powder bed. The scanning laser then sinters the powder layer by layer on the descending bed. A wide range of polymeric materials including elastomers, composites and nylon can be printed. Strong parts can be manufactured through SLS. Polymeric materials also come at a lowered cost if used in large volumes. The advantage of SLS is that the support structure is not required because the untouched powders after each cross section scanning itself will act as a support. The main disadvantage is the requirement of a significant infrastructure, for example, the need of compressed air and proper climate control. It creates messy powders, inhalation risks, increased cost of the technology and it produces a rough surface.[14]

6) Fused Deposition Modelling (FDM)[15]

It is the first 3D printing technology. Torabi K et al used this for their first medical model in 1999. The first FDM was introduced by Scott Crump in 1980's. An FDM printer uses a robotic gun fitted with an extruder which is either traverse on a platform which is stationary, or on a platform that is able to move below an extruder that is stationary. The Objects in FDM technique is 'sliced' in a layer by layer manner by the software and the coordinates are then transferred to the printer. The nature of the material must be thermoplastic. Polylactic Acid (PLA) and Acrylonitrile Butadiene Styrene (ABS) are the frequently used materials. PLA is referred to as polymer polylactic acid. The speed at which the material travels from the extruder, the rate at which it flows and also the size will determine the accuracy. FDM printers are available in more expensive and accurate varieties. It also has applications in studying anatomy by helping make models and has lesser applications in

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7) Direct Metal Laser Sintering (DMLS)[16]

It was developed in the year 1994 by Rapid Product Innovations (RPI) and EOS GmbH. This was the first method in which metal parts can be produced in single process. DMLS uses a high power laser beam to melt the metal powder (Free of flux agents or binders) to build the metal parts same as that of the original material. Advantage of DMLS is that the metal parts can be built with higher precision because of the smaller diameter of the metal powder. Materials that are used in DMLS include bronze, stainless steel, alloy steel,cobalt-chrome, aluminum, tool steel and titanium. In addition to the functional prototypes, DMLS is more often used to produce medical implants and rapid tooling. The DMLS can be performed by 2 different methods,

i) **Powder deposition-** the metal powder is contained in a hopper that melts the powder and deposits a thin layer onto the build platform

ii) **Powder bed-** distributes a layer of powder onto the powder bed. A laser then sinters the layer of powder metal.

Materials used in 3D Printing Technology

Unlike other technologies, 3D printing technology demands for higher quality materials to get the desired outcome with their respective properties same as that of their original materials. For a wide range of workers like suppliers, purchasers, and end-users of the material are involved to meet this requirement. The materials that are used in 3D printing include a wide variety, namely

i) Metals like cobalt-based alloys, stainless steels, nickel-based alloys,aluminium alloys and titanium alloys.[17, 18, 19, 20,]

ii) Polymers like Polymethyl methacrylate (PMMA), Polyether ether ketone (PEEK), acrylonitrile butadiene styrene (ABS), polyethylene (PE), polylactic acid (PLA) and polypropylene (PP) [21, 22]

iii) Ceramics like alumina, zirconia and bioactive glass [23, 24, 25]

iv) Composites like glass fibers reinforced polymer composite and carbon fibers reinforced polymer composites.[26, 27]

v) Smart materials like shape memory polymers and alloys.[28, 29]

vi) Special materials like Food (chocolate, pizza, meat, sauce, candy etc.), Lunar dusts, Textile (clothing and jewellery) [30, 31]

Applications in dentistry

The dental industry has been revolutionized by 3D printing in last decade. Different applications of 3D printing have been developed to restore missing teeth.

It is applied across a wide of applications that stretch across fields such as medical modelling, making of surgical guides, in prosthodontics and implantology, restorative dentistry, in making orthodontic appliances, and also in manufacturing instruments. The 3D printing technology has been adopted in this fields mainly because of the improvements in high-end imaging technologies like CT scans. It has an inherent advantage over the present computer-aided design/computer-aided manufacturing milling technique.

Besides commercial software (some programs require an annual subscription fee), free design software is also available. These programs can be used to design and 3D print:

- Study models
- Diagnostic wax-up models

- Models to finish crowns and bridges
- Models to fabricate orthodontic aligners
- Occlusal guards
- Custom trays
- Temporary prefabricated crowns and bridges
- Wax try-in of dentures, base plates and wax rims
- Surgical guides

Dentists have found ways to implement 3D printing into their work, though a few applications, in particular, and have become universally popular.

Oral surgery- Dentists can print a model of the patient's mouth easily, and can use this to verify that their crown, implant, or aligner will fit with precision.[32] It will only require a simple intraoral scan. They can also crosscheck their work before surgical phase of dental implants. These are simple yet useful.[33, 34] Preoperative acrylic model in case of maxillofacial defects and a wide craniofacial defects for better treatment planning. In case of fractures, morphological reconstruction of bony defect area and customised reconstruction plates can also be produced using 3D printing technology.[35] Orthognathic surgeries can also be planned and performed with the help of 3D printed surgical wafers and dental splints.

Prosthodontics- With the use of cobalt- chromium alloy it is possible to fabricate a perfect fit removable partial framework. Thereby opening the way for the construction of the removable framework without the need for the investment and casting procedures using 3D printing technology.[36] A 3D printing fabrication method called "Robocasting" is used for the fabrication of the fixed partial dentures.[37] With the help of Inkjet printing technology, it is possible to build up high strength zirconia restorations with a density of 96.6%.[38] This technology is superior to the CAD/CAM milling as it overcomes the issues like wastage of the materials and accuracy.[38]

Restorative dentistry- The conventional procedure for fabrication of crowns is time consuming. 3D printing cuts down the time of fabrication. The Dentist can just scan the broken tooth and 3D printed crown can be fabricated immediately. This can be done in the Dental office in a lesser than 30 minute time frame using a CNC technology and special resin.[39, 40] Temporary crowns can be fabricated using polyjet 3D printers with greater accuracy than the conventional counterparts.[41]

Guided Endodontics- For patients with calcified canal and apical pathologies, special drills and surgical templates can be made using 3D printing technology. This guided endodontics makes it easier to locate canals and prevent perforations, thereby making it minimally invasive.[42]

Implantology- 3D printed titanium implants and zirconia implants have gained popularity in recent days. These 3D printed implants have shown successive clinical outcomes in replacement of single missing tooth.[43] In situations where conventional implants cannot be placed, customized dental implants can be printed using Selective laser melting (SLM). These customized implants have shown better clinical results (adequate density and accuracy).[44]

Surgical guides- 3D printed surgical guides help in accurate placement of the dental implants in the preplanned site. Non-guided surgery can be performed using implant drilling guides with increased precision. Surgery for craniofacial synostosis can be performed with the help of 3D printed guides, which provides information about the osteotome.[45, 46]

Digital Orthodontics- Dentists can perform a simple scan of the patient's mouth and print an aligner similar to an orthodontic appliance with holes where the implants are to be placed with the help of softwares available in the market. These are produced with the same resin used to make aligners but at quicker pace. Transparent aligners and night guards are the common applications of 3D printing.[47]

Maxillofacial prosthesis- Both hard and soft tissue reconstructions can be done with the help of 3D printing technology. 3D printed implants are used in the reconstruction of hard tissue defects (zygomatic bones, mandible, temporal bones, calvarial bones) and cosmetic corrections can also be achieved with this 3D printing technology.[48]

DISCUSSION

The profession has accepted digital manufacturing technologies. The use of CAD/CAM technology along with intra oral and CBCT scanners are becoming more and more common in the dental labs, and dental surgeries. In recent days dentists and dental technicians are becoming well acquainted with this digital technology. Subtractive manufacturing preceded additive manufacturing technology. The digital technology allows easy procurement of three dimensional scanned data enabling incorporation of fine details such that the output is made customizable.[49]

In dentistry, 3D printing already has a wide range of applicability, through which many new treatments and exciting approaches are made possible. Till date the national regulatory bodies haven't implemented any guidance in the use of 3D printing in the field of dentistry and in surgery, but this technology needs an appropriate set standards at its earliest.

The development in this technology, its access to the intra oral scanner, computer-aided design software and raw computational power has made the use of this 3D printing technology practical. And the commercial and public interest towards this digital technology has raised awareness and improved access to the 3D printing apparatus and the resources.

A large number of new material options are available for the production of restorations. This became possible only after the introduction of the milling technology. 3D printing has a wide range of indications in the field of dentistry. It can be said that this profession has a broader experience in these 3D manufacturing technology than any other profession.[49]

The most commonly used technologies are selective laser sintering (SLS), material jetting (MJ), Stereolithography (SLA), and fused deposition modelling (FDM). The SLA technology is the most commonly used technology of 3D printer in dentistry. It uses printable resin material that is cured layer by layer. The disadvantage is the scarcity of biocompatible resins. Additional challenges are the use of photoinitiators and radicals that are cytotoxic. With FDM technology the main disadvantage that it cannot be used in dentistry as the accuracy is questionable when compared with resin based 3D printers. Photopolymer jetting can be used to make study models and is also quiet cheap. But the disadvantage is that the tenacious support material is difficult to remove. It also cannot be heat sterilized. With powder binder the process is relatively fast and the materials are safer to use.

CAD software should be handled by well-trained and computer literate individuals. But in the coming days there won't be any need for these operators because the softwares are becoming more and more user- friendly. The key future developments apart from the obvious benefits of lowered costs, faster manufacturing process, quicker, lesser invasive procedures for the patients add to the strength of 3D printing in ceramic materials with staining and digital coloration, the reduction in the steps of the post-processing that is needed for metal parts, and the integration of milling/ machining of 3D printed metal parts into the metal printing workflow.

Evolving digital technology has increased the awareness and the use of these technologies, with the opportunity for mainstream use of 3D printing technology in the dental laboratory, and in surgery. With much more development in this 3D printing technology, including the development of individual items of equipment and design

software that help create a smooth, rigorous and streamlined workflow. The use of this technology is going to be extensive.[50]

This new technology creates room for new opportunities to be more creative in developing new materials, less invasive, less costly with more predictable procedures and outcomes for the patients. And we must also avoid being entied by this creative aspects of digital technology. A definite standards are needed for this digital technology for the better outcomes and development. Despite the numerous benefits such as faster and accurate service, cost-effective, reduced fabrication time, accurate sizing, lesser material wastage, additive manufacturing has certain limitations like slower build rates, higher production costs, the considerable efforts in its application design and setting up the process, post processing requirements, discontinuous process production, its limited components and small built volumes it a field that needs further research on its application in each aspect of dentistry.

CONCLUSION

3D printing has impacted dentistry in all aspects. At present this technology focuses on planning of implant placement and the indirect production of restorations and aligners used in Orthodontics by printing the moulds for these objects, and also personalized tissue engineering scaffolds are being created for use in oral surgery, which serve as carriers for growth factors and other bioactive molecules including cells.

Thus, with this 3D printing technology, it is possible to make one or complex geometrical forms accurately from the available digital data, with a variety of materials, locally or in industrial centers. Almost everything can be made with this technology for our patients but the real challenge is no single technology is sufficient for all our patients' needs. Despite all the advantages and development, the need for the health and safety protocols must also be considered. So it is very clear that this 3D printing technology will have an increasing importance in the field of dentistry.

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