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3D Printing and Its Application in Pediatric Dental Practice

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Abstract

Technological modernization has served as tool for mankind to achieve many extraordinary milestones and dentistry is no exception to the same. Incorporation of modern technology in the field of dentistry is in high demand. Various researchers are co working with their engineering counterparts to ensure smooth amalgamation of technology with clinical practice. Additive Manufacturing, or simply known as 3D printing has shown to produce attractive results in terms of patient satisfaction and the use of this technology in the field of pediatric dentistry is a comparatively less explored avenue and review of applications of 3D printing in pediatric dentistry is sure to shed some light on the same.

Keywords: additive manufacturing, customization, lasers, 3D printed guides, virtual treatment planning.

Introduction

With the advent of contemporary technology, the face of dental practice is an ever-changing continuum of new intriguing techniques assisting the dental practitioners. As the saying goes, “Update or Go Obsolete”, the use of newer technology provides an alternative dimension to the quality of treatment that can provided which satisfies the age-old ethical principle of **“**To do good” to the patient.

3D Printing or Additive Manufacturing (AM), as it is sometimes referred to, is the process by which materials, in various of the phases of matter (solid, liquid, gas), are combined to construct a three-dimensional product under computerized control.[1] 3D printing is being advocated as the key concept of the next industrial revolution due to the engineering advantages offered by the same.[2]

The use of 3D Printing in pediatric dental practice is a growing field of interest as the use of technology improves the quality of treatment provided to the children and in turn, the quality of life. Various conventional treatments like fabrication of space maintainers are being attempted with the use of 3D printing and results are pragmatic and promising.[3] Therefore, the employment of these modalities in pediatric dental practice is worth a look in for evolution of an updated clinical practice aided by technology.

The evolution

The pilot process of 3D printing was by Charles Hull in 1983 and was named as “stereolithography”.[4] With the rapid development of 3D printers, it gained patronage due to the reduction in wastage, accuracy of fit and patient specific customization.[1]

The use of 3D printing technology attracted the practitioners in the medical field and pioneer usage of technology was cited in the early 90s. (Fig 1) The process of subtractive manufacturing or milling has been in use in dentistry for long and has replaced conventional casting.[5] However, for reconstructing a lost or damaged part of human dentition and associated structures to its original form while also being absolutely custom made, multi axis CAD CAM milling could serve the purpose, but is tedious and the precision required could not be achieved to the desired level.[5]

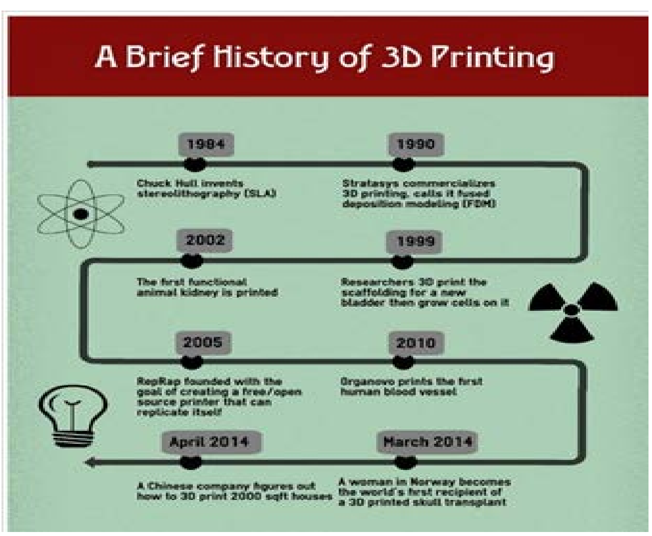

Figure 1: Evolution of 3D printing (Source: Internet)

Hence, to overcome such limitations, the use of 3D Printing has a stand out purpose for manufacture of complex structures of the craniofacial region and it currently is the most sought-after technology in the field of dentistry.[6]

The process

The term digital dentistry encompasses a wide range of terms from the use of intra oral scanning devices for making digital impressions, high resolution imaging aids, subtractive milling (CAD/CAM) and additive manufacturing (3D printing). For the purpose of 3D printing, the use of 3D imaging modalities plays a vital role in virtual treatment planning which has a positive impact on the outcomes of the treatment.[7] The process begins with the precise capture of patient’s anatomical structures with the aid of an intra-oral 3D scanner (Fig 2). Various intra oral scanners are available for use and the accuracy that is required to be utilizable clinically has been achieved frequently.[8]

Figure 2: Intra oral scanner CS 3500 (Source: Internet).

The impressions made using conventional methods and stone models can be sent to the lab facilities where desktop optical scanners are used and the data is uploaded into CAD software and subsequently it can be utilized for the purpose of digital design of 3D models can be done. The current crop of CAD systems offers user friendly design processes for various treatment planning agendas like smile design,[9] prosthesis design etc.

Following the 3D design, the models are sent to 3D printers and the required product can be manufactured by additive technology (Fig 3). Hence, various products such as surgical guides, prosthesis, aligners and retainers can be made with utmost customization that is there to offer.[10]

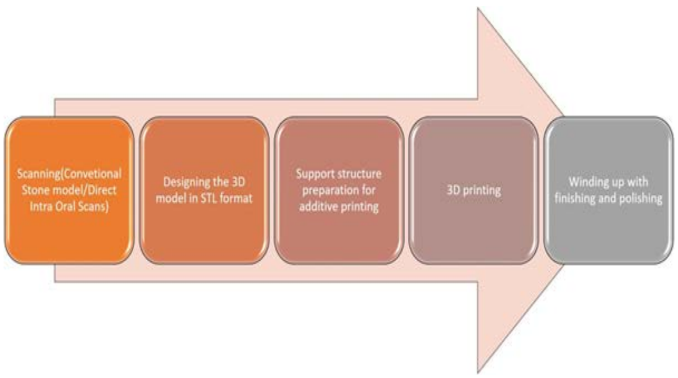

Figure 3: Digital Workflow of 3D printing.

There are several existing processes in the field of additive manufacturing of which the following processes are of significance in the field of dentistry:

1. Stereolithography and Digital Light Processing
2. Photopolymer jetting and Material jetting
3. Selective Laser Sintering and Laser Melting
4. Fused Deposition Modeling

Stereolithography and digital light processing :(SLA and DLP)

In simple terms, stereolithography uses ultraviolet (UV) laser for the purpose of fusing surfaces containing UV sensitive liquid monomer with the help of motorized lenses and two electric scanning mirrors for focusing the lasers which polymerizes the liquid resin.[11] The process comprises of a build platform, a reservoir for the liquid resin, UV lasers and mirrors. Due to its various advantages, most of the machines today use top-down approach as it prevents oxygen polymerization, reduces operator risk to laser exposure, and the smooth finish that is obtained in the final product.[12]

Digital light processing is a projection-based technique which has a rectangularly arranged mirror microsystem known as the digital micro mirror device which has adjustable angles and act as light switches to project the light as individual pixels on the projection surface. Hence, higher resolutions can be achieved by this process. Tumble stone introduced the use of continuous liquid interface production (CLIP) which allows the process to print continuously and consequently hastens the process.[13] This process is patented by Carbon3D and it offers the advantage of an oxygen rich dead zone where no polymerization occurs and hence making the detachment of the object from the build platform unnecessary.[14] Thicknesses of 25 to 100 microns can be achieved by this process.[15]

SLA/DLP is oldest technique of 3D printing and the process is applicable for the manufacture of high-resolution biomedical apparatus and is gradually outdating the conventional lost wax process of casting.

Photopolymer jetting and material jetting: (polyjet)

This technique uses several array type shower heads to spray photosensitive liquid resin on the building platform in layers. The most common system which uses this technology is Polyjet (Strasys, Eden Prarie, MN, USA) which can print five different materials in over 500,000 colors.[14] A thickness of as low as 16 microns can be achieved with this technique and highly accurate margins and internal fit of metal crowns has been produced by this technique.[16]

Selective laser sintering and laser melting:(SLS And SLM)

SLS involves the use of high-power laser pulses for the purpose of fusion of thermoplastic polymeric materials like ceramics and creation of surface layers which are sintered one upon the other.[17] A minor difference between SLS and SLM is that SLM involves completely melting the metal to form the desired 3D structure. To produce high resolutions, lasers with the power of 100 W, diameter of 0.2 to 0.4 microns and resulting layer thickness of 30 microns are used.[2]

Sometimes electron beams can be used to replace the lasers and the process is known as electron beam melting. 99.8% Titanium material density can be achieved by this process but will require proper finishing due to size of the particles.[2] However, printing of polyamides, polystyrenes, polyether ether ketone (PEEK), polymethyl methacrylate (PMMA)etc. is not permissible due to the temperature limitations of the SLS. Most SLS machines can reach upto 200^{o}C but materials like PEEK require a maximum temperature of 345^{0}C making it inoperable.

However, since the use of above said materials is being embraced rapidly, modifications and pilot testing have been carried out for PMMA printing but the results achieved are not conclusive enough for their use commercially in dentistry.[18]

Fused deposition modeling: (FDM)

The process involves an extrusion-based technique in which the melted thermoplastic materials are made into filaments which are used for the fabrication of desired object by means of deposition.[19] Founded by Strasys, FDM is the trade name for Fused Filament Fabrication technology and various materials like polylactides, Acro nitrile-butadiene-styrene and waxes can be used here.

This technique provides the luxury of adjustment of the molding speeds according to the filling density that is required. The system as such is comprised of a nozzle to feed the material filament, the heating module for the purpose of heating the material in the nozzle, wire feeder to adjust the diameter of the filament and motion mechanisms to control the axial movement of the material in x, y and z axes respectively.

The changing paradigms in pediatric dentistry

Dental Clinical practice is an ever-changing landscape and the field of pedodontics is no exception to the same. As discussed already, 3D printing can play a significant role to improve pediatric dentistry and achieve superior results benefitting the patient as an end result.

Ease of impression making

Most pediatric dentists struggle for impression making due to increased occurrence of gag in children. Though sectional trays can be used to prevent such occurrences, there is almost always a need of full mouth impressions and in such situations, intra oral scanning and 3D printed models make the procedure more acceptable to the patient and less strenuous to the clinician.[20]

Enigmatic approach to pediatric endodontics

Guided access opening is a promising application of 3D printing in clinical scenarios where conventional methods like canal exploration and negotiation is a challenge owing various reasons such as narrowing of the orifices due to dentin deposition, canal obliteration due to caries or trauma or orthodontic procedures etc.[21] Here, digital impressions and CBCT can be made and with the aid of a CAD software, access guides can be printed by stereolithography which can be used to perform minimal and precise access cavities by targeting the burs to the specific areas guided by the access guides. This approach can also be used in rare cases like dens invaginatus[22] where the precision of the procedure plays a vital role due to the complexity of the anatomy of the involved tooth. Also, use of such guided methods helps in adaptation of properly customized post enabling the clinician to achieve esthetic results without much compromise of tooth structure by maintaining the ferrule.[23]

3D printed surgical guides can be used to perform exact osteotomy cuts and root end resections in endodontic microsurgeries along with the utilization of magnification which aids in improved healing, patient comfort due to reduced pain post-surgery and overall improvement in the outcomes.[21]

Regenerative endodontics has come to limelight over the past 2 decades and the procedures of revascularization and regeneration of pulp tissue has remarkably increased the scope of preservation of patient's natural dentition. Additive manufacturing comes into fore in this field for the purpose of developing biocompatible, porous printed scaffolds by use of various polymers compatible to 3D printing.[22] Recent studies have shown that polycaprolactone, a 3D printable polymer when coated with freeze dried PRP (platelet rich plasma) and applied to pulpal stem cells has shown significant odontogenic activity.[22] Hydroxyapatite can also be used to produce scaffold mimicking tooth through 3D printing and such scaffolds have demonstrated to have excellent outcomes of treatment.

Auto transplantation-the aspirational alternative

Auto transplantation or autogenous transplantation involves the transfer of one's own tooth into ectopic positions which may be extraction sockets or specifically prepared sites. Auto transplantation is indicated in cases where there is severe destruction of permanent teeth in adolescents due to caries, in cases of trauma to maxillary incisors, especially cases of avulsion with extra oral time of more than 24 hours and in cases of congenitally missing teeth.[24]

Third molars are considered as candidates for replacing carious 1st molar while mandibular premolars are considered as ideal replacements of missing maxillary central incisors. 3D printing plays a role in the preparation of the surgical area by providing duplicates which can manipulate the surgical site before extraction of the above said teeth for the above said purpose which helps in preserving the PDL of the transplanted teeth and hence help in improving the prognosis of the same.[25]

Customised orthodontics

Pediatric dentists play a vital role in early identification of developing malocclusion and have a major hand in the field of preventive and interceptive orthodontics. Though the age-old technique of band and loop fabrication is the gold standard of space maintenance, various disadvantages like solder breakage,[26] arch wire deformation due to overheating during soldering[27] have been outlined and overall, it is a very tardy process. The attention span and cooperative time of a pediatric patient is comparatively less than that of an adult and hence this warrants the need for faster procedures. With the advent of additive manufacturing, 3D designed appliances bypasses the conventional clinical procedures and since the appliance can be fabricated as a single unit, the chances for breakage reduces. Also, the accurate adaptation of the appliance improves the patient comfort and accurate dimensions of the loop construction can be achieved by 3D printing. Also, it was observed that occlusal forces were not transferred to the 3D printed appliance due to its customized fit and in contrast, conventional design of the appliance shows signs of breakage on follow up visits.[3]

Brackets can be precisely configured with tip and torque that is indicated for the particular patient and the desired material can be used for the purpose of printing customized brackets[28] and the changes that will be produced by the same can be visualized in advance.[29] Such brackets can also be used for interception using 2x4 appliance for precise movement of the teeth. However, the question arises whether the advantages of such appliances must outweigh the disadvantages such as cost, for it to be of use in day-to-day practice.

Studies have also outlined the use of 3D printed appliances for nasoalveolar molding therapy which is a pre requisite for use before the repair of cleft lip and palate.[30]

3D printed splints have been used to treat TMJ disorders and it has been documented that such splints have better aesthetics, are more comfortable and less bulky than the conventional splints due to the close fit to the occlusal level of the teeth.[31] Such splints can be employed in pediatric dentistry for fabrication of night guards against bruxism and also for mouth guards in sports dentistry.

3d Prostho in pedodontics: the scarcely explored Avenure

Early loss of crowns of maxillary deciduous anterior teeth due to early childhood caries is cause of both esthetic and functional concern to many parents. Zirconia crowns are being increasingly used due to their superior esthetics and functional capability when compared to the conventional esthetic crowns in pediatric dental practice.[32] Zirconia crowns can be manufactured by additive printing which may produce crowns that have properties comparable to that of those produced by milling process.[20] However, as explained above in the section of various techniques of 3D printing, it is ascertained that the 3D printed structures are comparatively more porous than the ones manufactured by milling and such porosities need to be completely excluded to produce a clinically acceptable prosthesis and need for further development of such techniques is warranted. 3D printed resin crowns can also be used for restoration of multi surface carious lesions in deciduous molars as an alternative to stainless steel crown.

3D printed prosthesis can be used in cases of congenital oligodontia for interim periods till definitive fixed prosthetics like implants can be planned. They have shown higher resistance to wear and tear and better retention when compared to conventional dentures. Also, with esthetics being the primary concern in such cases, the levels that can be achieved by these dentures is unmatchable.[33]

Pediatric oral surgery-Minimising loss and maximizing benefits

Many cases of odontogenic cysts and tumors are being identified by pediatric dentists and hence, they play an active role in the treatment of the same in concomitance with the oral and maxillofacial surgeon**.** Virtual treatment planning aids the surgeon to decide the outcome of the treatment prior to the surgery and guided surgeries can be performed with the use of additive technologies which can be used to print guides to assist in harvesting grafts for reconstruction and also for preparation of recipient site.[17]

3D printing can be used in treatment of multiple mandibular fractures in children[34] where maxillary and mandibular borders can be 3D printed and the surgery can be simulated as to where plating can be done without affecting the permanent tooth germs. Above said models can also be used for planning the treatment of unerupted/impacted maxillary anteriors which presents as a clinical challenge to orthodontists, oral surgeons and pedodontists.[35]

Ceramic scaffolds can be used to aid in the correction of congenital craniofacial anomalies and they have shown to support various osteogenic components for the purpose of reconstruction.[36]

Training the budding Pedodontists

Additive manufacturing offers scope for accurately simulating the anatomy of the oral cavity in the form of models and hence hands on experience can be provided to improve the skills of the pediatric dentists. Various simulations from caries excavation to crown preparation can be done with models mimicking the properties of natural teeth such as hardness, color and designing carious lesions similar to those that occur clinically and assessment can be done which provides the scope for a learning curve pre clinically and has shown to produce significant refinement of skills in dentists.[17,37]

Additive manufacturing also helps in simulating dental trauma and can increase the clinical knowledge of pediatric dental students as dental trauma is one of the most important and most frequently occurring dental emergencies and active participation of a student in management of trauma is limited as the nature of the situation warrants the presence of an experienced professional. These simulations have shown significant results in improving the student's speed of action during the emergency and better management of the trauma, subsequently leading to better prognosis and outcome.[38]

Conclusion

3D printing technology comes with a potential of rejuvenating and reinvigorating the field of pediatric dentistry. However, it is still in its nascent stages of development with regards to pediatric dentistry and there are various questions that remain unanswered and various disadvantages that are yet to be overcome. Some of them include the technical difficulties in handling the materials, lack of specificity to the field of dentistry, cost of running and maintenance of the machines, cost of the 3D printed prostheses/appliances and ethical concerns.[39] However, with the speed at which technology is progressing and ease of which it has been integrated to day to day practice over the years, it is safe to suggest that pediatric dental practice is heading towards greener pastures and on the horizon, 3D printing will take center stage and lighten up the field of pedodontics.

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