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Applications of 3D Printing in Pediatric Dentistry: A Literature Review

Marwa Basim [1], Ali R. Al-Khatib* [2], Zainul A. Rajion [3]

[1, 2] Department of Pedodontics Orthodontics and Preventive Dentistry, College of Dentistry, Mosul University / Iraq.

[3] College of Dentistry, Islamic International University, Malaysia.

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***Correspondence**
E-mail: alirajih@uomosul.edu.iq

Abstract

Many challenges may occur during the dental intervention of pediatric patients. One of the steps to overcome these challenges is shifting towards 3D technology to obtain superior and precise performance. Among these advancements, the applications of 3D printing concepts have recently emerged. Dental professionals and patients may get many benefits from the use of 3D printing technology. This review will help the researchers and clinicians to consider the applications, benefits as well as constraints of this modern digital technology for efficient implementation of their procedures in pediatric dental practice.

تطبيقات الطباعة ثلاثية الأبعاد في طب أسنان الأطفال: مراجعة مقال

الملخص

هناك العديد من التحديات التي تواجه أطباء أسنان الأطفال أثناء علاج الأطفال، وذلك بسبب شعورهم بالقلق والخوف الشديد من علاج الأسنان، كما أنهم غير ناضجين عاطفياً. في الوقت الحاضر يتم التحول في طب أسنان الأطفال نحو علاج الأسنان المتقدم للحصول على أداء متفوق ودقيق. ومن بين هذه التطورات، ظهر مؤخرًا مفهوم الطباعة ثلاثية الأبعاد. يتمتع أخصائيو طب الأسنان والمرضى بالعديد من الفوائد من استخدام تقنية الطباعة ثلاثية الأبعاد. تسلط هذه المراجعة الضوء على تطبيقات التقنيات الرقمية الحديثة مثل الطباعة ثلاثية الأبعاد في طب أسنان الأطفال من أجل التنفيذ الفعال، بالإضافة إلى إظهار فوائد وقيود استخدام هذه التكنولوجيا.

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INTRODUCTION

Technology has emerged as a crucial element of dentistry in recent years, leading to the creation of instruments and apparatus to enhance treatment protocols and education in the fields of implants, endodontics, orthognathic, Pedodontics, maxillofacial, craniofacial, and periodontal applications. Three components make up the "digital workflow," which increases the use of technology in dentistry: data processing through computer-aided design (CAD) software, data processing through scanning, and using the data to manufacture products through computer-aided manufacturing (CAM) (1).

Three-dimensional (3D) printing is a revolutionary technology that involves the deposition of materials to create three-dimensional things using materials such as metals, ceramics, polymeric polymers, and living cells. Several uses of additive manufacturing have drawn a lot of interest in the fields of dentistry and medicine (2).

To overcome the drawbacks of traditional techniques, modern dentistry is always changing. Dental patients and clinicians have reportedly benefited greatly from the introduction of digital intraoral scanners in recent years. These scanners offer several advantages over traditional impression-making techniques when it comes to the creation of various dental prostheses and appliances (3-5).

For pediatric dentists, 3D printed models are useful for pre-operative planning and accurate anatomical visualization of craniofacial abnormalities (6). The development of three-dimensional (3D) printing technology in the 21th century has evolved dentistry. Dental professionals have adapted from traditional treatment procedures to a digital plan while treating their patients due to their unwavering efforts to improve and streamline their practice. It is extremely skilled, scalable, and offers quick, accurate results affordably (7).

3D printing is a relatively new technology that is revolutionizing many industries, including manufacturing and medicine. In addition, it is the only technology, that has no industrial restrictions. More and better data demonstrates that 3D printing is rapidly becoming a widely available technology that could completely transform society as a whole, as well as the future methods of producing dental and medical models and prototypes (8). Because this technology eliminates the need for labor-intensive artisanal production procedures and makes it possible to use materials that would be difficult to work with, dental lab technicians can develop their manual skills in more creative aspects of the manufacturing process (9).

History

In the early 1980s, 3D technologies were known as rapid prototyping technologies (8).

3D printing technology that is called "Stereolithography" (SLA) was invented in 1983 by Charles Hull who is regarded as the father of 3D Printing technology [10].

In this field, advancements have been made continuously ever since. The selective laser sintering process was created in 1986 by Carl Deckard [11]. Emanuel Sachs in 1992 created the phrase "3D Printing" Otherwise, it was earlier also known as "additive manufacturing" but now is famous as 3D printing [8].

The first 3D-printed organ for transplantation was created in 1999 by Wake Forest University, whereas, in 2003, the first inkjet bio-printer was presented. The Organovo Company created the first 3D-printed blood vessels in 2009 [11].

The CAD-CAM technology utilizes "subtractive manufacturing" technology that lacks accuracy and that could not completely replace the manual involvement operation as compared to 3D scanning technology for designing 3D objects. The advent of intraoral scanners (IOS) and the availability of 3D printers with compatible materials increased the use of 3D printing methods [12]. Additive manufacturing is a process of manufacturing 3D objects from a 3D model or digital computerized file. Additive manufacturing consists of several techniques to build the 3D objects in a "layer by layer" manner [13].

Processing of 3D printing

The printing of 3D objects, involves a certain controlled set of processing stages, as follows (Figure 1) [14].

Initially, using CAD software to create a three-dimensional (3D) file, then, transforming 3D files into STL file formats so that the printer can read them.

After that, the STL file is imported into a program known as slicer, which slices file layers. After receiving the model, the slicer transforms it into a G-code that contains instructions for 3D printers and Computer numerical control (CNC) machines. Printing a 3D model layer by layer in a stepwise manner, and finally, the Processing (Figure 2) [15].

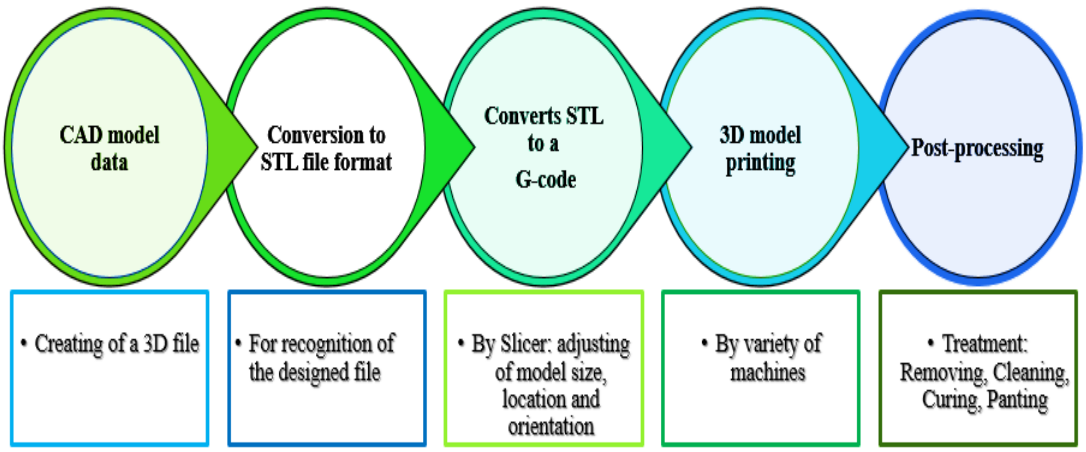

Figure 1: Shows the stages of 3D printing [14].

Figure 2: Shows the 3D printing steps from design to printing [15].

Benefits and features of digital dentistry in pediatric dentistry

The accuracy of appliances and prostheses made from 3D-printed digital models is higher in quality, and they require fewer clinical and laboratory steps and manual labor during processing. By using these methods, impression materials that naturally shrink and distort are avoided [13 & 16]. One of the many positive aspects of using digital impressions for patient safety is that there is no risk of gag reflex, elicitation, or aspiration of foreign bodies. Therefore, compared to the traditional impression technique, the digital scanning procedure for intraoral impressions has been reported to be more comfortable for pediatric patients and more accepted by the child and their parents/caregivers for dental procedures [13].

Due to the lack of analogous traditional dental impressions, the prosthesis (appliance) can be processed and fabricated more quickly. The 3D printer produces the appliance or prosthesis more quickly. In the digital IOS, there is no need for the right powder ratio of the impression material, handling of the mix, waiting for the material to set, or choosing an accurate impression tray [16-18].

In addition to improving patient comfort and efficiency, digital impressions can lower the overall cost of the dental procedure in the end. IOS digital impressions are being successfully used in pediatric dentistry, which can benefit both the patients and the dentists. These digital impressions have been used regularly in other dental specialties. Because it was more comfortable than using alginate to create impressions, 77% of patients favored intraoral scanning, according to a prior study [16].

Furthermore, the IOS is environment-friendly because no disposal of waste of the impression material is needed, as in the case of conventional impression materials. All the above-mentioned factors are critical to managing young pediatric dental patients in terms of favorable clinical behavior for rendering the optimum dental treatment effectively and efficiently [(4)].

Disadvantages of digital workflow and computer-aided design/computer-aided manufacturing/3D-printing technology

In comparison to the conventional dental method, digital instruments and machines are more expensive, and dentists need specialized and advanced expertise and training to operate them [(16)].

Another important consideration is the appropriate size of the intra-oral scanner (IOS) for scanning inside the mouth cavity, particularly for pediatric patients who need impressions taken for dental prostheses or appliances. There is a requirement for referral to special and specific digital dental laboratories for 3D printing/CAD-CAM processing for digital workflow [(16-18)].

Because 3D-printed appliances and prostheses use uncured monomer or polymer resins, there may be a health risk involved. Furthermore, because a 3D printer creates products using layer-by-layer technology, under some circumstances it may delaminate when subjected to particular forces or orientations [(16 & 17)].

Applications of 3D Printing in Pediatric Dentistry

1- 3D Printing in Behaviour Management of Uncooperative Children and Special Health Care Needs (SHCN)

In pediatric clinical practice, intraoral scanners have proven to be a great help to uncooperative children, especially SHCN when there is a need for creating space maintainers and habit-breaking appliances. The intraoral scanner (IOS) is a suitable alternative option for children who are afraid or have strong gag reflexes, in which the conventional method of impression-taking will be difficult. To capture a complete scan of their teeth and display it in 360 degrees on a vibrant touch screen, the phrase "magic wand" might be used as a euphemism [(19)].

2-3D Printing in Pediatric Oral and Maxillofacial Procedures

3D printing may be used to effectively design surgeries for aggressive oral cancer and mandibular fractures, providing the surgeon with more information to work with while arranging the procedure. Furthermore, as a visual assistance, 3D printed models let parents and surgeons assess the advantages and disadvantages of various treatment options and choose the best course of action [(20 & 21)].

One further possible use of this technology is the treatment of children's mandibular fractures using a patient-specific digital cap splint. During impressions, the patient no longer has to be sedated or in discomfort, which also significantly reduces the amount of time spent performing the surgery while under general anesthesia. Additionally, there is no need for intraoperative adjustments because the 3D cap-splint fits flawlessly. When compared to the conventional acrylic cap splint, the splint also has a higher cosmetic appeal [22].

3- Cleft lip cleft palate patients

When creating an obturator or feeding device for a newborn or infant with cleft lip and palate (CLCP), impression-making is seen to be a laborious, dangerous, and technique-sensitive process since it runs the risk of dislodging the impression material (aspiration) or obstructing the airway. Compared to a conventional impression-taking procedure employing alginate impression material, digital scanning of the cleft areas was reported to be faster, more accurate, and safer [23].

4-Pediatric Endodontics and Restorative Dentistry

With the use of 3D printed templates, guided endodontics is an inventive approach for treating teeth with calcified canals, extensive restorations, or mal-positioning for access opening. These templates are intended to target burs, thereby reducing iatrogenic errors and preserving tooth structure [24].

3D printing has applications in the treatment of tooth abnormalities that are frequently challenging to manage during endodontic procedures, such as dilaceration, pulp stones, and dens in dente. To get an accurate working length and successfully improve the quality and precision of such anomalous teeth, a transparent tooth model with its intricate internal anatomy may be generated using 3D printing in conjunction with CBCT and a tailored guide [25 & 26].

Appropriate placement, angulation, and bur penetration depth are necessary for effective endodontic surgery, including root-end excision and osteotomy treatments. To reduce iatrogenic mistakes and provide more precise, accurate, localized, and minimally invasive micro-operations, surgical stent-like guidance was made using 3D printed technology [27].

5-3D Printing in Regenerative Endodontics

Apicectomy and access opening preparation are two clinical applications of additive manufacturing in endodontics. Evidence has shown that guided access cavity preparation is preferable to traditional methods [24].

These guided endodontic procedures may be very helpful for challenging teeth with anatomical abnormalities related to root canal therapy. Models made by 3D printing may be used as a foundation to print a guide for endodontic treatment (27). It is also possible to employ this procedure on primary and immature permanent molars with complex root canal anatomy [28].

6-3D Printing Application in Auto-transplantation

With the use of 3D printing, it would be simple to undertake auto-transplantation for impacted permanent teeth, tooth loss from trauma, and cases of congenital hypodontia. In autogenous tooth transplantation, a recipient socket needs to be created to implant the donor's tooth. Additionally, the extraoral handling time of the donor's tooth should be minimized if feasible as it has a negative impact on the tooth's vitality [29 & 30].

When children and teenagers suffer trauma and severe dental injuries, they can replace their lost teeth using a procedure called in-vivo tooth auto-transplantation. To ensure full healing, pediatric dentists sometimes need to wait (3-4) months before teeth reshaping for aesthetic purposes. The design and fabrication of chair-side temporary veneers may be done without delay because of using 3D printing technology [31].

Utilizing 3D printing technology reduces extra-oral time and limits potential harm to the donor tooth's periodontal tissue by printing dental replicas to serve as surgical guides. All of this encourages the creation of a new recipient socket, removing risks for the donor's tooth and, more generally, contributing to the technique's standardization [30].

7- 3D Printing in Interceptive Orthodontic Procedures

For young preschoolers with early anterior crossbites, clear, removable occlusal splints have been created via 3D printing. Because this splint did not have any wires, it was more comfortable and simpler to wear than the traditional device, which will decrease young children's dental anxiety. Furthermore, after six months, the front crossbite was fixed, preventing future complications and promoting the maxilla and mandible's normal growth [32].

3D printing may be used to create a variety of functional appliances, removable appliances (like Hawley's retainer), and appliances for arch extension. These elements have the potential to significantly shorten a pedodontist's professional time, with no need for impression [33].

To better understand the physiology of cartilage and bone formation, 3D printing is now being utilized in animal models to modify tooth mobility and mandibular growth. Several of these findings will support orthodontic tooth movement acceleration, improved tooth anchoring, and growth modification [34].

8- 3D Printing in Fixed Orthodontics

Nowadays, aligners are made using 3D printing in orthodontics to fix teeth that are misaligned. Software for computers is used to digitally implant teeth in the ideal location. After the 3D model is presented, a casting mold is specially constructed [35].

Fixed orthodontics' long treatment times are shortened via 3D printing. This reduces the likelihood of teeth demineralization, orthodontic white spot lesions, and root resorption by favoring younger individuals clinically [36].

In addition, printing guidelines for indirect bonding or temporary anchoring device placement may be very important in orthodontics down the road. Moreover, CAD/CAM technology may be used to produce auxiliary orthodontic devices like Herbst, Andresen, and sleep apnea appliances, resulting in a superior intraoral fit [37].

9- Laboratory Training of Pedodontists

Preclinical activities in dental education have traditionally relied on extracted teeth because they offer clinical circumstances that are somewhat realistic. However, the availability of abnormalities in those teeth is never entirely clear. By providing visual, auditory, and tactile proprioception during preclinical training, 3D printing techniques can also be used to construct 3D dental models for preclinical purposes. This allows for the creation of more realistic anatomic structures, such as teeth with internal and external resorption defects, open apex, dilacerations, dens in dente, and much more. It also helps to develop endodontic skills [25].

10-Pediatric Prosthodontics

The use of 3D printing to manufacture removable prostheses has also gained attention, particularly in cases involving adolescents who suffer from oligodontia. Using materials like acrylic resin or poly (methyl methacrylate), this method prints the prosthesis as a single unit, increasing its mechanical qualities. Because there are no interfaces, this prosthesis weighs less and is more fracture-resistant than traditional overlay dentures. In addition, this denture is readily trimmable, adjustable, and reline-able with appropriate material if teeth shift during growth spurts. Reprinting the denture as often as necessary is made easier by the information being stored as a digital file [38].

11-3D Printing in Fabrication of Crowns and Space Maintainers

Band and loop space maintainers have also been made using 3D printing. These devices are created as a single piece with exceptional precision, reducing the possibility of human mistakes and appliance breakage and enhancing the success of clinical settings. Furthermore, there is no need for additional laboratory work for stabilizing, welding the loop on the band, and polishing it, which reduces chair side time, which is a crucial factor for a pediatric dentist. A 3D-printed model has a better degree of detail and a more complex construction than a traditional appliance [39].

It was effectively demonstrated that another 3D printed band and loop space maintainer can revolutionize preventative orthodontics and pediatric dentistry through digital workflow [40].

A conventional space maintainer is a large group of appliances that belong to each other. With the advancement of digital technology, dentistry has shown tremendous growth in recent years. Space maintainers that use such technology are called Digitainers / Digital space maintainers [41].

Conventional space maintainers

Space maintenance is essential in pediatric dentistry, and pediatric dentists have long supported and used conventional space maintainers, commonly used fixed space maintainers like bands and loops that are prone to breaking and de-cementing due to their poor design, which causes ulceration [42 & 43]. In other types of space maintainers such as the Nance palatal arch, the acrylic button causes tissue irritation and increases gagging [44]. Furthermore, other drawbacks were found in the case of the Lingual arch, which causes an increase in the occlusal load and interferes with tongue movements [45].

Trauma may result from the trans palatal arch space maintainer's loop pressing against the palate tissue [46]. Moreover, root resorption is more likely to occur as the roots of the anchoring tooth are situated on the cortical bone plate [47].

Digital Space Maintainers

Numerous studies highlighting the shortcomings of conventional space maintainers explain the use of newer materials and innovative technologies. Digital workflow is presently used in the production of space maintenance equipment instead of the more traditional method [41]. In addition to their benefits in terms of bettering aesthetics, lowering processing mistakes, and a smaller number of appointments, 3-D printed space maintainers might be employed in patients who have a metal allergy, such as nickel, or who need to undergo an MRI of the head area [48 -52].

According to earlier studies, 3D printing has several drawbacks, including the need for materials that are difficult to eliminate later and some materials that can't be autoclaved or sterilized, which limits and minimizes their use [53]. Missing try-in appointments, and requiring skills, in addition to the high fabricating cost of this, are considered the main drawbacks of technology [49 ,52].

Future perspectives

Digital dentistry using devices and machines integrated with digital computerized technologies should be made easily available and accessible in a cost-effective manner for dental professionals. Thus, it can be highly beneficial for contemporary pediatric dentistry, especially by using IOS/CAD/CAM/3D printing [54].

In the future, 4D-printed restorative materials for dentistry may be used to avoid fractures and marginal leaks by changing both their shape and position from the center to the margins over a predetermined period. To move teeth in the correct direction and angle, orthodontic appliances can be made with customizable, self-propelled action. The field of dentistry may change if this incredible technology is utilized, as it has the potential to progress in a manner akin to CAD-CAM and 3D printing [7].

Nowadays, 4D printing is considered an upcoming technology that has huge potential in restorative dentistry. 4D printed materials could eliminate the need to use dental drilling and bonding systems because they rely more on retention by mechanical means rather than chemical aids [53].

CONCLUSION

Clinicians have been more empowered in recent decades due to 3D printing, in addition to improving diagnostic and surgical skills as it has allowed real-world training, better visualization, and surgical planning. It is possible to create precise, accurate, and complex geometry by using can be created either a wide and different range of materials, which are local or in industrial units 3D printing. This expertise has revolutionized evidence and can provide maximum precision in a short chair-side time and small clinical setting.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

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