Review Article

A Review on Revolutionizing Pediatric Dental Treatments with 3D Printing Technology: Current Trends and Future Prospects

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ABSTRACT

The advent of 3D printing technology has revolutionized the field of dentistry, leading to significant advancements in clinical applications and research. The integration of 3D printing with CAD-CAM technology facilitates the layer-by-layer manufacturing of three-dimensional objects by sequentially adding material. 3D printing is a resourceful technique that allows the development of fully digitalized and personalized treatment plans, thereby helping to customize dental appliances for patients. It is highly competent, replicable, and provides fast and precise results in a reasonably priced style. Recently, 3D printing technology has played a major role in pediatric dentistry from the printing of individualized imprint trays, orthodontic models, maxillo-facial growth evaluation, interceptive appliances, fabrication of prosthetics, and crowns, during fracture, surgical cases, and navigating complex root canal treatments in pediatric patients. Through this review, we intend to discuss the scope of 3D printing in the field of pediatric dentistry.

Key words: 3D Printing, Pediatric dentistry, Additive manufacturing

Three-dimensional printing, commonly known as additive manufacturing, is a revolutionary technology that refers to the process of designing and fabricating 3D objects by incremental deposition of materials like polymers, metals, ceramics, and also living cells.[1] 3D printing has been embraced in different areas of health and medicine, including regenerative medicine, tissue engineering, dentistry, engineered tissue models, medical equipment, human anatomical models, organ printing, and the Pharmaceutical industry.[2]

In the field of dentistry, in specific, Pediatric dentistry, the application of 3D printing has various expanses such as restorative treatment, space maintainers, nasoalveolar molding therapy, myo-functional appliances, dental and maxillofacial trauma, autotransplantation of tooth and endodontic applications, craniofacial congenital anomalies, patient and parent education, personalized drug printing, customized tools, and instrument printing.[3]

Thus, looking into this newer technology, this review article aims to explore the current scope and future perspectives of 3D printing technology within the field of pediatric dentistry.

HISTORY OF 3D PRINTING

The origins of 3D Printing trace back to the 1980s, when the technology was initially known as “rapid prototyping” (Figure 1).[4-7]

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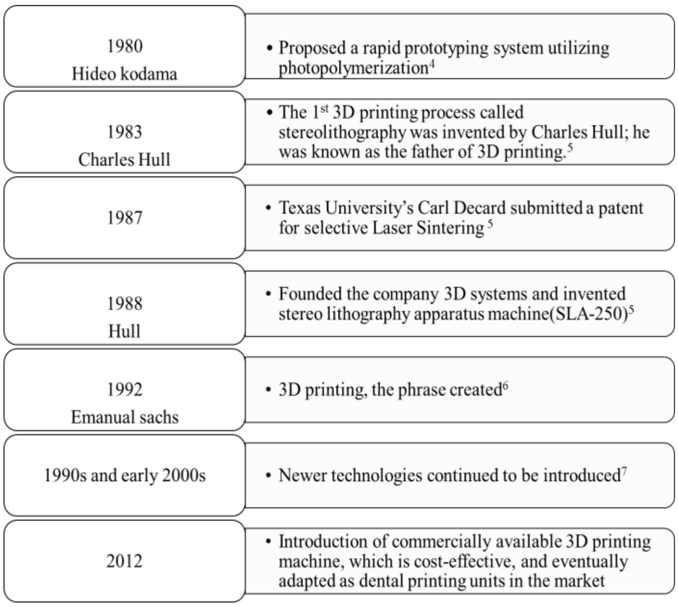

Figure 1: History of 3D printing

MATERIALS USED IN DENTAL THREE-DIMENSIONAL PRINTING

The array of printable materials extended to include polymers, metals, ceramics, and human tissue.

(a) Polymers

Polycaprolactone (PCL) - PCL is a semi-crystalline aliphatic thermoplastic biodegradable resin that has a low melting point (63 °C) and softens around 40°C.[7, 8]

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Polylactic acid (PLA) - PLA is a rigid green polymer obtained from renewable monomers, which require an optimum temperature to show the properties of a 3D material.[7]

Acrylonitrile butadiene styrene - It is an oil-based material with high durability. It has a bone stimulatory effect with easier processing.[7, 9]

Polylactic-co-glycolic acid - It is a biocompatible material as the parent materials are biological byproducts. Its extensive application in 3D printing is due to its well-defined architecture and regular-sized pores, which lead to high transparency and porosity.[7]

(b) Bio-inorganic material

Ceramic - Bioinert ceramics include carbon, alumina (Al2O3), zirconia (ZrO2), and single oxide ceramics. They allow the development of capsules that are fibrous in nature without forming any physical bond with the bone. Restorative material like porcelain-fused metal dental crowns is another category of ceramic material that has its place in 3D dentistry. They possess high compressible and tensile strength with adorable aesthetics.[10]

Hydroxyapatite (HA) - Nanosized HA particles synthesized by the 3D technique are similar to hydroxyapatite found in the biological system. Smaller HA particles have additional characteristics of better adhesion, cell growth, and cellular adherence with the host cells.[7]

Plaster - Stereolithographic printers are used for digital printing using plaster. It helps in the construction of digital libraries and the plaster cast conversion when required.[7]

(c) Metal - Ti-Zr alloy, titanium alloy, Co-Cr alloy, etc., have been extensively utilized in the fabrication of dental prosthesis.[11]

TECHNIQUES OF 3D PRINTING APPLIED TO DENTISTRY

(a) STEREOLITHOGRAPHY

It is the most commonly used and earliest technique in 3D printing that uses monomer resin which is photosensitive in nature is exposed to UV light, and then transforms into a polymer that eventually solidifies. Curing of the layers is done in a sequential manner, which helps them bind to one another forming a mass that is solid in nature, and it begins from the bottom.[4, 6] It is employed in the production of resin-based entities, including provisional crowns, resin prosthetic teeth, removable dentures, mouth guards, implant guides, surgical stents, etc.[5]

(b) FUSED DEPOSITION MODELLING

A thermoplastic polymer material which is semi-liquid is deposited in increments layer by layer to construct an object by a nozzle system that is temperature-controlled, and the material's motion is computer-controlled, solidifies in 0.1 seconds, and bonds to the prior layer. The entire procedure is carried out in a chamber. It is employed in the production of anatomic models of the edentulous mandible.[4, 5]

(c) SELECTIVE LASER SINTERING

A high-powered laser is aimed at a small layer of powder on a substrate using a mirror. When the beam strikes the powder, it creates a melt pool, fusing the powder particles together. The powder bed is lowered by one layer of thickness after scanning each cross-section and a new layer of material is put on top. This procedure repeats itself till the thing is finished. It is employed in the fabrication of anatomical study models, cutting and drilling guides, implant bridge frameworks, cobalt chromium RPD frameworks, etc.[5]

(d) PHOTOPOLYMER JETTING

By using material jetting 3D printers, Micro droplets of liquid photopolymer resin are sprayed onto a build tray, which then polymerizes the resin using UV light. It's easy to use and does not require a final cure.[5] It is used in designing craniofacial implant guides, anatomic models, etc.[5, 7]

(e) ELECTRON BEAM MELTING

It is carried out in a high vacuum chamber, in which liquefaction of metal powder is done by using an electron beam which acts as a power source.[4, 6]

(f) POWER BINDER PRINTERS

In power binder printers, powder and liquid droplets that are pigmented are deposited in increments, layer by layer. The final model is built with a new layer of unfiltered powder on the surface.[4, 6]

(g) DIRECT LIGHT PROCESSING (DLP)

An elevating platform is used for the construction of the object, and a projector is used through which resin is deposited in layers and cured, and the layers are created upside down. Printing occurs in sequential layers after curing of the resin.[4, 6] DLP printers are frequently employed to produce resinous wax mimetic substances for casting purposes and the creation of dental models

(h) BIOPRINTING

The process involved in printing living tissues is known as 3D bioprinting. It employs the use of biomaterials, cells, or cell factors as bio ink to fabricate tissue structures. Parameters like biocompatibility, cell viability, and cellular microenvironments of the material can greatly alter the printed product. The goal of this method is to design 3D artificial tissues that consist of a scaffold, cells, and an environment that is similar to the real environment of the human body. It creates structures with living cells, soft and hard tissue scaffolds, 3-dimensional hydrogels, ceramics, and hydrogels, etc.[12]

STEPS IN 3D PRINTING

The patient's 3D model either physically/digitally is acquired

↓

Designing with compatible software to create STL files and object files and review scan

↓

Patient-specific surgical guide design

↓

Optimization and export for the final print

↓

Material selection and printing followed by validation and post-processing

↓

Sterilization and disinfection

APPLICATIONS IN PEDIATRIC DENTISTRY

3D printing technology has recently gained the utmost importance in the field of pediatric dentistry.

(1) DIAGNOSIS AND TREATMENT PLAN

Nasopharyngeal obstruction in children is a prevalent concern impacting their well-being and development, with numerous etiologies. Adenoid hypertrophy is one among them that need early diagnosis and management. 3D printing technology combined with cone beam computed tomography (CBCT) to make 3D printed models can do wonders when identifying a nasopharyngeal obstruction, as compared to direct clinical evaluation, which can give limited visualization.[13]

(2) ANTERIOR TEETH RESTORATION

Aesthetic restoration of the central incisors is carried out with a template, produced by 3D printing. Expected results were achieved, including appropriate colour, tooth anatomy, and translucency of the tooth. The composite injection technique, which offers a complete digital workflow, is used in the restoration of post-orthodontic treatment in the anterior teeth and teeth in microdontia.[4, 14]

(3) PEDIATRIC ENDODONTICS

Analysing complex root canal anatomy with obliterated and lateral canals can be challenging with 2D radiographs. By using 3D printing technology, a custom-made endodontic guide can be designed, which can navigate the obliterated pulp. Thus, iatrogenic root damage can be reduced by decreasing the risk of severe dentin destruction or root perforation. While planning for treatment during complex root canals or surgical endodontics like apicoectomy with the help of 3D printing a patient's root canal, 3D architecture can be printed by using digital data from the patient's CBCT.[4, 15]

(4) PROSTHETIC RESTORATIONS

Recently, in pediatric dentistry, 3D printing has become widespread in the production of aesthetic pediatric dental crowns. The crowns produced with 3D printing displayed superior retention and gingival response, suggesting their reliability and efficiency for restoring primary molars. The clinical performance of 3D-printed crowns is compared with direct composite celluloid crowns in primary molar restorations. Both restorations offered suitable aesthetic alternatives but the 3D-printed crowns exhibited greater marginal integrity and superior gingival health.[16]

(5) 3D PRINTED OCCLUSAL SPLINTS

Clear, removable occlusal splints have been fabricated with 3D printing in early anterior cross bites for preschool children. These splints relieved the dental phobia of young children, as it was comfortable and easier to wear than conventional appliances, as they do not have any wire components in them. Also, the cross-bite in the anterior region was corrected in six months, which promotes the normal development of the maxilla and mandible and avoids difficulties in the future.[17]

(6) 3D PRINTED SPACE MAINTAINERS

Space maintenance fabricated through CAD-CAM or 3D printing technologies using biocompatible substances is referred to as digital space maintenance. The 3D printed space maintenance can serve as an alternatives to conventional space maintenance as they have high strength, smooth surface, quick fabrication time, lightweight and do not cause gingival trauma. The chances of fracture are solder failure might mitigated, as it is printed as one unit with no need of polishing, thereby saving chair side time.[18]

(7) INTERCEPTIVE ORTHODONTICS FOR YOUNG AND ADOLESCENTS

With 3D printing technology and artificial intelligence software, it is now very much possible to virtually present facial changes to patients. The patients can see and feel the three-dimensional models of corrected arches and precise changes in their hands.[5]

Stereolithography can 3D print customized braces with specific tips and torque or individualized clear aligners for patients. In the foreseeable future, it will be very much possible to 3D print precise myofunctional appliances like the Herbst appliance, the activator appliance, and twin box block appliances for growing patients according to their needs. Bioprinting of complex oral tissue structures can help to study the biological response to forces induced by orthodontic treatment.[19]

(8) 3D PRINTED SURGICAL GUIDES

Orthognathic surgery is another field of surgical dentistry where 3D printing technology can be very helpful in the future. Auto-rotation of the temporomandibular joint during orthognathic surgery leads to condylar instability, which is a major problem. A personalized orthognathic surgical glide system is used to hold the condyle in the correct position with the help of screws or titanium plates. Highly patient-specific titanium plates and screws can be produced by using 3D printing technology with a CAD CAM, device which results in better surgical compatibility and high accuracy.[20, 21]

(9) MANAGEMENT OF FRACTURED MANDIBLE

Managing pediatric fractures poses a significant challenge, given the crucial role of patient cooperation in most cases. In addition, fractures are treated differently than in adults. In cases of mild fractures, where the displacement is not pronounced, a conservative approach is generally advised. When there is a clear displacement, the necessity for accurate and minimally invasive surgical intervention becomes paramount to mitigate effects on the growth and development of the jaw and the eruption of permanent teeth in pediatric patients. Such interventions are rendered more intricate due to the unique anatomical and physiological properties of children's jaw bones, which are notably thin and elastic. Thus, with the use of 3D printing, digital construction of a 3D splint is facilitated by CT scan information, and the resulting splint can be cemented or cured in place in the traumatized region.[22]

Bone plate contouring is a challenging and laborious approach in mandibular fracture treatment. With the advent of 3D printing templates, plate contouring in complex mandibular fractures can be made easy. 3D printers help in producing bone tissues that are customized scaffolds that are biomimetic in nature, which can also help in bone cell augmentation, tissue development, and differentiation.[5]

(10) MANAGEMENT OF CRANIOMAXILLOFACIAL CONGENITAL ANOMALIES

In patients with orofacial defects, 3D printing allows the creation of 3D models, which helps in visualizing maxillofacial defects, pre-surgical planning, and the development of surgical guides. These models also help in the fabrication of obturators for cleft defect patients.[5]

3D printing has materialized a bio ceramic scaffold which serves to function as an autogenous graft with osteogenic potential and a safety profile for pediatric bone tissue engineering. It could provide a local delivery mechanism that possibly enhances the extracellular concentration of adenosine, which induces osteogenesis and also finds application in congenital anomalies such as craniosynostosis.[7]

(11) REGENERATIVE ENDODONTICS

3D printing is used in delivering stem cells, producing biocompatible pulp scaffolds, and carrier membranes for PRP. 3D printing can be used to develop injectable calcium hydroxide molecules and growth factors, and gene therapy in regenerative endodontics.[23] Calcium hydroxide medicament and calcium phosphate cement in the form of porous scaffolds developed by 3D printing technology can be used for the regeneration of the pulp-dentin complex.[24]

(12) PEDIATRIC FULL MOUTH REHABILITATION

While treating a young patient who is mentally and physically disabled, or a child with TMJ disorders or orofacial deformities, the rehabilitation process sometimes becomes very time-consuming, cumbersome, and physically and psychologically traumatic and requires several appointments, but 3D printing technology with CAD CAM devices can digitally scan and print the diagnostic models, maxillofacial prostheses without traumatizing young patients or special children, and minimizes dental appointments.[25]

OTHER APPLICATIONS IN DENTISTRY

- Patient and parent education
- Medical models for enhanced education and treatment planning
- Personalized appliances

Table 1: Advantages and disadvantages of 3D printing

ADVANTAGES	DISADVANTAGES
3D printing allows for the design and printing of more complex designs.	Limited materials
Rapid prototyping.	Restricted build size
Strong and lightweight parts	Design in accuracy
Minimising wastage	
Ease of access	
Used in advanced healthcare	

ADVANTAGES AND DISADVANTAGES OF 3D PRINTING: This is shown in Table 1.

LIMITATIONS

Though there are many applications, 3D printing has its own limitations like high fabricating costs, technique sensitive, lack of qualified operators, non-sterilizable and autoclavable materials used in 3D Printing, and low ethical and legal clearance.[26]

4D PRINTING – THE FUTURE

The ongoing development of software and digital imaging techniques will streamline the design and manufacturing process making 3D printing more accessible and cost effective for dental practices. 4D printing is an upcoming technology that has immense possibilities. Skylar Tibbett and his coworkers designed self-folding structures that reshape under certain environmental conditions. They converted the steady 3D printing materials into actively changing objects by this approach. This 4D printing helps in the making of materials that shape shifts over a certain time or space. 4D printed materials can move in different directions as programmed before they are constructed.[27]

Future applications can include (a) 4D printed restorative materials in dentistry that can alter their shape as well as position from the center to the margins in a known time and can prevent fracture or marginal leakage. (b) Designing orthodontic appliances with a controlled self-folding motion to move the teeth in the required direction and angulation is possible.

CONCLUSION

3D printing is less invasive, precise, accurate, and reduces chair side time which is a great advantage in pediatric patients. 3D printing technologies have an enormous capability in the field of research, treatment modality, and education purposes in dentistry. The use of 3D printing in pediatric dentistry is just beginning. Integrating 3D printing technology into pediatric dentistry will advance clinical practice and education.

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