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3D Printing -A Revolution in Prosthetic Dentistry

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Abstract **Review Article**

3D printing has been heralded as a innovative technology that will revolutionize industry. it is already used in aerospace, defense, art, and design, which becoming a popular subject in surgery. Digital advancements, smart biomaterials, and enhanced cell culture, in combination with 3D printing, give promising ground for patient-tailored therapies. Dental applications for three-dimensional (3D) printing in various departments range from prosthodontics, oral and maxillofacial surgery, and oral implantology through orthodontics, endodontics, and periodontology. The uses of 3D printing in prosthodontics can help provide patients with lower-cost, more customized services and ease the complicated workflow associated with the manufacturing of all dental equipment due to its quick production, high precision, and personal customization. The technique comprises intraoral or model scanning and designing, 3D printing, and post-processing and is used to fabricate surgical guides, removable, fixed, and maxillofacial prostheses.They can also have drawbacks, such as expensive and lengthy postprocessing. This study gives a practical and scientific overview of 3D printing technologies, which will be the future of digital dentistry, due to the development of new materials and technology.

Keywords: Digital Dentistry, CAD/CAM, Additive Manufactiring, Digital Work Flow.

INTRODUCTION

Digitalization has an impact on all aspects of dentistry. It has altered the flow of traditional treatment processes. Process of workflow between dentist, surgeons and laboratory professionals has been changed drastically. Digitalization has become an integral part of prosthodontics. Starting from the changing in perspective as well as practices in radiographic technology, impression making, recording virtual jaw relation and fabrication of removable and fixed prosthesis almost everything has become digital now. In this era, digital dentistry has developed itself as a major branch of dentistry and currently, most of the practising dentists now are in favour of the use of this technique due to its versatility of benefits [1].

Digital dentistry itself is a vast technology and it encompasses procedure like the use of CAD/CAM, rapid prototyping, virtual articulators, 3D scanning, 3D software, and the with the continuing research is thought to be endless. The discovery of 3D printing is credited to Charles Hull of the University of Colorado, USA. He started working on 3D printing in the early 1980s using ultraviolet radiation. 3D printing is a method which creates a virtual 3D model into a physical object, where the obtained 3D object is created by successive layering down layers of material [2]. Digital dentistry may be defined in a broad scope as any dental technology or device that incorporates digital or computer-controlled components in contrast to that of mechanical or electrical alone.The term 3D printing is generally used to describe a manufacturing approach

that builds objects one layer at a time, adding multiple layers to form an object. This process is more correctly described as additive manufacturing and is also referred to as rapid prototyping [3]. Additive manufacturing file: acronym is AMF; data format proposed by the American Society of Testing and Materials (ASTM); this file is used in additive manufacturing of any three dimensional (3D) object to be fabricated on any 3D printer; AMF has shape and composition for colour, materials, and texture [4].

CLASSIFICATION OF 3D PRINTING TECHNOLOGIES

According to Kruth, the material accretion technologies may be divided by the state of the prototype material before the beginning of the process [5]. It has the following types (Figure 1 & 2).

1. Selective laser sintering
2. Fused deposition modelling
3. Multi-jet modelling
4. Stereolithography(SL)

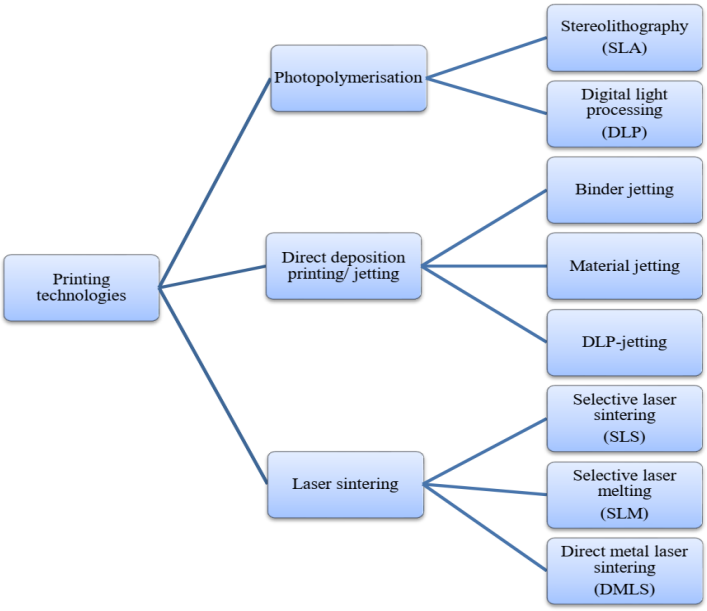

Figure 1: Based on printing technologies

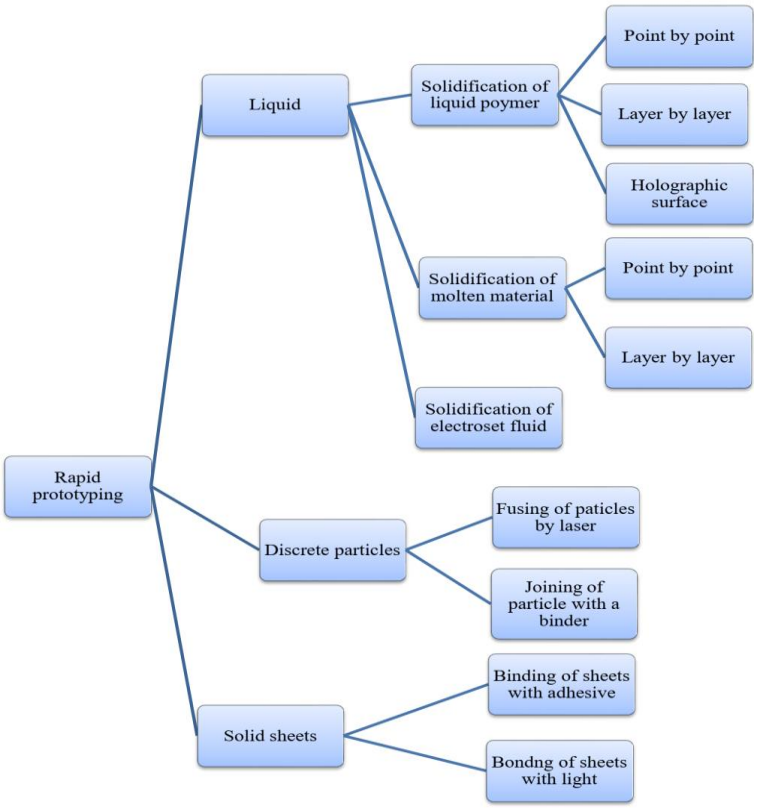

Figure 2: Classification of rapid prototyping technologies

MECHANISM OF ACTION OF 3D PRINTING

Models can be created with either computer-aided design (CAD) or via a 3D scan of the oral cavity, teeth and its associated structures, impression or model. Steps of 3D printing include acquisition of data either by physical method or digital method. Next step is the creation of tessellation-STL file and transfer of this STL file to a 3D printer for preparation of printing of the desired model. Now after the transfer of STL file to 3D printer, printer lay down the model layer by layer. Following the printing of the final model printing, post-processing procedures like removal of support, jet washing and heat treatment are done (Figure 3) [6].

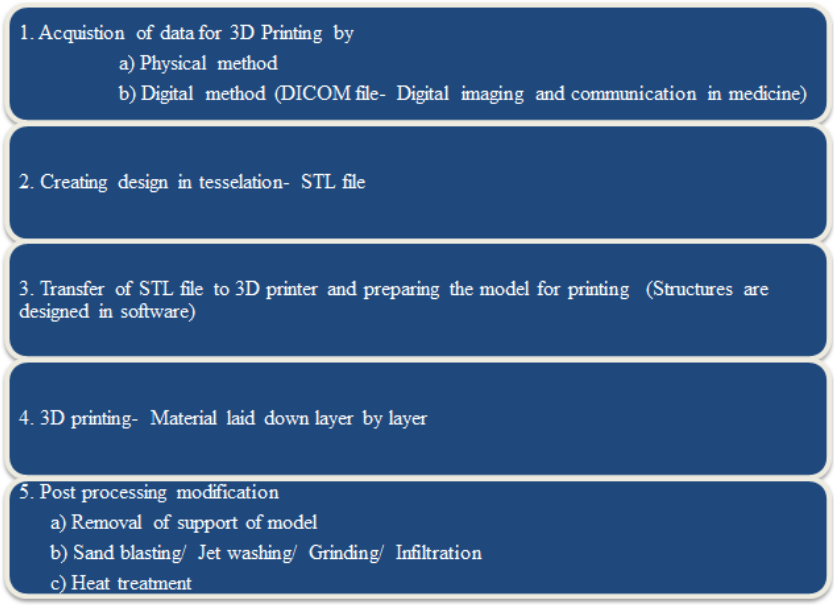

Figure 3: Mechanism of 3D Printing

3D PRINTING MATERIALS

Based on which material is going to be used accordingly the printing methods are decided. Variety of materials are available for particular 3D printing methods like plastic, alumide, resin, wax and metals. Each of them has its advantages and disadvantages which are listed below [6].

Techniques /material	Advantages	Disadvantages
Light cure resin		
SLA	a) The rapid technique of fabrication. b) Cost of material is low if used in bulk.	Only available as light cure material. Resin is a little bit messy and may create irritation to skin and cause skin allergies
Photojet	It is relatively faster Finishing off the high-quality model may be expected	Cost of material is high May cause skin irritation
DLP	Relatively faster Good accuracy as well as smooth surface creation	Resin is a little bit messy and may create irritation to skin and cause skin allergies Can't be heat sterilized
Powder binder		
Inkjet technique	Cost of material is low Colour printing can be achieved	The powder is messy, low strength Can't be heat sterilized
Sintered powder		
SLS for polymers	Lower cost material if used in bulk. The polymeric material used may be autoclaved	Complex armamentarium required like compressed air. The powder is messy and there is a risk of inhalation of powder
SLS for metal alloys	Strength of the object will be high Fine detailing is possible and metal can be recycled	Complex armamentarium required Dust and nanoparticle of metal may be hazardous to health
Thermoplastic		
FDM	Cost of material is in mid-range Some of the material can be heat sterilized	Limited shape complexity for biologic material

FUSED DEPOSITION MODELLING (FDM)

It was developed by Schott Crump. This technique utilizes thermoplastic resin material which extruded through a nozzle of the 3D printer. Material generally hardens within a second just after extrusion from the nozzle. The heating and extrusion of material are controlled by temperature regulated device. A processor helps in the control and distribution of extruded material over the platform. Materials used in this technique are butyro-styrene ABS, Polysulfones as well as polycarbonates [7].

SELECTIVE LASER SINTERING (SLS)

This technique was developed at the University of Texas. In these techniques, fine powders are fused with help of scanning laser that incrementally builds the structures. When the first bed of powder sintered completely, printer lay down the next bed of powder and scanning laser sintered the next layer. One of the advantages of this technique is gaining the high resolution that is about 60 um [7].

POWDER BINDER PRINTER

This type of printer uses a modified inkjet head to print the model. In this technique, liquid droplets infiltrate and form a single uniform layer powder one after another. Bed of powder increases in an incremental manner and the printer finally lays down the final model [7].

DIGITAL LIGHT PROCESSING (DLP)

This technique is almost similar to selective laser gelation technique with an exception that it utilizes a digital micromirror device that helps to project a cross-sectional UV image instead of moving beam [7].

STEREOLITHOGRAPHY (SLA)

This type of 3D printing dates back to 1984 and the credit of discovery go to Hall. This system utilizes both photosensitive liquid resin as well as UV laser for curing the polymeric resin. The layer of resin is cured sequentially and each layer bonded together to form the solid final model of the object [8].

ADVANTAGES 3D PRINTING [8, 9]

a) Rate and speed of formation of objects and model are one of the obvious advantages of 3D printing that helps in time-saving.
b) Accurate details and scan help in providing good quality work and consistent results.
c) It imparts designer the ability to quickly turn the concepts of 2D into 3D models or prototype.
d) Wastage of material is almost negligible hence processing is clean.
e) 3D printing which is an additive technique in contrast to a subtractive technique like CAD/CAM may produce a complex model or shape of the object. Whereas this is the limitation of the subtractive technique.
f) These techniques can be operated easily no skilled operators required.

DISADVANTAGES OF 3D PRINTING [8, 9]

a) Components or models fabricated by 3D printing technology usually do not offer great mechanical strength.
b) Certain material after processing may still require additional treatment to reach the final strength like Zirconia and E- max block may require further sintering to attain higher strength.
c) Finishing of final products or post-processing may be time-consuming.
d) One of the major limitations of Stereolithography is that it is done only using light curable liquid polymer.
e) The resin used may cause skin irritation; inflammation of powder can be inhaled.
f) Most of the resin used in 3D printing technologies can't be heat sterilized
g) Cost of the raw material and cost of the 3D printer is also may act asa limiting factor

APPLICATIONS OF 3D PRINTING IN PROSTHODONTICS

Various applications are have been cited in the literature related to 3D printing in the field of prosthodontics which are summarizwd below (Figure 4).

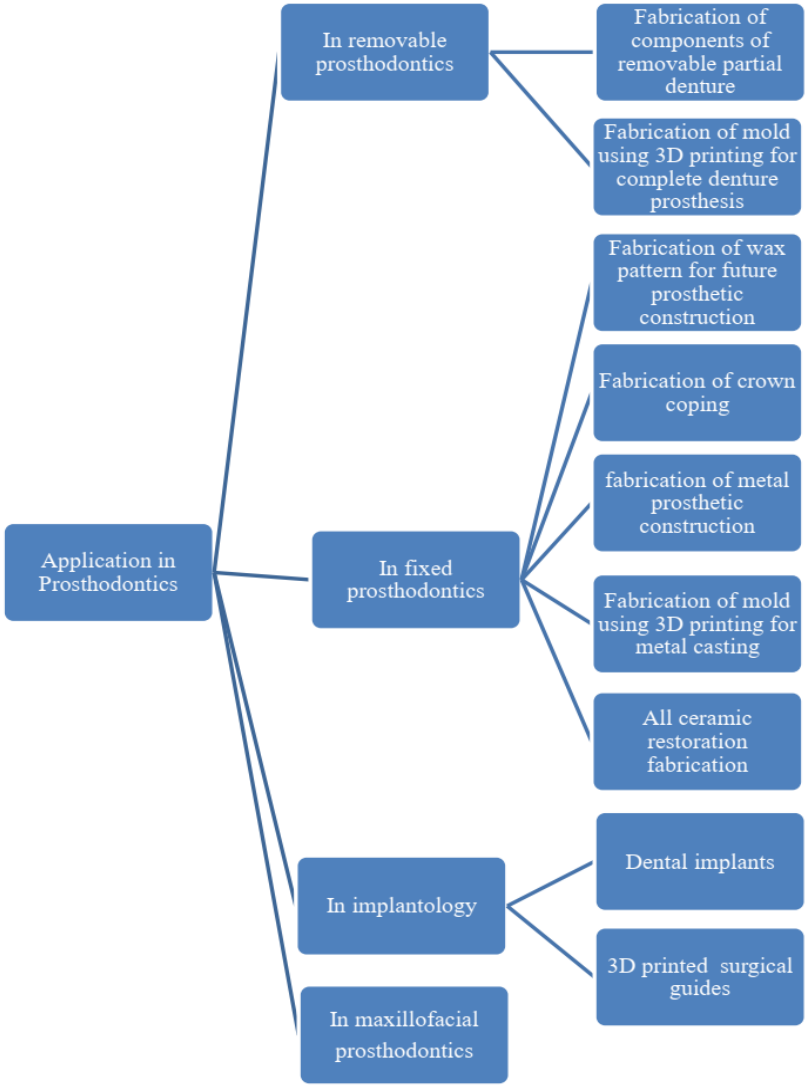

Figure 4: Application of 3D printing in Prosthodontics

APPLICATION OF 3D PRINTING IN REMOVABLE PROSTHODONTICS

a) Fabrication of mould using 3D printing for complete denture prosthesis

Fabrication of complete dentures is now possible with additive manufacturing. The process of complete denture fabrication using 3D printing encompasses the establishment of a 3D graphic database for positioning, ad arrangement of the artificial tooth as well as getting data of edentulous models and rims in centric relation. After the formation of mould complete denture utilizes traditional techniques of manufacturing. One of the major drawbacks of the 3D printed dentures is their lack of physical properties. Very few kinds of literature are there on the fabrication of 3D printed denture and this shows that this technique has not been extensively utilized in this particular field of application [10, 13].

b) Fabrication or components of removable partial denture

3D printing can also produce components of removable partial denture and studies have claimed that 3D printed frameworks show precise fit in compare to that fabricated conventionally. Process of fabrication includes the acquisition of data, digital designing and digital wax-up of the framework, converting the designed data and fabrication of framework using selective laser sintering or casting of resin printed framework [14].

APPLICATION OF 3D PRINTING IN FIXED PROSTHODONTICS

a) Fabrication of wax pattern for future prosthetic construction

In the traditional technique, fabrication of wax pattern seems to be one of the most critical steps in the fabrication of porcelain fused metal crowns, ceramic crowns as well as removable partial denture framework. With the newer technology like 3D printing these particular steps now seem to be easy. This recent technology utilizes three steps in the fabrication of a wax pattern that includes obtaining the digital master model by using an optical scanner. The full arch as well as opposing arch scanning for digitization should be done. Next step includes digital designing of the wax

pattern by utilizing CAD (Computer-aided designing) software. The last step is the fabrication of wax pattern by rapid prototyping technology utilizing fused deposition modelling and 3D printer [10, 13, 18].

b) Fabrication of crown coping

In fixed prosthodontics, crown coping can also be prepared with rapid prototyping technology. Planned restoration can be designed using CAD software and this scan data can be used to print the coping of crowns [7, 19].

c) Fabrication of direct metal prosthetic restorations

Now a day's fabrication of direct metal prosthesis is achievable and this can be achieved through newer techniques like selective laser sintering or selective laser melting. These technologies overrule the older concept like making of the wax pattern for the fabrication of prosthesis and subsequent tedious and time taking procedure and thus they eliminate the possible errors that may go to happen at every stage [10].

d) Fabrication of mould using 3D printing for metal casting

3D printing technologies have the potential benefit in the fabrication of ceramic casting model as they lay down the model through an incremental technique without the need of manufacturing wax pattern and subsequent steps in the wax eliminating procedures [10].

e) All ceramic restoration fabrication

Since the development of CAD/CAM milling system, these techniques are actively used in the production of milled restorations but these techniques have some flaws like wastage of significant amount of raw material, limitations of milling tools in more complex design formation. These drawbacks can be overcome by so-called additive manufacturing technology. A direct inkjet procedure can be employed in the fabrication of all-ceramic restorations. This technique utilizes printing of a suspension with a solids content of zirconia powder and drops on-demand inkjet printhead. Extrusion of slurry from inkjet head depends on several factors like solid loading, Ph value etc. After extrusion of slurry, green part of restoration needs to be sintered for final strength. Hence this restoration sintered in furnance at a temperature range of 900^0 C to 950^0 C for 5 to 8 minutes [10, 13].

APPLICATION OF 3D PRINTING IN IMPLANTOLOGY

a) Dental implant

Several manufacturers have tried to produce a dental implant by using 3D printing technology. 3D printing technology can create micro details of complex anatomical structures like bone-like morphology in contrast to milled technology and hence 3D printing technology can also be used in the fabrication of dental implants [6, 7].

b) 3D printed surgical guide for implant placement

Accurate placement of an implant at the preset area is most critical and this accuracy can be achieved with rapidly emerging technology like additive manufacturing. Surgical guide fabricates by 3D printing technology offers accuracy as well as safety to treatment so that implant can be placed at the preset area [15].

APPLICATION OF 3D PRINTING IN MAXILLOFACIAL PROSTHODONTICS

Recent emerging technologies like rapid prototyping now a day are also being extensively used in managing the maxillofacial defects. As this technique employs fabrication of more complex geometrical shapes this technique thought to be more helpful in the production of complex orofacial structures. Field of the maxillofacial prosthodontics 3D printing technology can be utilized for the following applications [16, 17].

- Fabrication of ocular, auricular, nasal and other facial prostheses
- Fabrication of obturator in cases of partial of complete maxillectomy or any other pathology resection
- Fabrication of radiation shielding appliances to protect the healthy surrounding tissues from ill effects of radiotherapy
- Fabrication of burn stent where the burned area can be scanned rather taking impression which can be painful
- Fabrication of ocular, auricular, nasal and other facial prostheses
- Fabrication of surgical stents for the patient with pathology and scheduled for excision of the pathology
- 3D printed models with defect area in the case where mock surgeries are in need to be performed
- 3D visualization of facial structures by forming models

APPLICATION OF 3D PRINTING IN OTHER SPECIALTIES OF DENTISTRY

a) Oral and maxillofacial surgery

Three-dimensional imaging using computed tomography scan helps in the fabrication of 3D printed models and this 3D printed models ay help in preoperative diagnosis and treatment planning as well as mock surgery preparation.

In reconstructive surgeries which may require bone grafting can be successfully tackled by a 3D printed allogenic bone graft. The advantages of these grafts include no ethical consideration, patients specific, customized as well as there is no donor site morbidity.

3D printed models may also help in the fabrication of customized surgical guides that helps in accurate and precise placement of dental implants [6, 9, 11, 16].

b) Restorative dentistry

3D scanning of mouth, teeth and adjacent structures are helpful in patients with a gag reflex, painful temporomandibular joint disorders or in decreased mouth opening cases where conventional impression technique is almost impossible.

3D printed models of the specific tooth where canal localization is thought to be difficult can be easily tackled down [6, 9, 11, 16].

c) Orthodontics

Orthodontics hasalso been benefitted from 3D printing. 3D printing has enabled the formation of 3D printed clear aligners, 3D printed brackets, orthodontic wire, mouth guard, palatal expander, sleep apnea appliances and 3D printed models. Fabrication of these 3D printed devices has led to much accurate and easily handling practice in orthodontia [6, 9, 11, 16].

d) Endodontics

3D printed surgical guides for guided apicectomy surgical procedure as well as fabrication of 3d printed models for visualization of complex root canal morphology has lead to more convenient and easy learning in this field [6, 9, 16].

e) Periodontics

Gingival reconstruction surgeries and plastic surgeries require a high degree of accuracy in cases where aesthetic is of paramount. The conventional technique may result in some degree of deviation from the desired result. Use of 3D printed guides in these surgeries has enabled the operators to gain the maximum desired results [6, 9, 11, 16].

FUTURE PERSPECTIVE OF 3D PRINTING

3D printing has revolutionized the dentistry. Now a days 3D printing technologies are being extensively used in almost every field of dentistry. After touching almost every aspect of dentistry, researchers are now exploring the use of 3D printing in the field of tissue engineering also. With the help of 3D printing technology research is going on for the development of scaffolds which serves and act as a carrier for the growth factor as well as biomolecules [20].

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Conflict of interest: Nil

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