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3d printing and its uses in dentistry

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Abstract

3D printing has been acclaimed as a disruptive technology which will change manufacturing. The technology has a particular resonance with dentistry. It has become of great importance with advancement in 3D imaging and modelling technologies such as CBCT, intraoral scanning and CAD CAM in dentistry.

Advancement of technology in dentistry have improved the diagnostic accuracy, eased treatment delivery and reduced chair time allowing the dentist to provide more effective treatment.3D Printing allows the dentist to visualise, record hard and soft tissue significantly with precise measurement and print the models.

Uses of 3D printing include the production of drill guides for dental implants, the production of physical models for prosthodontics, orthodontics and surgery, the manufacture of dental, craniomaxillofacial and orthopedic implants and the fabrication of copings and frameworks for implant and dental restorations.

Multiple 3D printing methods such as Stereolithography (SLA), Inkjet based system, Selective laser sintering (SLM) and Fused deposition modelling (FDM) allows us rapid prototyping. Each technology offers specific advantages in the creation of particular type of products. In the dental field SLA and Inkjet based systems are most commonly used.

This paper reviews the types of 3D printing technologies available and their various applications in dentistry.

Keywords: Three-dimensional printing, Rapid additive manufacturing, Selective laser sintering, Stereo lithography.

Introduction

Three-Dimensional (3D) printing, also known as rapid prototyping (RP) or additive manufacturing (AM), involves the actual layer by layer addition of a material to fabricate an object or a structure using computer-aided designs and computer-aided manufacturing (CAD/CAM) technology or using advanced imaging and scanning[1].

The rise of 3D printing in dentistry has been parallel with CAD advancements and enhanced imaging techniques like cone beam computed tomography (CBCT) and magnetic resonance imaging (MRI) to plan

and print dental and maxillofacial prosthesis to restore and replace lost structures[2].

Previously, dentistry was mainly influenced by the process of subtractive manufacturing, also known as milling. However, it did not take into account the internal structure and hence could not reproduce the complex models in its entirety[3]. Nowadays, modern CAD software is available, which uses intricate algorithmic designs and artificial intelligence to aid in modelling any object or tissue and reproducing it exactly as the clinician desires[4].

3D printing has been used for a number of clinical applications in medicine and dentistry. In the field of medicine, the use of 3D printing to synthesize customized scaffolds for bone regeneration is perhaps its most important use[5].

This review discusses how this digital workflow materializes into the fabrication of diverse dental and orofacial prosthesis across various disciplines in dentistry.

History of 3d printing

A 3Dimensional object was printed for the first time by Charles Hull in the year 1983.Hull invented 3D printing which he named “stereolithography”. Stereolithography interprets the data in a CAD file by using the file in STL format.

Apart from shape the instructions may also include information on colour, texture and thickness of the object to be printed. Hull later founded the company 3D Systems which introduced the first commercially available 3D printer named SLA-250 in 1988[6].

3d printing techniques used in dentistry

Techniques	Advantages	Disadvantages
Stereolithography	Adaptable to variable material selection Highest resolution and accuracy Suitable for fine details and functional prototyping	High cost per part Complex post processing Biohazardous materials are used The final part is mechanically and vertically weak High maintenance laser
Selective laser sintering	Low cost for parts Mechanical properties maintained for functional prototyping, Wide range of materials	Polymer must be in powder Not suitable for large parts Designs with thing walls
Digital light processing	Simple components for the machine One of the smoothest finishes on parts is created by DLP	Larger parts would have lower resolution Not suitable for surgical guides requiring high accuracy Resolution only increases if the available build area is limited, (only visible on highly detailed models) small vertical voxel lines are created

Fused deposition modelling	Low cost - No flammable material hence no risk of explosion - Suitable for complex structures - Wide range of materials	Low accuracy and resolution Parts would need smoothening process after the print

Table 1: Advantages and disadvantages of the most commonly used additive manufacturing (AM) methods utilized in dentistry[7-10]

3d printing in oral surgery

Using 3D printing methods anatomical models can be constructed which can be used as a new approach for surgical treatment planning and simulation. This allows the surgeon to get an overview of the complex structures before performing the surgery[11].

In the early 1990s Anderl et al using CT guided stereolithography fabricated an acrylic model that allowed pre-operative treatment planning and intraoperative management in surgical correction of a wide midline craniofacial cleft in a 8 month old successfully[12].

In reconstruction of maxillofacial defects apart from maintenance of anatomic uniformity and appearance, it is also important to restore the tissue functions.

Autologous bone grafts remain as the gold standard in reconstruction of maxillofacial defects due to their osteoconductive and osteo-inductive properties. But the major disadvantage of autologous bone graft is that they require manual sculpting of defect shape.

Hence a treatment which is less invasive to treat bone defects are in need. Computer animated modelling and rapid manufacturing requires a series of events during which a computer designed virtual 3dimensional image turns into a solid model for clinical application[13].

3D printing can also be used to produce customised reconstruction plates and morphological reconstruction of bony defect area for cases of fractures and reconstruction surgery. It can also be used to design and construct a customised non-absorbable barrier of titanium mesh[14].

3d printing in endodontics

Since the late 80s, the diverse applications of 3D printing techniques have revolutionized the scope of design possibilities for creating new restorations, dental models and surgical guides, increasing the success rate of conventional surgeries dramatically[15].

Although use of 3D printing in endodontic treatments are yet to be explored, there are several reports and pre-clinical studies that describe the improvements brought in guided access, maneuvering obliterated pulp canals, auto transplantation, but most importantly in endodontic and general dental education[16].

Using a CAD/CAM-guided surgical template in endodontic surgery allows surgeons to target the root apex, especially in teeth with problematic anatomies.

Guided osteotomy and apex localization had been achieved using these templates in cases such as a mandibular molar with a thick buccal bone template.

In CBCT, the use of CAD/CAM has leveraged the data regarding the objects used in surgical or nonsurgical endodontics. The anatomically challenging cases have also been defined using targeted endodontic microsurgery (EMS) using 3D printed guides, and trephine burs.

When estimating control of depth, diameter and angle of root-resection, targeted EMS mainly benefits osteotomy more than traditional approaches. Irreversible pulpitis, pulp necrosis or apical periodontitis can now be dealt with using nonsurgical root canal treatment and EMS, which consequently relinquishes better outcomes (about 35% higher success rate) compared to the traditional

techniques allowing for superior visualization, magnification and illumination[17].

3d printing in prosthodontics

Restorations using crowns and bridges are among the common clinical procedures in prosthodontics. Traditionally, they were fabricated using the lost-wax technique, which is labour intensive and prone to human errors.

Understandably, comparative studies for evaluating various dental restorations parameters like crowns and bridges have been performed in light of the current popularity of 3D printing technologies to predict their reliability. Mai et al. (2017) reported that milling and additive manufacturing showed more accurate results regarding marginal fit compared with manual techniques. Moreover, 3D printed crowns had the most accurate occlusal fit and least internal discrepancies[18]

Several dental materials with varying mechanical properties have been used in fabricating dental crowns. Amongst them, ceramic materials, including alumina (AlO3) and zirconia (ZrO2) ceramics, have gained popularity in 3D printing due to their high bond strength, providing unique mechanical properties to crowns and bridges[19].

A previous study has reported that when DLP technique was used to print zirconia implants, they demonstrated sufficient dimensional accuracy. Moreover, an earlier in vitro study revealed that 3D printed zirconia crowns demonstrated similar trueness of the CAD/CAM crowns. This demonstrates that zirconia is a useful material for 3D printing in the field of prosthodontic dentistry. Nevertheless, the final verdict of their clinical success versus the cost involved still requires more systematic and comparative studies[20-22].

The exponential growth of using digital technologies in the field of prosthetic dentistry can be mainly attributed to their application in the fabrication of removable prosthesis, such as complete and partial dentures.

In recent years, dentures fabricated by digital techniques have become increasingly popular. Because there is a variety of different CAD/CAM programs and protocols, the procedures for the digital manufacturing of dentures can vary, with some requiring only two appointments with the dentist[23-24].

In addition to the reduced chair time for patients, digital dentistry allows for the storage of electronic data, enabling technicians to precisely duplicate a denture in a matter of hours. Furthermore, variability in quality can be minimized.

3d printing in maxillofacial prosthesis

3D printed implants are used for replacement and reconstruction of zygomatic bones, temporal bones including ear ossicles, calvarial bones and mandibles. They are also used in soft tissue reconstruction of head and neck.

These are more suitable following a trauma or a tumour resection. After a tumour resection of ameloblastomas there is a requirement of considerable bone and soft tissue reconstruction. With the help of 3D implants cosmetic defects associated with these surgeries has been reduced significantly[25]

3d printing in dental implantology

The introduction of 3D printing allows the fabrication of precise and economical dental implants. The 3D printing process involves designing a 3D model which is constructed by computer-aided design software.

The obtained 3D model is then changed into cross-sectional parts and then directed to the 3D printer, which deposits coating after coating of the selected material to yield an item. Concerning dental implants, 3D printing is usually performed to obtain a surgical guide for the future accurate placement of implants. However,

scientific literature reports 3D printing to manufacture osteosynthesis plates and mandibular reconstruction as well[26,27].

3d printing in dental education

To prepare dental students for their first living patient, extensive hands-on training is required in a preclinical setting. With computerized dentistry becoming an essential fragment of dental learning and dental practice, 3D printing has started to enhance components of dental education.

Regardless of progress in 3D printing, only straightforward tooth models have been available for dental students to enhance their manual skills [28,29].

Current challenges and future directions

3D printing is a technique gaining popularity in dentistry and is different from conventional subtractive computer-aided manufacturing techniques.

In comparison, 3D printing is an additive process with little material waste, is more accurate, and can operate using several materials such as plastics, metals, and ceramics, which are applicable to dentistry.

While 3D printing has changed the workflow and has allowed for innovation in several aspects, it still faces some challenges. For example, in surgery, computed tomography and 3D printing are paving the way to produce surgical guides; however, some of the materials used may not be autoclavable and sterilizable, thus limiting their use.

In addition, accuracy is often dictated by the quality of the original scan taken by intraoral scanners, which remain inaccurate when taking full arch scans or surfaces with irregularities.

Due to the increased popularization and accessibility of 3D printing and intraoral scanners, the dental workflow is experiencing a shift to the digital realm, with many practices digitizing their patient data.

The 3D printers allow dentists to print models when needed and work digitally on other cases that permit it.

This shift allows a decrease need for storage space in offices.

However, it increases ethical issues such as data privacy, protection, and confidentiality, especially since digitizing patient data can make it more accessible for research use [30-32].

Conclusion

With the help of 3D Imaging and CAD/CAM Technology 3D printing is in the forefront position hugely impacting on all aspects. It enables to create a complex geometrical form using a variety of materials from digital data in specific patients.

With the increased use of intra-oral scanning system, it is already applied practically in orthodontics by high resolution printing resin, printing models for restorative dentistry and lost wax process pattern.

In craniofacial and implant surgery 3D printed anatomical model is becoming more essential as it guides in treatment planning of complex surgeries. It is also widely accepted that the surgery becomes less invasive, more predictable and accurate with the help of surgical guides made from resins.

Even though 3D printing is becoming cost effective in the present but still the cost of running, materials used and maintenance of the machines are still areas of concern. The demand for well-trained operators, post processing, adherence to strict health and safety measures should be considered.

As the technology evolves, it is important for the dentist to be alongside the advances that may have the future to benefit both the dentist and the patient.

3D printing is emerging as a promising technology, with innate curiosity and creativity of the dentist, makes this an extremely exciting time to be in the industry.

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