REVIEW ARTICLE

APPLICATION OF 3D PRINTING IN IMPLANT DENTISTRY AND ITS RECENT ADVANCEMENTS

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ABSTRACT

Additive manufacturing, or 3D printing, has helped to resolve a number of significant issues with general manufacturing, including three-dimensional tissue structure, challenges with controlling microenvironments, efficiency and repeatability in product production, etc. It has also increased the precision and speed of manufacturing of customized bone implants and greatly aided in the recovery of patients. The technology is especially relevant to dentistry, and given the development of 3D modeling and imaging techniques like intraoral scanning and cone beam computed tomography, as well as the CAD/CAM technology use in dentistry, its significance is only going to grow. Drill guides for dental implants, tangible models for prosthodontics, orthodontics, and surgery, dental, craniomaxillofacial, and orthopedic implant manufacturing, and the creation of copings and frameworks for implant and dental restorations are just a few applications for 3D printing. This review examines the different kinds of 3D printing technologies that are now on the market and how they are being used in maxillofacial surgery and dentistry.

KEY WORDS

3D printing, Implant, Additive manufacturing , CAD-CAM , Robotics

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INTRODUCTION

3D printing is an innovative approach in manufacturing that produces an object by adding multiple layers with one layer at a time. All the hype involving 3D printing could be attributed to the international press wherein this technology has been in use for fashion industry, architectural model and armaments alike. 3D printing is a robotic device that makes use of computer-aided design (CAD) software to materialize an object in a virtual environment which is becoming a future in dentistry. It has widespread application in restoration of an edentulous space, which utilizes titanium and magnesium alloy along with some inorganic, non metallic materials for the fabrication of grafts and dental implants using extrusion based printing.

Edentulism is an incapacitating and permanent ailment and is often described as the “final marker of disease burden for oral health”[1]. Edentulism causes a number of oral problems, including poor nutrition and masticatory function impairment. As a result, dentistry, is important for preserving good oral health. It has been catering to the never ending demand of patients over decades starting from tooth restorations, dentures, to acidic monomers and polymers for composite materials to promote healing. The remarkable properties of titanium metal were discovered by Swedish physician Per-Ingvar Branemark, who is regarded as the founder of modern dental implantology. This led to an investigation into the metal's potential applications in dental implantology. The pace of deterioration at the implant site, however, continues to be a significant issue for the wide range of adaptable implants. Thus, advanced manufacturing technology has anticipated the growing demand for dental materials that are both safe and aesthetically pleasing. In this context, additive manufacturing, or 3D printing, has emerged as a potential alternative to traditional treatment strategies for the replacement or repair of defective dental implants. Chuck Hull's development of stereolithography marked the beginning of more than three decades of 3D printing wherein they have developed the ".stl" file format in computer-aided design (CAD) software, which is used to direct the printer to print a 3D object, thereby making a substantial contribution to closing the communication gap between computers and fast prototyping methods[2].

In order to create visually appealing 3D implants for dentistry, materials utilized in 3D printing must meet specific requirements. In order for the graft to cohabit with the recipient's current histological condition, the material must first be biocompatible. The second factor that relates to the material's printability is its ability to produce flawless temporal construction of the grafts with less effort. Third, materials that are chosen with the right mechanical qualities allow the implant to withstand force. When it came to replacing traditional import materials for bone restoration, functionally graded material (FGM) was first introduced in Japan in 1986[3]. FGM offers the implant a greater rate of biocompatibility, a reduced stress effect, a lower incidence of mechanical failure, and enhanced biodegradability. The FGM dental implant is made up of a cylindrical structure with a highly degradable lower site and a robust upper section. This structure aids in giving the occlusal force delivered to the top, which is directly conveyed to the implant's bottom after it is inserted into the gum. Combining titanium (Ti) and hydroxyapatite (HA) is regarded as a good amalgam for creating dental implants with excellent mechanical reinforcement. In order to solve the current dental issues, this review discusses the utilization of 3D printing technology to produce new dental implants.

APPLICATIONS OF 3D PRINTING IN IMPLANT DENTISTRY

The American Society for Testing and Materials categorization standard divides 3D printing into seven categories: sheet lamination, directed energy deposition, material extrusion (MEX), powder bed fusion (PBF), material jetting, binder jetting, and vat photopolymerization (VPP). While there are numerous AM techniques, implant dentistry does not employ them all. The technologies that are commonly utilized in implant dental practice are MEX (fused deposition modeling), PBF (selective laser melting, selective laser sintering, etc.), and VPP (stereolithography, SLA, DLP, etc.). Figure 1.The "additive" method is the foundation of all 3D printing technologies; the primary distinctions between them are in the materials and molding techniques employed. Technology for 3D printing should be chosen with consideration for the intended use.[4]

Steriolithography (SLA)

Utilizing a three-axis moving stage, high-power pulsed laser light is used in the laser melting/sintering process to raise the temperature in particular locations in order to fuse or sinter the new material. Glass, ceramics, metals, and thermoplastic polymers are just a few of the thermoplastic materials that can be fused using the SLS process. The surfaces can then be refreshed using a roller or blade to create new surface layers. Lastly, each sintered layer is covered with a powdered substance. The ability of sintering processes to produce an autoclavable product that can be handled safely using standard dental procedures is one of their most significant benefits.[5]

Digital Light Processing (DLP)

Dental model manufacturing is one of the main applications for DLP printers. There are variations between DLP and SLA in terms of the kind of light source and how it is managed to illuminate and cure the resin in a targeted manner. Whereas DLP employs a projector that looks like a movie projection device to light up the complete shape of the printed object at the liquid's surface, SLA uses a laser as its light source. The majority of DLP devices lack the great resolution that SLA laser beams can offer. Consequently, SLA is better for printing precise components with fine details, while DLP is better for printing larger parts quickly and with fewer details.[4]

Powder Bed Fusion (PBF)

The most widely used metal printing technology in the industry is PBF. For biomedical applications, titanium and Cr-Co alloys are the metal of choice due to their mechanical qualities, biocompatibility, electrical, magnetic, and thermal conductivity, as well as their overall resistance to high temperatures. PBF consists of SLM, electron beam melting (EBM), direct metal laser sintering (DMLS), and SLS. These methods usually involve melting microscopic particles, including glass, metal, ceramic, or plastic, in powder form using strong lasers or electron beams. Prior to printing, the powder is typically heated to a temperature lower than the material's melting point. The printer is then able to selectively melt powder on the powder bed's surface by controlling the energy source. One layer is melted, the powder bed shrinks to the height of one layer, and a fresh layer of powder is rolled onto the top to finish printing the new layer. [4]Due to its ability to create three-dimensional geometries, like delicate lattices, PBF technology is extensively utilized in orthopedics and dentistry, among other medical specialties, to create prostheses that encourage bone ingrowth. Furthermore, this method can be used to create implant frames and customized titanium mesh.[4]

Material Extrusion

The extrusion-based techniques use a computer-controlled nozzle with a specific diameter to dispense the material in three directions. In order to create a 3D structure at the centimeter scale, these techniques rely on a constant ejection of extruded material forced out of the nozzle, either mechanically or pneumatically. Several materials, including thermoplastic polymers, are melted and then forced out of the nozzle in the extrusion-based FDM process. The primary stage in

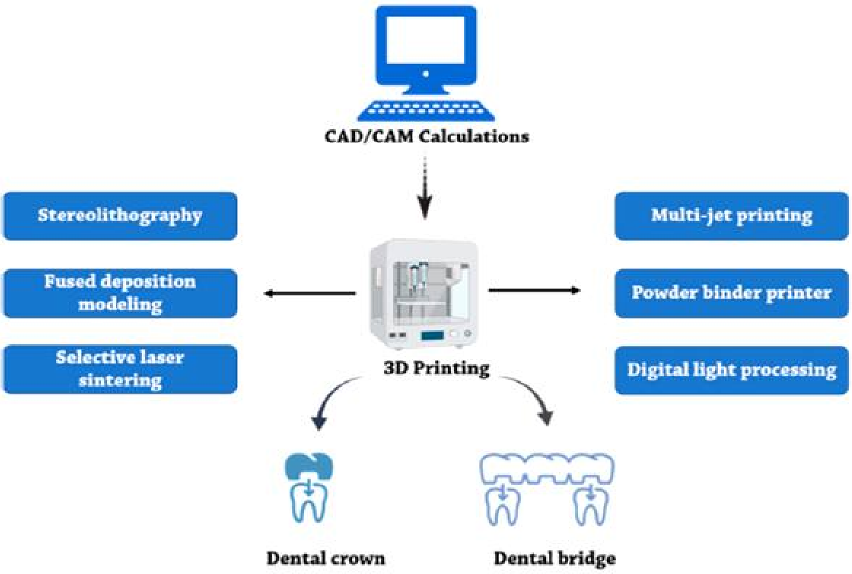


Figure 1 : Different 3D-printing models used in implant dentistry

creating advantageous three-dimensional structures is the cooling of molten material, which occurs concurrently with the melting material deposition on the instrument support.[5]

Material Extrusion

The Israeli company Objet filed for a patent in 2000 on the PolyJet technology, which is currently held by Stratasys. PolyJet uses UV light to instantly solidify a liquid photopolymer layer that is sprayed over the building tray. When compared to SLA, the PolyJet laser spot diameter is between 0.06 and 0.10 mm, which allows for significantly better printing accuracy and makes it easier to fabricate precise and smooth objects. Furthermore, PolyJet does not require secondary curing and may achieve quick printing because to its high-speed raster building technique. It has been shown that implant guides created with PolyJet technology are more precise than those created with SLA technology.[6]

Applications of 3D Printing in Implant Dentistry

Surgical Guides

For almost a decade, 3D printed surgical guides have been in use. The digital workflow for these guides is as follows. Based on data from 3D imaging, virtual planning and design is carried out utilizing computer software and digital work flows for manufacturing and planning. These plans are then transferred using 3D printed surgical guides.[Figure 2(A)] SLA is currently the most popular method because of its speed and economy. The creation of guides is also possible with some more recent technologies, including PolyJet [Figure3.4] Henprasert et al. discovered

Figure 2 : Applications of 3D printing technologies in implant dentistry clinical practice.

(A) 3D printed surgical guide.

(B) Personalized titanium mesh.

(C) Standardimplant.

(D) Customized root-analogue implant.

(E) Custom tray.

(F) Implant models.

(G) Implant framework.

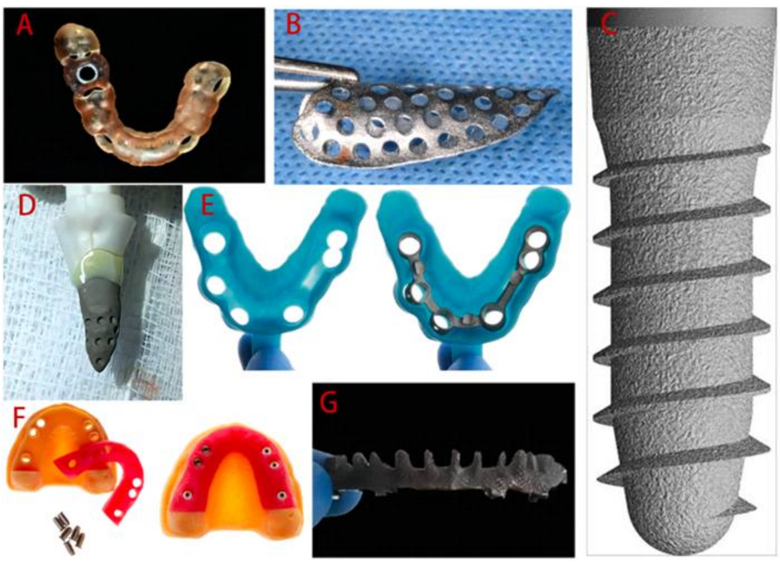


Figure 3 : Schematic diagram of guide production.

(A) Cone-beam computed tomography is used to generate 3D data from the teeth and jaws.

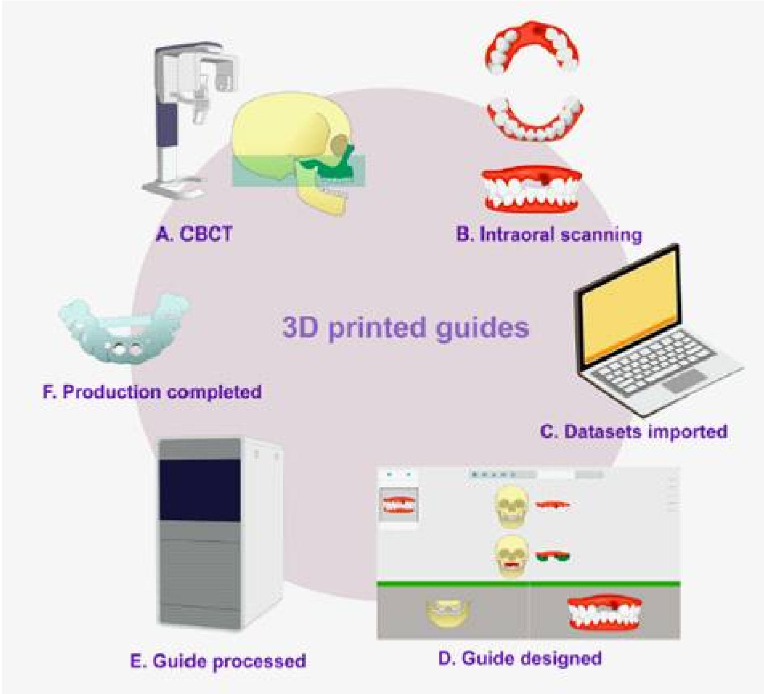
(B) Three dimensional information from the teeth and surrounding soft tissue is obtained by intraoral optical impression or scanned from a traditional plaster model.

(C)In the guide design software, the two datasets are imported in turn and then matched, checked, and confirmed.

(D) The guide is designed.

(E) 3D printing isused to fabricate the guide.

(F) The final guide is completed.



that while there was no discernible difference in accuracy between milled and 3D-printed guides, the former offered the benefits of increased efficiency and decreased material waste.[7]

Customized Titanium Mesh

GBR research and application are now concentrating on the creation of customized titanium mesh made possible by 3D printing technology in an effort to address the drawbacks of conventional titanium mesh. Using CAD software, the optimal alveolar bone is virtually built based on patient CBCT three-dimensional jaw data, taking into account the projected implant site and the geometry of the dental arch. Next, the reconstructed alveolar bone model is used directly to design the corresponding tailored titanium mesh. Finally, SLM is used in the production of bespoke titanium mesh [Figure 4.4]

Customized CAD/CAM titanium mesh[Figure 2(B)] can be utilized in bone augmentation surgery to treat horizontal and vertical bone deficiencies, especially those with a wide area and complex structure. Collecting intraoral scans and DICOM data from patients allows for computerized design and augmentation of the alveolar bone around the appropriate implant site. This approach provides improved precision and efficiency compared to regular GBR.[4]

Dental implants

By using 3D printing, titanium implants with a consistent micron-scale porosity structure can be created. Dental implants are normally prepared using SLM and EBM, and the materials utilized are primarily titanium and titanium alloys, while some researchers have tried using zirconia. Additionally, some researchers have suggested creating one-piece implants that can achieve optimal osseointegration

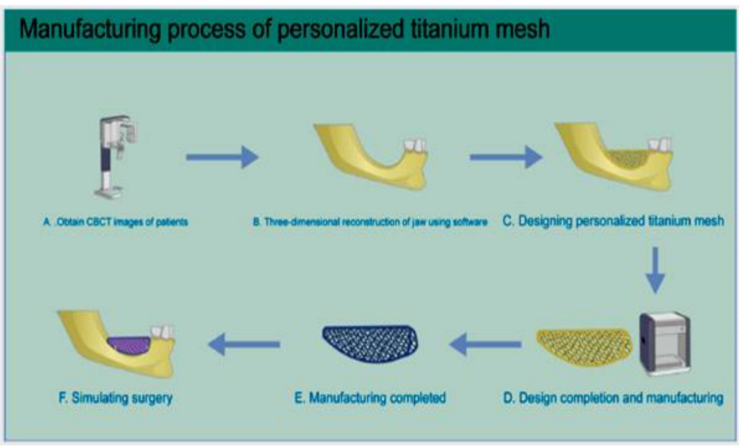


Figure 4 : Schematic diagram of personalized titanium mesh production. (A) Three dimensional CBCT image data of the patient's jaws is obtained. (B) The three dimensional jaw structure is reconstructed. (C) Personalized titanium mesh is designed according to the condition of alveolar bone defect. (D) After the design is completed, the file is imported into the 3D printer for manufacturing. (E) After printing is completed, the titanium mesh is treated by ultrasonic cleaning, sandblasting, and acid etching. (F) The situation is simulated during the operation.

and ideal soft tissue attachment by using titanium for the root section and zirconium for the abutment portion.[4]

3D printing allows for customization of implants that mimic natural root structures Figure 2(D). Implants that are customized can match the patient's extraction socket shape exactly. This method can replicate the ideal gingival profile of natural teeth and achieve good initial stability in immediate implant placement.[4]

In contrast to 3D printed root-analogue implants, another class of implants known as patient-matched implants are less customized. For instance, some researchers have utilized 3D printing to create narrow-diameter implants for patients with inadequate alveolar bone breadth[8]. Furthermore, dental implants that are not customized-like the ones that are now sold-are also made via 3D printing. Similar to a typical implant, the Italian "Tixos" implant is made using DMLS technology and is available in multiple sizes.[4]

3D printed implants made of polyether ether ketone (PEEK) have also drawn interest. PEEK is a bioinert material with low surface energy, which presents a difficulty for its use as a dental implant material despite its many advantages. As a result, suitable solutions should be devised to enhance PEEK's biological activity and achieve its potential benefits. PEEK implants can be printed using FDM or SLS 3D printing processes, with the former being utilized more frequently. But PEEK implants are largely still at the laboratory research stage when it comes to 3D printing, and more clinical studies and fundamental research data are needed before PEEK implants can be widely used in clinics.[4]

3D printed custom trays

Custom implant trays were made using three-dimensional printing technology. When compared to manually made customized trays, 3D printed custom trays[Figure 2(E)] provide numerous benefits. In order to provide more accurate oral tissue records, custom trays, first, have a sufficient extension range and more uniform 3D impression material space between the splinting structure and the tray; second, they shorten the time needed to fix the impression rod using materials like resin, shorten the duration of the clinical operation, and prevent the inaccuracies in definitive models that result from resin polymerization shrinkage.[4]

3D printed implant models

One of the first uses of 3D printing in dentistry is the materialization of digital impressions. The precise placement of the implant and its relationship to neighboring teeth must be guaranteed by the final implant model. The advantages of 3D printed models Figure 2(F) over traditional plaster models include reduced weight, damage resistance, superior finish, superior wear resistance, and the avoidance of incorrect analogue positioning-a problem that could arise from the artificial fixation of the implant analogue on the impression. Furthermore, the physical model makes it easier to assess the occlusal condition and interproximal contact, which is another way that 3D printed models outperform digital ones in this regard.[4]

3D printed implant framework

Implant-supported prosthesis frameworks [Figure 2(G)] are designed and manufactured in large quantities using CAD/CAM technologies. Following the completion of the CAD for implant-supported frameworks, addition or subtraction manufacturing is used to turn the virtual design into a tangible product. Subtractive methods result in material loss and may not capture the finer features of frameworks, even while they reduce some clinical stages and eliminate some human errors. Implant frameworks are also made using metal additive manufacturing (AM) techniques like SLM or EBM, which significantly lower material waste. Implant frameworks made using 3D printing may have mechanical qualities that are on par with or even superior to those of conventional casting. Furthermore, retainers on frames can be arbitrarily shaped to improve the adherence between the resin material and the framework.[4]

CONCLUSION

Technologies like CAD and 3D modelling and imaging are having a significant impact on every facet of dentistry. Using this digital data, 3D printing enables the precise creation of unique, intricate geometric shapes in a range of materials, either locally or at large industrial hubs. Even while 3D printers can currently manufacture almost whatever we need for our patients, no one technology can meet all of their needs. Similar technology is being used to print models for restorative dentistry and patterns for the lost wax process, which is becoming more significant with the rise of intraoral scanning systems. The technology is already widely used in orthodontics, where high-resolution printing in resin is already a completely practical proposition.

Using anatomical models created using a variety of 3D printing processes to help with treatment planning is becoming standard practice in maxillofacial and implant surgery. It is well known that using surgical guides printed in autoclavable nylon or resins (often) can make surgery less invasive and more predictable. Even though the cost of 3D printers is coming down, there are still a number of expenses to take into account, including post-processing requirements, adherence to stringent health and safety regulations, the cost of operating, supplies, maintenance, and the requirement for skilled operators. It seems certain that 3D printing will play a bigger and bigger part in dentistry despite these reservations.

Being in dentistry nowadays is incredibly interesting due to the convergence of technology such as scanning, visualisation, CAD, milling, and 3D printing, as well as the inherent creativity and curiosity of the field.

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