

Applications of 3D-printing in Prosthodontics: A Critical Review

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Abstract

Dentistry as well as all other industrial sectors have seen a change in manufacturing since the advent of 3D printing. With its uses in various fields of dentistry, such as orthodontics, oral surgery, and other treatments, this technology has also had a significant impact on prosthodontics. With the use of this technology, the process of fabricating prostheses is thought to be easier and less complicated. While some of the claims made about 3D printing have been validated, there are still some obstacles that need to be addressed to optimize the technology's use for the benefit of clinicians. Some of these uses of 3D printing in prosthodontics are covered in this review, along with the issues that still need to be handled.

Keywords: 3D printing, Prosthodontics aspects and challenges

INTRODUCTION

Three-dimensional printing has grown rapidly over the years, since its introduction by Charles Hull in 1986, and has been widely used in various fields of engineering, industry, design, and manufacturing, for nearly 30 years.^[1] Over these years, it has evolved with printers becoming smaller and cheaper, ease of printability of complex structures, expansion in the range of printable materials including plastics, metal, ceramics, and even human tissue, and has found wide applications in medicine and dentistry.^[2,3]

Dentistry has not remained untouched by this technology and has seen quite a lot of developments in the field of oral surgeries, orthodontics, intraoral prostheses, maxillofacial prosthetics, etc.^[3] Present times have seen an upsurge, to incorporate this technology of 3D printing in the day-to-day prosthodontics, such as complete and partial removable dentures, implants prostheses, crowns and bridges, and maxillofacial prostheses. This has expedited and simplified the work of prosthodontists and laboratory technicians, by cutting down some of the clinical as well as laboratory procedures, and reducing patient visits. Even if the research on the accuracy of this technique is still under progress, it is highly looked upon as a bright future by dentists and laboratory technicians.

In this review, we shall discuss some aspects of 3D printing, which might help a clinician to make better use of this technology.

3D PRINTING

This revolution began in the 1980s, when Charles Hull invented his stereolithography (SLA) (a technology of 3D printing) machine. From that time to the present condition, 3D printing technology has immensely evolved, only to become better.^[4]

Basically, 3D printing technology consists of two types- the Subtractive manufacturing technology and the Additive manufacturing technology. The method of fabrication, which utilizes 'subtraction manufacturing' from large solid blocks, is known as Subtractive Manufacturing. In this, power-driven machine tools are used with a sharp cutting tool to mechanically cut the material to achieve the desired geometry with all the steps controlled by a computer program. A lot of material wastage is involved and only the external structure can be replicated.

Additive manufacturing involves adding the material in a layer-by-layer method, to form a complete structure. In this method, material wastage is reduced as well as complex geometries can be manufactured.^[5]

Additive manufacturing involves several types of technologies

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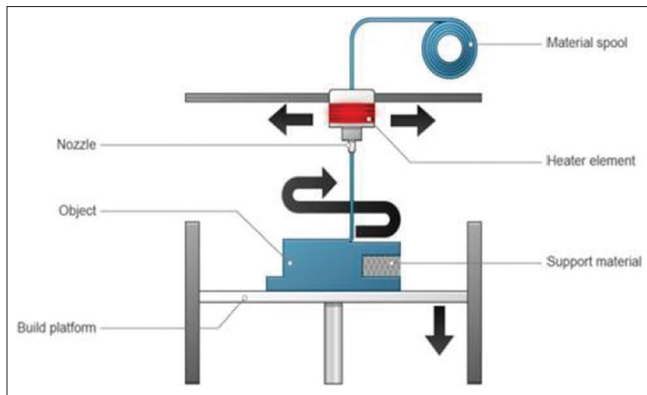
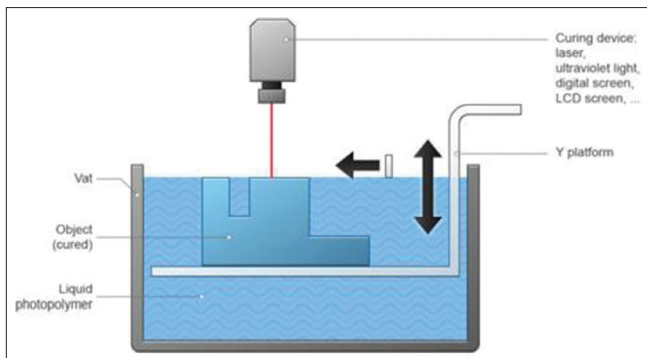
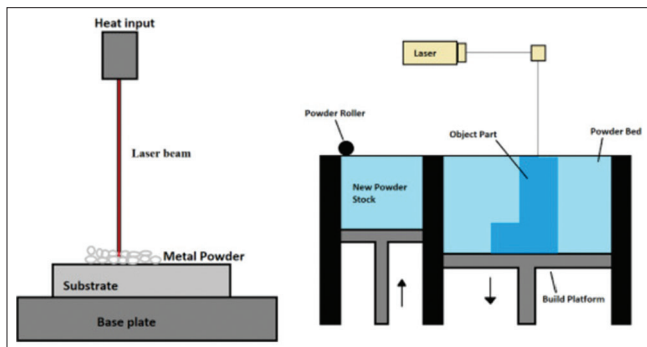
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Figure 1: Material extrusion^[5]Figure 2: Vat polymerization^[5]Figure 3: Powder bed fusion^[5]

by which layer-by-layer manufacturing is done. It includes.^[5]

1. Material extrusion
 - a. Fused deposition modeling
 - b. Material jetting.
2. Vat polymerization
 - a. SLA
 - b. Digital light processing (DLP).
3. Powder bed fusion
 - a. Selective laser melting
 - b. Selective laser sintering
 - c. Direct metal laser sintering
 - d. Binder jetting.

Material extrusion

In this process, a layer-by-layer deposition of the material occurs as the material moves through the nozzle [Figure 1]. The filament is heated to a temperature above its melting point till it can easily flow through the nozzle onto a build platform. The material is deposited onto the build platform over the previous layer while the platform goes down by the height of the deposited layer. Part to be produced is built on the build platform.^[5]

Vat polymerization

VP is a 3-dimensional Printing process using photopolymerization to cure the liquid resin hosted in a vat/ container into a desired structure in a layer-by-layer fashion [Figure 2]. This is a process where there is a liquid in the build platform and the formation of the desired part is a light activated process. The material is in the form of resin-based liquid. It is used for materials, such as polymers and ceramics. The principle of vat polymerization lies behind both SLA and DLP.^[5]

Powder bed fusion

In this technique, very complex geometric structures can be printed with high precision using a heat source mainly a laser or electron beam to fuse the powder particles layer-by-layer [Figure 3]. This process is extremely useful for intricate designs and can be done using different types of printing material.^[5]

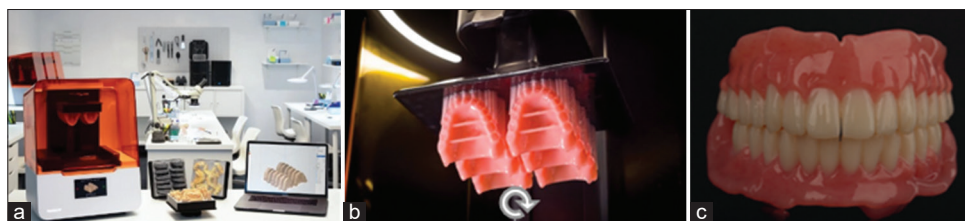
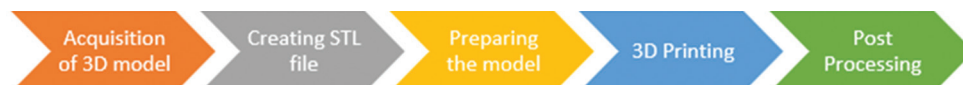
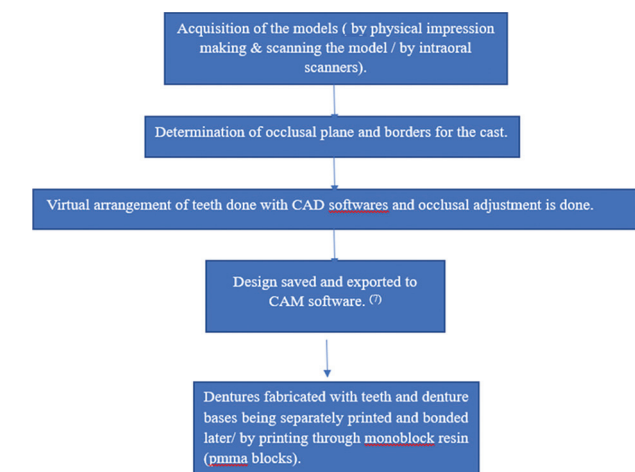
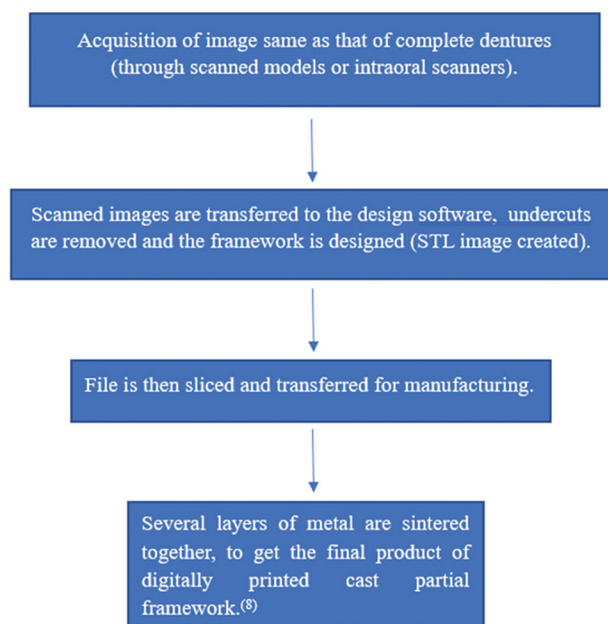


Figure 4: (a-c) digitally printed complete dentures

Flowchart 1: Flowchart of 3D printing process^[6]



Flowchart 2: The workflow for the fabrication of complete dentures



Flowchart 3: The workflow for fabrication of partial dentures

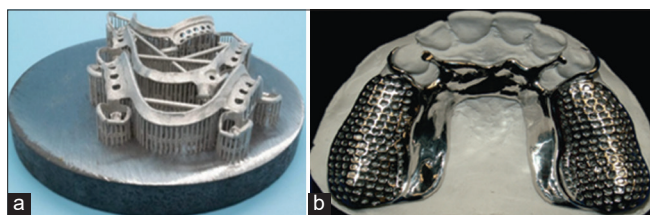


Figure 5: (a and b) digitally printed cast partial denture framework



Figure 6: Digitally printed crowns

How the 3D PRINTING (ADDITIVE MANUFACTURING) Works

The process of 3D printing can be understood in a simpler manner with the help of the following flowchart.

APPLICATION OF 3D PRINTING IN PROSTHODONTICS

Complete dentures

Computer-aided design and computer-aided manufacturing (CAD/CAM) has emerged as a new approach for the design and fabrication of complete dentures. (Figure 4a-c) Unlike traditional methods that rely on physical impressions and manual adjustments, digital denture fabrication utilizes computer-aided design (CAD) and computer-aided manufacturing (CAM) techniques. The digital workflow of Complete Denture fabrication can be easily understood by the following flowchart (Flowchart 2).

Partial denture

Digital removable partial dentures are emerging as a significant innovation that combines advanced technology with personalized patient care. The CAD (computer-aided design) software allows for customization of the denture. The CAM (computer-aided manufacturing) techniques, then bring this digital design to life (Figure 5 a,b). The following workflow presents the fabrication of partial dentures by digital planning (Flowchart 3).

Crowns and bridges

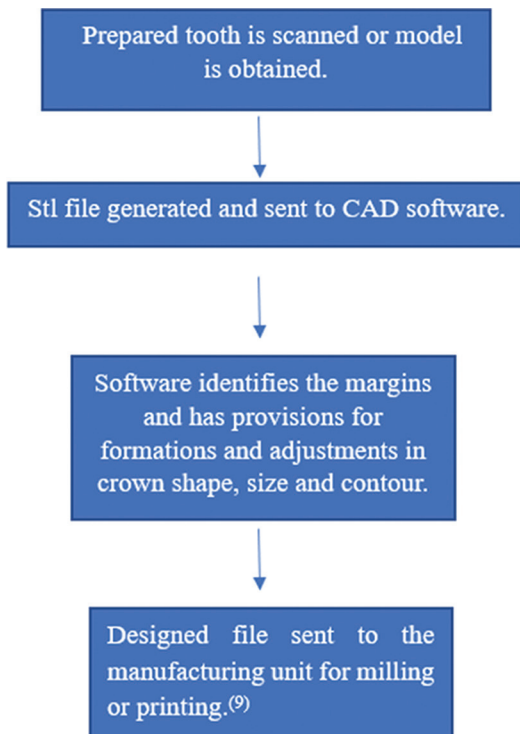
Computer aided design and computer aided manufacturing (CAD/CAM) is being utilized in both removable and fixed prosthodontics, and 3-dimensional (3D) printing has been an area of digital technology growth (Figure 6). The digital workflow of fixed partial dentures can be easily understood with the help of the following flowchart (Flowchart 4).

Implantology

3D-printing technology has become a subject of substantial interest in digital implant dentistry. Implantology has employed 3D printing in numerous applications, including implant surgery, and implant and restoration products, such as surgical guides for implantation, custom titanium meshes for bone augmentation, personalized or non-personalized dental implants, custom trays, implant casts, and implant-support frameworks. It benefits the patient in the sense of saving time and decreasing the number of dental office visits. Furthermore, the accuracy has been reported to be satisfactory, but more

Table 1: Prosthodontics aspects and its challenges

Prosthodontic aspects	Challenges
Removable prostheses	- Problems occur with image acquisition regarding accuracy. Some authors (Patzelt <i>et al.</i>) have even contraindicated the usage of intra-oral scanners for complete removable prostheses.^[9-11] - High cost, wastage of materials. - The variety of materials that can be used for 3D printing, the need for immediate relines of the prosthesis, problems with esthetics, phonetics, and occlusal-vertical dimensions, etc. are some of the aspects of the field of removable prosthetics that have to be addressed.^[12,13] - Occlusion and tooth arrangement errors, tooth wear, additional visits, post-insertion adjustments, overall patient dissatisfaction, and the need for remake^[10,13] (CAD/CAM dentures) 3D-printed dentures also have the same clinical disadvantages of CAD/CAM dentures along with reduced retention, compromised esthetics and low strength,^[14] also milled dentures seemed to have considerably better material properties.^[15]
Fixed partial dentures	- Difficulty in detecting deep marginal lines of prepared teeth, using intraoral scanners for image acquisition.^[16-19] - The intraoral environment, including improper scanning distance, patient body movements, and saliva secretion, can affect the accuracy of intraoral scanners.^[20] - The accuracy of intraoral scanners also depends on the type of scanning principles (namely - Confocal Microscopy, Active wavefront sampling, Triangulation, Stereophotogrammetry, and Optical Coherent Tomography) used in those scanners. Different scanners have proven to be better in different conditions.^[21] - The accuracy of scanning using intraoral scanners has also been reported to be dependent on the practitioner's skill. Dentists need sufficient training on the use of intraoral scanners and accurate operational procedures before the application of the technique in routine practice.^[22] - According to Natsubori <i>et al.</i>,^[23] intraoral scanners can be used in patients with two to three missing teeth. This is because the accuracy of the intraoral scanners in regions with two or three missing teeth was comparable to that in previous reports.^[24-26] - Ahlholm <i>et al.</i>, have even contraindicated their use for long-span fixed partial dentures and/or fixed full arches (6–8 elements)^[27] - A mean marginal gap of 47–193 μm^[28] was found in provisional crowns, in a study, comparing CAD/CAM versus conventional methods by Abdullah <i>et al.</i>
Implantology	- In a study by Natsubori <i>et al.</i>,^[23] it was shown that intraoral scanners are not suitable in terms of accuracy for capturing optical impressions of full arches^[29] and these can be used for dental implant treatment using a verification index. - Intraoral scanning is contraindicated by many authors in prostheses involving long-span implant-supported fixed partial dentures and/or fixed full arches (6–8 implants)^[30-32] - Several authors have reported reduced accuracy when digital planning is compared to implant placement.^[33-35] - More experienced operators place more implants accurately, as concluded by Cushen and coworkers while investigating the effect of operator experience on implant placement accuracy with stereolithographic surgical guides. - Practitioners who want to utilize this advanced procedure should acquire comprehensive training^[33,34,36] as there is a learning curve for this method like other innovative procedures.

**Flowchart 4:** The workflow for fabrication of crowns and bridges**Figure 7:** 3D-printed surgical guide with drill holes**Figure 8:** 3D-printed model with patient-specific implant

research is required in this field.^[7] Here is an example of utilization of this technology in printing surgical guides and 3D printed models with patient specific implants (Figure 7, 8).

DISCUSSION

3D-printing techniques have started being widely utilized in various fields of prosthodontic rehabilitation of dentulous and edentulous patients, implantology, maxillofacial prosthetics, etc. One of the most benefitted procedures in prosthodontics would be the fabrication of crowns and bridges. Fabrication of single units of provisional crowns can be done in as little as 10–20 min. Recently, implant insertion with the help of surgical guides has become popular. Despite the belief in the precision of CAD/CAM surgical guides for carrying of accurate implant placement surgeries, especially among novice practitioners, few reports have identified the risk of errors and complications that clinicians might face from digital planning to actual implant surgery.^[8] While there are several advantages of 3D-printed prosthetics, a number of challenges also await to be overcome. These are tabulated as follows (Table 1):

CONCLUSION AND FUTURE SCOPE OF RESEARCH

Despite the popularity and advancements in the field of digital dentistry and prosthodontics, a greater number of studies and further research is required to attain the maximum possible accuracy and betterment of the patient. Major challenges include the increased cost of treatment, dimensional changes, the accuracy of the prostheses, the influence of scan patterns on the trueness and precision of intraoral scanners, and the lack of a great number of studies in the field. There is a significant gap between the performance and fabrication needs for maxillofacial prosthesis and the current availability of sophisticated soft polymeric materials and composites for additive manufacturing and commercialization of 3D-printed maxillofacial prosthesis is still a challenge.^[37]

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