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3-D Printing: Its Applications in Pediatric Dental Practice: A Review of Literature

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Abstract

Background: Over the last few years, Three-dimensional (3-D) printing, and prototyping has gained popularity within medical and dental profession and among patients alike. 3-D printing is an additive manufacturing technique in which objects are formed by deposition of material layer by layer. 3-D printers are machines that produce representations of objects either planned with a CAD program or scanned with a 3-D scanner. This article highlights the evolution, benefits and application of 3-D printers in pediatric dentistry.

Keywords: Additive Manufacturing, 3-D printers, Pediatric Dentistry, customization, digital dentistry

Introduction

Three-dimensional (3-D) printing is the incremental addition of multiple layer of materials that leads to the fabrication of an object using a computer aided design or computer aided manufacturing (CAD/ CAM) technology or scanning[1]. It is also known as Rapid Prototyping (RP), Solid Freeform Fabrication or Additive Manufacturing (AM)[1]. The last few years have seen an expansion of 3-D printing in the field of Medicine and Dentistry in the form of anatomical models, regenerative medicine, surgical guides [2]. The use of 3-D printing in the field of medicine and dentistry allows for customization and personalization of medical and dental products. In the past 3-D printing was considered a laborious and expensive technique but with the invent of new technique 3-D printing has been shown to be a rather cost effective method[2,3]. Improved technology like increased accuracy, better resolution imaging and state of art 3-D printers have lead 3-D printing to become mainstream technique in various different fields[4]. In dentistry diagnosis is the key to treatment, especially in a field like Pediatric dentistry. The main goal of pediatric dentistry is to provide the best dental care to the child without instilling fear in the child[5]. 3-D printing reduces the hassles of manual techniques and allows us to replace them with automated devices such as intra oral scanners and advanced imaging which provide much better precision and less associated errors.[1]

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Review Method

An electronic data search was done using electronic databases such as ScienceDirect®, MEDLINE/PubMed®, Embase, British Medical Journals, Biomed and Cochrane databases for all the articles related to 3-D printing and its applications in Pediatric Dentistry. Abstracts or full text articles including original research, reviews or systematic reviews and meta-analysis related to 3-D printing in Pediatric Dentistry met with the inclusion criteria. The following search sequences for different databases with suitable alterations were used: "additive manufacturing", "3-D Printing", "digital dentistry", "rapid prototyping" and "3-D Print technology".

Evolution of 3-D Printing [2,4]

Charles Hull in the year 1984 invented the stereolithography (SLA) 3-D printing. This was followed by the development of the selective laser sintering (SLS) process by Carl Deckard in 1986. The year 1988 saw the dawn of bioprinting by 2-D micropositioning of cells by Charles Hull along with the production of the first commercial SLA 3-D printer. 1999 saw a breakthrough in 3-D printing where the first 3-D printed organ – a bladder was used in a transplantation by the Wake Forest Institute for regenerative medicine. This paved the way for 3-D printed organs to be used in transplants. In 2000 Envision TEC launched the 3-D Bioplotter which is the first commercial extrusion based bioprinter, which lead to the first early stage 3-D printed kidney prototype to be printed by the Wake Forest Institute in 2002. The first 3-D printed prosthetic leg was in the year 2008 followed by 3-D printed blood vessels by Organovo in 2009. A breakthrough in the field of dentistry was seen in the year 2012 when the first prosthetic jaw was 3-D printed. In the year 2015 another innovation seen in dentistry was when the first implanted 3-D printed bioresorbable scaffold was used for periodontal repair by the University of Michigan.

3D Printing and its uses in Dentistry

In dentistry the most common techniques of 3-D printing are stereolithography (SLA), fused deposition modelling (FDM), selective laser sintering (SLS) and digital light processing (DLP)[1,4,6].

- **Stereolithography (SLA/SLG)**: It is a technique of 3-D printing which makes use of mirrors and mechanizes the mirror to selectively move an ultraviolet (UV) beam of light to fuse two surfaces containing liquid photoreactive resin. This process is followed up by a wiper blade recoating the surface that has been cured and fusion step with the possibility of dyeing and permeating certain specific areas[4,7]. Advantages of SLA are flexible to varying material selection, highest accuracy and resolution and ideal for functional prototypes[1,4]. Some drawbacks may include high cost per part and the high maintenance laser[1].
- **Fused deposition modelling (FDM)**: It is an extrusion based printing technique where thermoplastic materials are melted to develop fibers , deposited to create customized objects. (8) Extrusion based techniques depend on continuous deposition of materials pushed out of a syringe by an inflatable or mechanical forces creating a 3-D construct at the centimeter scale[9]. Advantages of FDM include low cost, wide variety of materials and its suitability for construction of complex structures[1,4]. Some disadvantages to FDM are decreased accuracy and individual parts requiring a smoothening after each print[1].
- **Selective laser sintering (SLS)**: In this technique, a high-powered laser is used to fuse thermoplastic polymer materials. This leads to formation of surface layers which are refreshed using rollers or blades using a powdered material. The most important benefit of a 3-D printed model using the SLS technique is that they are thermoplastic in nature and hence can be autoclaved before use. Other advantages of SLS include low cost of the parts and can be used for functional prototyping. Drawbacks of SLS are the polymer is in the form of a powder, designs with thin walls that is less than 1mm are difficult to print and high maintenance[1,4,7].
- **Digital light processing (DLP)**: This technique is similar to that of stereolithography used for printing 3-D models. Instead of the moving mirrors as used in SLA, a micromirror is used to create a cross sectional UV image. The use of photocurable resins in dentistry

is highly suitable and the process of DLP employs this technique for the fabrication of a single layer using UV and white light. The ultimate outcome of the 3-D print model can be modified by making small manipulations in the resin's characteristics. DLP technique has one of the smoothest finishes on 3-D print models. However DLP cannot be used to print surgical guides requiring high accuracy[7].

Materials used in Dental 3-D Printing

An array of materials can be employed for 3-D printing like hydrogels, polymers and thermoplastics, ceramics and metals:

1. **Hydrogels:**

   They are materials used for 3-D printing and are believed to be the most ideal material for this technique. They are porous crosslinked polymers which have hydrophilic characteristics that causes them to preserve water[10–12]. This comes as an advantage as this property bear a resemblance to that of the natural extra cellular matrix. The ability for a hydrogel to be printed is defined by its viscosity. Hydrogels should be flowable enough and should have the ability to be ejected out of the nozzle, however they should also be thick enough to allow formation and support to the different structural layers. Various permutations of hydrogels are available. Photocrosslinkable gels are combination hydrogels which can be both created and destroyed by UV light[1]. Reinforced composite or composite polymer hydrogels are another form of combination of hydrogels. These incorporate natural or synthetic polymers[1]. Interpenetrating polymer networks are also an example of combination hydrogels[1]. Some synthetic polymers used in 3-D printing are polyacrylamide, polyethylene glycol, polyvinyl alcohol, owing to their mechanical properties and controllable properties in degradation[1].

2. **Polymers and Thermoplastic Materials[1]:**

   Polymers are the most commonly used materials amongst all available materials in additive manufacturing. Resins and Polymers are 3-D printed using the photopolymerization technique. Photopolymerization has several advantages like easy to use and time efficient which benefits the 3-D printed model by providing a smooth finish, excellent chemical bonding and mechanical strength[13]. Thermoplastic polymeric materials are made from polymers which are heated and the deposited through a large syringe allowing the materials to be customized for a particular structure. Most recent advances in 3-D dental printing is the use of high melting thermoplastic substances like polyether ether ketone (PEEK) and polymethyl methacrylate (PMMA)[14].

3. **Ceramics (1):**

   Another common material used for 3-D printing in dentistry are ceramics. Ceramic powders or pre sintered ceramic used in the SLA and SLS techniques and are targeted to increase bond strength[15]. Owing to ceramics high density there are certain post-processing challenges faced, porous structures have been seen to be developed using powdered ceramic through SLS. In addition, 3-D printing techniques using ceramic shows constraints as sintering this material can lead to anisotropic shrinkage and further fabrication leads to stair-step defects on the exteriors[15].

4. **Metals[1]:**

   Metals are also a common material used in the field of dentistry. It is more commonly used in the field of 3-D printing using the SLS method. Similar to ceramics, using metals for creating 3-D prostheses lead to the formation of porous structures. However Titanium and Cobalt chromium (CoCr) are the most favourable metals used for fabricating 3-D dental prostheses. Barazanchi et al. in 2020 demonstrated that CoCr materials that have been engineered by SLS were seen to have a superior bonding ability with porcelain as compared to CoCr materials that were manufactured by soft milling.

These properties lead to the conclusion that the alloys demonstrated a good strength in the oral cavity and acceptance against loads, making it a preferred material for 3D-printing of dental prostheses in long term applications[15].

Benefits of 3-D Printing

The biggest advantage provided by 3-D printers in the field of dentistry is the ability of customization providing value to both the dentist and patient. Custom made prostheses, surgical guides, fixtures has a positive impact on the time taken for treatment and post treatment recovery[4]. It has also been seen that 3-D printing allows for customized drug dosage forms for individual patients.

- ***Increased cost effectiveness[4]:***

  An important benefit of 3-D printing is the ability to produce items at a reasonable price. Manufacturing methods cost less in a large-scale production. The cost to custom-print a 3D object is very less and is advantageous for companies with low production volumes. There is also a reduction in manufacturing costs by decreasingunnecessary resources.

- ***Enhanced productivity[4]:***

  3-D printing is considered to be a faster procedure as compared to milling and forging which lead to a longer delivery time. It also provides higher accuracy, resolution and reliability.

Uses of 3-D printing in Dentistry[16]

Dental cast of patient's teeth have always been made with dental plaster/stone for orthodontic correction and prosthodontic rehabilitation. On the other hand orthodontic appliances, prosthodontic dentures and implants were fabricated using basic techniques. Now it has become possible to directly fabricate orthodontic appliances, crowns and bridges or implant stents using 3D printers based on the patient's dentition data which is scanned using digital-based devices such as 3-D scanners and dental CBCT. In addition to this, it is possible to fabricate jawbones, dental models and surgical instruments increasing the efficiency of the treatment.

The amalgamation of 3-D printing technology that includes 3-D oral scanning, CAD- CAM and design software, allows dental laboratories to produce various dental orthodontic devices such as dental stone models, transparent braces and veneer prototypes quickly and precisely which are similar to the real teeth.

Another major advantage of 3-D printing in dentistry is that the patient's case report can be archived as digital data, instead of saving piles of physical records. SLA printers are used specially for orthodontic retainer fabrication. For prosthodontic purposes a DLP printer is preferred for coping. DLP, SLA, and polyjet printers are used to fabricate the dental model, FDM, DLP and SLS are used for the fabrication of denture frameworks.

Applications in Pediatric Dentistry

The field of pediatric dentistry aims at providing comprehensive oral health care in infants and toddlers through adolescence. Various studies[16] have been performed to understand the use of 3-D printing in diagnosis and treatment of patients in pediatric dentistry.

a) Autogenous Transplantation of Teeth

Missing teeth, impacted teeth or supernumerary teeth can be a problem in growing children, autogenous tooth implant has been used as a treatment modality in such cases[16]. Reducing damage to the periodontal fascia of the donor tooth is the most important criteria for a successful autogenous tooth transplantation. A model of the tooth to be donated is 3-D printed to be used as a guide. The extraction of the donor tooth model should be done with utmost care. The alveolar fossa at the recipient site should be in contact with the root of the donor tooth for transfer or oxygen and nutrients. To avoid excessive contact of the donor tooth with the alveolar fossa in the recipient site, autogenous tooth transplant method using rapid prototyping is performed by using the model tooth as a guide in the trial-and-error method instead ofthe natural tooth.

Using a 3D image analysis program, simulation can also be performed in advance regarding the direction, inclination, and depth of the implanted teeth avoiding unnecessary damage to periodontal fascia and decreasing extra oral time.

b) Surgical Guide in Diagnosis and Treatment

Joseph et. al. [17] in 2021 used 3-D printing in the diagnosis and treatment of a patient with unerupted maxillary central incisors. In this study CBCT and 3-D imaging were used simultaneously to produce a 3-D model of the patient's dentition. The time taken for fabrication of one model cast and 2 guides using 3-D printing was less in comparison to that of the manual technique. There were no technical issues faced during the construction of the cast. Using 3-D printed models and guides the surgical team assessed the distance between the unerupted maxillary central incisors to its surrounding structures. Based on the 3-D printed templates used as surgical guides, the risks involved in the treatment were explained to the parents in advance.

c) 3-D Printed Band and Loop Space Maintainer

Pawar et. al.[18] in 2019 3-D printed a Band and Loop space maintainer for management of premature loss of a lower left first deciduous molar. In this particular case report an ideal mixed dentition cast was poured using a standard dye. A 3-D digital dental scanner was used to scan the cast, which was followed up by designing the space maintainer on the dental CAD. Two space maintainers were fabricated using two different techniques. The first type of band and loop was fabricated using a metal powder by the micro laser sintering technique, whereas the second band and loop was printed using clear photopolymer resin. Use of a 3-D printer in such cases increases the precision of the appliance, reduces lab work by avoiding soldering of the band and reduces chair side time of the patient. A 3-D printed structure has more complex structure and higher level of detail.

Khanna et. al.[19] in 2021 fabricated a band and loop appliance using powdered metal using the micro laser sintering technique. It was observed that there was a drastic change in patient behaviour and cooperation due to the reduced chair side time. In the follow up visit post 6 months the 3-D printed band and loop was intact and there was no plaque accumulation as would be seen with a conventional band and loop space maintainer. The gingival sulcus on the buccal aspect of the conventional band and loop showed slight inflammation owing to the solder joint which was not seen in the case of the 3-D printed band and loop. The solder joint on the conventional band and loop also demonstrated a crack. All this led to the conclusion that the 3-D printed space maintainer showed excellent fit, increased longevity, and an accurate detail.

d) Custom Crowns

Custom crowns can also be printed using rapid prototyping. The process of fitting a prefabricated crown to a tooth requires increased chair side time as trimming of the crown is required to achieve the perfect fit. After removal of the tooth, or pulp therapy procedure a digital scan of the dental arch is taken to create a 3-D model of the dentition. The same digital dentition data can be used to design the custom crown and3-D print the crown. These crowns are 3-D printed and wrapped upto the thickness of 1mm.

e) 3-D Printed Drug Formulations

Another innovation of 3-D printing in the field of Pediatric dentistry is the 3-D printed drug formulations[20]. This method allows for the fabrication of gummy drug formulation specifically tailored to an individual patient's needs. The gummy drug formulations are ejected from the nozzle of the 3D bio-printer under air pressure and coated from the bottom in an incremental layering process. This study proved to be a promising scope for future setting of personalized medicine in a clinical setup.

f) 3-D Printed Mini Tablets

Another study focusing on 3-D printed mini tablets was performed by Krause et. al[21].This study focused on the production of mini tablets using fused deposition modelling (FDM). Subsequently mini tablets having diameters ranging between 1.5mm to 4mm were printed. It highlighted the benefit of an FDM printer in 3-D printing of patient specific, small batch, on demand pediatric dosage medications.

Conclusion[22]

3-D printing is an additive process with minimal wastage of material, precision outcome, and wide variety of materials whichare applicable to dentistry can be used. 3-D printing is a revolution in the field of dentistry. It has proven to be beneficial in patient diagnosis, treatment, and compliance. In children and adolescents with the tendency to gag, uncooperative behaviour and in those with special needs, 3-D printing is an ideal choice for diagnosisand treatment planning. It makes taking impressions for crowns, restorations, orthodontic treatment much simpler.

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