ejpmr, 2023, 10(10), 169-177

SJIF Impact Factor 6.222

EUROPEAN JOURNAL OF PHARMACEUTICAL AND MEDICAL RESEARCH

www.ejpmr.com

Review Article

ISSN 2394-3211

EJPMR

DIGITIZATION IN PEDIATRIC DENTISTRY: A LITERATURE REVIEW

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Article Received on 29/07/2023 **Article Revised on 20/08/2023** **Article Accepted on 10/09/2023**

ABSTRACT

Modern digital pediatric dentistry is growing to overcome the pitfalls of the traditional techniques. In recent years, emergence of advanced digital intraoral scanners and computer aided designing/ computer aided manufacturing (CAD/CAM) technology have been reported to be quite beneficial in pediatric dental patients because of various advantages of IOS and CAD over the regular methods of dental appliance fabrication or impression making. Manufacturing of the appliance can be done by either two techniques- milling or 3-D printing. Awareness about such modern technologies among dental professionals is of paramount importance to enhance the judicious use in pediatric dental procedures with scientific evidence-based approach. However, in existing literature, there is insufficiency of comprehensive literature review articles in the context of different aspects of digital workflow. Therefore, the present article attempts to review and highlight the recent dental literature relevant to modern digital technologies such as intraoral scan (IOS), computer aided designing/ computer aided manufacturing (CAD/CAM), and 3D-printing, its advantages, and applications in the domain of pediatric dentistry.

KEYWORDS: 3-D printing; 3-D imaging; computer aided designing; computer aided manufacturing; pediatric dentistry.

INTRODUCTION

The conventional methods of dental appliance fabrication in pediatric dental patients present many challenges to the dentist such as - prolonged and multiple appointments, increased chairside time, disparity in the accuracy or fit of prosthesis, burdensome lengthy dental laboratory procedures; and behavioural problems, gag reflex, foreign body aspiration, and choking (breathing) concerns during the impression making process. Delivering dental care to child patient in stress free and friendly way is the most desirable outcome for any formulated dental treatment plan. In the recent decade, many novel inventions relevant to pediatric dentistry have emerged and have been introduced to overcome the shortcomings of the existing conventional techniques. The use of digital Intra-Oral Scanner (IOS) and computer-aided design/computer-aided manufacturing (CAD-CAM) technology have the potential to increase efficiency and improve the quality of treatment provided to the pediatric patient in the most simple and convenient manner.[1]

The whole process of digital workflow can be described as: The dentist creates a digital data set on the computer (computer-aided design, CAD) and then designs a three-dimensional object whose data is transferred to the 3D printer, where it is converted into a physical object.[2]

Latterly, several original research and case-report articles have been published in existing literature regarding the evaluation and assessment of IOS, CAD-CAM, and 3D-printing technology in different fields of dentistry. However, there is insufficiency of comprehensive literature review articles in the context of different aspects of Digital CAD-CAM/3D-printing technology relevant to pediatric dentistry. Hence, the present review has attempted to highlight the various applications and advantages of digital dentistry in pediatrics.

HISTORY

The idea of an optical imprint was speculated in the 1970s by François Duret, who is considered as the father of “modern digital dentistry.” He was the first to fabricate a dental crown by using CAD software (1983). Charles W. Hull (founder of 3D Systems), Hans J. Langer and Hans Steinbichler (founders of EOS) and S. Scott Crump (founder of Stratasys) are considered pioneers in 3D printing. Charles W. Hull, who is regarded as the "Father of 3D Printing technology" patented the first 3D printer in 1986. In earlier 1980s, 3D technologies were called as rapid prototyping technologies. Emanuel Sachs in 1992 created the phrase "3D Printing." Otherwise, it was earlier known as "additive manufacturing" but now is famous as 3D Printing. Hull invented the Standard Tessellation Language (STL) file format. STL file is a triangular depiction of an object's surface geometry. Each object is made up of many triangles and the peak of each triangle is represented by the coordinates system. In 1985, first chair-side inlay using a ceramic block (fine grain feldspathic ceramic) was manufactured by CAD/CAM technology. Since 1980s, various CAD/CAM systems have been evolved, for example, CEREC. The evolution of 3D printing was first done by Scott Crump. Hull developed a new 3D-printing process/technique named as "Fused deposition modelling" (FDM).[1,2] Following the expiration of the patent for the fused deposition modeling (FDM) process in 2009, the 3D printers began to make extensive invasion into the consumer sector. This dynamic eventually reached the dental sector. Printing units became smaller and cheaper, and their fields of application differed. Variety of printable materials broadened to include plastics, metal, ceramics, and even human tissue. Rapid-prototyping processes can be classified by the type of materials used (plastics, metals, or powder).[2]

ROLE OF DIGITIZATION IN PEDIATRIC DENTISTRY

Intraoral Scanners

The term scanner in dentistry means data collection tools that assesses jaw and tooth structures and converts them into sets of digital data. Intraoral scanners (IOS) are tools for making direct optical impressions in dentistry. Like other three-dimensional (3D) scanners, they focus a light source on the object to be scanned, in this case the dental arches, prepared teeth, and implant prosthesis. The images of the dento-gingival tissues recorded by imaging sensors are processed by scanning software which generates point clouds. These point clouds are then triangulated by the same software, forming a 3D surface replica (mesh). These surface replicas are the result of negative optical impression and act as alternative to conventional plaster models.[3]

Types of Intraoral Scanners

There are two different types of scanners: Optical scanners and Mechanical scanners.[4]

Optical scanners

They work on the principle of gathering three-dimensional data by a process known as "triangulation procedure". Here, the light source and the receptor unit are kept at a definite angle to each other. The computer utilizes this relationship to calculate a three-dimensional data set from the image on the receptor unit. This light source can be white light projections or a laser beam for illumination. Lava Scan ST (3M ESPE, White light), Everest Scan (KaVo, White light), es1 (etkon, Laser beam) are various examples of optical scanners in the dental market.[4]

Mechanical scanners

In this type, the master cast is analyzed mechanically by using a ruby ball and three-dimensional data is collected. Presently available mechanical scanners in dentistry are Procera Scanners Piccolo and Forte (Nobel Biocare). Mechanical scanners have comparitively high scanning accuracy, and the diameter of the ruby ball is kept at the smallest grinder in the milling unit, so that all the assembled data by the system can be milled. Disadvantages of these include very high cost and greater processing time as compared to optical scanners. Also, mechanical digitizers are extremely sensitive to any motion. Slight movement of patient during data acquisition would compromise the quality of the data, ultimately leading to compromised fit of the restoration.[4]

Advantages of Intraoral Scanners

- Increased patient comfort.
- Time-efficient as no chairside time is required.
- Simplified clinical procedures.
- Ability of recording and storing highly accurate information.
- Easy transfer to the dental technician.
- All the objects are fabricated on screen; thus, allowing boundless variety of shapes and complexity.[2,5]

Disadvantages of conventional impression making

- Increased chairside time.
- Lengthy dental laboratory procedures.
- Behavioural problems.
- Gag reflex
- Foreign body aspiration.
- Disparity in the accuracy or fit of prosthesis.

Applications of intraoral scanners in pediatric dentistry

Table 1: Digital impressions for fabrication of space maintainers.

Author	Study Design	Study	Groups	Inference
Vij A, Reddy A (2022)[6]	Case Report	To assess efficiency, comfort and time taken by digital impression for fabrication of lingual holding arch space maintainer.	-	- Digital impression was: More efficient More comfortable Reduce long-term costs of the procedure. Reduced chair time with an uncooperative patient. Enhanced compliance.

Table 2: Digital impression for cleft lip and palate cases.

Author	Study Design	Study	Groups	Inference
Benitez B et al (2022)[7]	A retrospective cohort study	To investigate the implementation and risks of digital impressions for the youngest patients with orofacial clefts.	A two-centre experience	- Digital impressions were safe in patients with cleft lip and palate in various age group from new-born to preschool age.
Dalessandri D et al (2019)[8]	A pilot study	To evaluate the clinical accuracy, invasiveness and impact of a digital oral impression protocol in the pre-surgical orthopedic treatment (PSOT) of new-born cleft lip and palate (CLP) patients undergoing primary alveolar surgical repair	-	- Digital protocol accelerate the process of passive plate moulding. - There is instantaneous transmission of the digital impression to the dental lab. - Maintains the same accuracy level as that of classical techniques. - Reduces the invasiveness of impression taking, avoiding any risk of impression material ingestion or inhalation.
E.V. Chalmers et al (2016)[9]	In-vivo study	To evaluate intraoral 3D scans as an alternative to dental impressions for assessing dental arch relationships and obtain patient/parent perceptions of conventional impressions v/s intraoral 3D scanning.	-	- Intraoral 3D scans can reduce the burden of storage and create digital model databases for future inter centre research and refinement of treatment protocols in cleft care.

Limitations of intraoral scanners

- Cost of procurement of the whole equipment and additional managing costs are very high.
- Optical impressions have difficulty in detecting deep margin lines in prepared teeth and/or in the case of bleeding.
- Learning curve.[3]

Computer aided designing/computer aided manufacturing technology

CAD/CAM technology is a digital technique in which various complex shapes, crowns, frameworks, or working models are fabricated by grinding resin blocks to achieve the desired geometry, designed by the CAD software. The three main parts of CAD/CAM systems are: a data acquiring unit, which collects data from the region of the prepared teeth and adjoining structures, and then converts them to virtual impressions (directly or indirectly); software for designing virtual restorations anchored in virtual impressions and setting up all the milling parameters; and a computerized manufacturing of the restoration with solid blocks or resin of the chosen restorative material.[10]

Computer aided designing

This process involves making an optical impression by surface digitizing which can be done in 2 ways - Direct (at the tooth) or Indirect method (via cast scanning). A distinct designated software called CAD software, given by the manufacturer is used in designing the restoration/appliance. The obtained data can be saved using various file formats like standard transformation language (STL), OBJ and PLY. The most common file format used in 3D printing is STL format as it is universally recognized, simple and small which makes processing them faster. When the software completes designing of the restoration/appliance, it is then transformed into virtual model using specific set of commands. Even in the most automated system, the operator has the choice to reshape the automatically designed restoration to personalize it to their requirement. Once the restoration/appliance is designed in the CAD, the data is transferred to CAM unit for the process of manufacturing (Subtractive/ Additive).[4]

Table 3: Applications of CAD in pediatric dentistry.

Author	Study Design	Study	Groups	Inference
Guo H, Wang Y, Zhao Y, Liu H (2020)[11]	In vitro study	Computer-aided design of removable pediatric space maintainers fabricated using polyetheretherketone (PEEK).	1 - Polyetheretherketone 2 - Conventional space maintainer	- Digitally designed removable space maintainer were superior to those produced using the conventional method.

Computer aided manufacturing

The digital design of restorations or prostheses can be fabricated using subtractive manufacturing techniques by milling or additive manufacturing technique by 3D printing.[12]

Subtractive manufacturing

Dental subtractive manufacturing utilizes end-milling of a fixed-size solidified block of ceramic, such as zirconia, wax, resin, or metal. The construction data produced by CAD software are transferred to milling software for the CAM-processing and finally loaded into the milling device. The CAM software has precise information about the mill including the material being milled, the size and shape of the cutting tools, the spindle controller, and the motors that rotates the stock and spindle.[13]

Processing devices used for manufacturing are classified by means of the number of milling axes: 3-axis devices, 4-axis devices, 5-axis devices.[14,15]

3-axis devices: The 3-axis milling device has degrees of movement in all the three spatial planes. In this system the mill path points are designated as X -, Y -, and Z – values. All 3-axis devices utilized in the dentistry can rotate the element by 180° while processing from outside and inside. A milling of axis divergences or convergences is not possible. Examples of these devices include in Lab (Sirona), Cercon brain (DeguDent), Lava (3M ESPE).[14]

4-axis milling devices: These devices contain a rotatable tension bridge in addition to movement in three spatial axes. As a result, substantial vertical height displacement is possible into the usual mould dimensions, thus saving material and milling time. Example: Zeno (Wieland-Imes).[14]

5-axis milling device: Milling spindle can also rotate (5th axis) in addition to the three spatial dimensions and the rotatable tension bridge (4th axis). Therefore, complex geometries with subsections can be fabricated, for example, lower jaw FPDs on converging abutment teeth.[14]

Milling Variants

Subtractive technique can be done by dry processing or wet processing.

Dry processing is majorly employed when using zirconium oxide blanks with a low degree of pre-sintering. Several benefits of these are minimal investment cost for milling device and no moisture absorption is seen by the die zirconium oxide mould, hence no initial drying times is needed for the ZrO_2 frame prior to sintering. Demerit of this technique being lesser degree of pre-sintering results in higher shrinkage values for the frameworks.[15]

Wet milling consists of a milling diamond or carbide cutter secured by a cold liquid spray against overheating of the milled material. This kind of processing is necessary for all metals, glass ceramic material, and acrylic to avoid damage through heat development. If zirconium oxide ceramic with a higher degree of pre-sintering is used for the milling process, 'wet' processing is recommended. A greater degree of pre-sintering results in a reduction of shrinkage factor and enables less sinter distortion. Few examples of wet milling systems: Everest (KaVo), Zeno 8060 (Wieland-Imes), inLab (Sirona).[15]

Advantages of Subtractive manufacturing

- Improved dimensional stability.
- Improved mechanical strength.
- Higher marginal and internal adaptation.
- Superior esthetics.

Table 4: Applications of subtractive technique in pediatric dentistry.

Author	Study Design	Study	Groups	Inference
Gupta G (2021)[16]	Case Report	Fabrication of zirconia crown using digital impression technique followed by CAD CAM procedure.	-	- Digital workflow produces ideal occlusal and achieves better marginal fit of the crown. - It shortens clinical working time, causes less wear of the opposing dentition, and gives choice of more biocompatible materials.
Kareem E, Gomaa F, Khattab N (2021)[17]	Randomized clinical trial	To evaluatethe clinical performance of PEEK polymeric material used as a CAD /CAM posterior fixed functional space maintainer.	-	- PEEK CAD/CAM space maintainers have superior clinical performance in one year follow up period when compared to conventional one.
Mourouzis P, Arhakis A (2019)[18]	Case Report	Computer-aided Design and Manufacturing Crown on primary molars using hybrid ceramic CAD/CAM block.	-	- CAD CAM technology reduces chairside time and provided superior esthetics as compared to stainless steel crown.
Ierardo G et al (2017)[19]	Pilot Study	To evaluate the efficiency of PEEK orthodontic space maintainers fabricated using CAD CAM technology	-	- Digital system reduced the systematic mistakes during the various phases, decreasing production time. - It had greater precision, less discomfort and saves space.

Limitations of subtractive manufacturing

- Technique consumes excessive material. The surrounding material is also processed, making it cumbersome to reuse the discarded material.
- Disposed materials are an economic and environmental burden.
- Difficult for the machine to reach undercuts or locations that are inaccessible to end-mills used in the production process.

Hence, 3D printing technologies were introduced to this field to overcome some of the pitfalls of the subtractive technique.[12,20]

Additive manufacturing

The additive manufacturing process (AM) or 3D printing process is the fabrication of any object by adding material layer by layer. In AM methods, sintering is performed by selectively directing a laser beam on the designated part of the material. This method does not consume irrelevant materials, as essentially only the desired part of the product is obtained; however, additional supporting material may be needed. There are different additive manufacturing methods present : Stereolithography, Fused deposition modeling, Selective Laser Sintering, Polyjet printing, and Bioprinting.[20,21] The AMs applied to dentistry are SLS (Selective Laser Sintering), which uses metal powder, and SLA (Stereolithography Apparatus), which uses photopolymerizing resin.[20]

Selective laser Sintering/ Melting (Laser powder forming technique): Mainly used in manufacturing of thermoplastic materials and metals by powder. Here, a high-power density laser is employed to soften and fuse the metal powder, following which fixed slices are received from these 3D shapes, which assembles layer by layer to form the desired parts. High-performance lasers are widely used in the industry for procedures requiring high accuracy, but the equipment is expensive.[20,22,23]

Stereolithography Apparatus: For the SLA method, the photopolymerizing resin is in liquid form at room temperature and is polymerized and hardened using ultraviolet light. Both the casts and restorations can be fabricated using SLA, and thus, it is frequently used and widely applied in the production of titanium implants, surgical guides for implants, resin models for temporary crown and bridge, and patient-specific scaffolds for regeneration.[20,22]

Digital Light Processing: The design of a DLP printer is like that of an SLA printer, the main difference being the light source used. They utilize projection technology from Texas Instruments where short-wave light (currently used wavelengths: 380 nm and 405 nm) is guided through a digital micromirror device (DMD) that constitutes the core of the DLP technology. The system employs controlled square micromirrors with an edge length of approximately 16 µm. The light is guided optically either onto the build platform, which is in a translucent vat of photopolymer (photopolymer bath) or onto a diffuse surface (absorber).[2]

Advantages of Additive Manufacturing

- Smooth prosthetic structures than the milling method.
- More accurate.
- Less material consumption.
- Superior esthetics.

Applications of Additive Technique in Paediatric Dentistry

Table 5: 3D printing in cleft lip and palate cases.

Author	Study Design	Study	Groups	Inference
El-Ashmawi NA, Fayed MMS, El-Beialy A, Fares AE, Attia KH (2022)[24]	Randomized clinical trial	Evaluation of facial esthetics following NAM vs CAD/NAM in infants with bilateral cleft lip and palate	Group 1 : NAM Group 2 : CAD NAM	- Both modalities improved nasolabial esthetics before the lip surgery. - No statistically significant difference was found between NAM and CAD/NAM groups.
Hanno K, Al-Shimy A, Habib A, Saad M, El-Fahham I (2020)[25]	In-vivo sudy	To quantify the effect of NAM therapy, fabricated by CAD/CAM additive manufacturing, in the improvement of nasolabial deformity in complete BCLP.	-	- CAD NAM significantly improved nasal esthetics and nasal symmetry. - The bialar width was drastically reduced.

Table 6: Fabrication of 3D printed space maintainers.

Author	Study Design	Study	Groups	Inference
Rana V, Srivastava N, Kaushik N, Kapoor S (2022)[26]	Case Reports	3D printed band and loop space maintainers.	-	- Survival time, gingival health and patient/parent satisfaction were improved remarkably in 3d printed space maintainer as compared to conventional one.
Khanna S, Rao	Case Report	3D printed band and loop	-	- 3D printed space maintainer

D, Panwar S, Pawar B, Ameen S (2021)[27]		space maintainers-advantages over conventional space maintainer.		showed accurate details and exceptional fit. - It reduced chair side time and laboratory hours.
Pawar B (2019)[28]	Case Reports	3D printed band and loop space maintainer.	-	- Conventional space maintainer have tendency for disintegration of cement and increased chairside and laboratory time. - 3D-printed SM is precise, quick, and easy.

Limitations of Additive Manufacturing

- Manufacturing more complex.
- Comparatively low mechanical strength.

Table 7: Comparison Between Subtractive and Additive Technique.

Author	Type of Study	Assessment Criteria	Groups	Inference
Sidhom M, Zaghloul H, Mosleh I, Eldwakhly E (2022)[12]	In vitro study	Effect of different CAD/CAM milling and 3d printing digital fabrication techniques on the accuracy of PMMA working models and vertical marginal fit of PMMA provisional dental prosthesis	A - Milled prosthesis B - 3D printed prosthesis	- Accuracy and marginal fit of working models manufactured by both the techniques were in comparable range. - Additive 3D printing technology can replace subtractive counterpart in the construction of provisional restorations for maximum accuracy, precise fit, and cost-effectiveness.
Al-Halabi M, Bshara N, Nassar J, Comisi J, Rizk C (2021)[29]	Randomized clinical trial	To evaluate clinical outcome of two type of esthetic crown fabricated by CAD CAM technology as an alternative to full-coronal restorations.	Group A : CAD/CAM crowns using PMMA blocks Group B: 3D printed crowns using GC photopolymer resin.	- The survival rate of 3D-printable crowns was 84% compared with 80% survival rate using CAD/CAM fabricated crowns at the end of 12th-month follow-up. - 3D-printed resin crowns showed less cementing failure and performed better regarding gingival response compared with PMMA crowns.
Earar K et al (2020)[30]	In vitro study	To compare additive and subtractive CAD/CAM procedures in manufacturing of the PMMA interim dental crowns	1 - PMMA interim milled crown 2 – PMMA interim 3D printed crown	- 3d printed PMMA crowns were more accurate. - Milled PMMA interim crowns show larger internal dimensional variations. - Fit variation among interim crowns fabricated by both procedures was statistically non-significant.
Marcel R (2020)[31]	In vitro study	To investigate and compare the accuracy of CAD/CAM-fabricated bite splints by milling and 3d printing.	Control -Milled bite splints Experiment – 3D printed bite splints in horizontal or vertical position	- Milled splints show higher trueness. - 3D-printed ones show higher reproducibility.

Cases done in the department of pedodontics and paediatric dentistry (Bapuji dental college and hospital, davangere): Intraoral scanning - Figures 1 and 2 (scanning for 3d printed space maintainer).

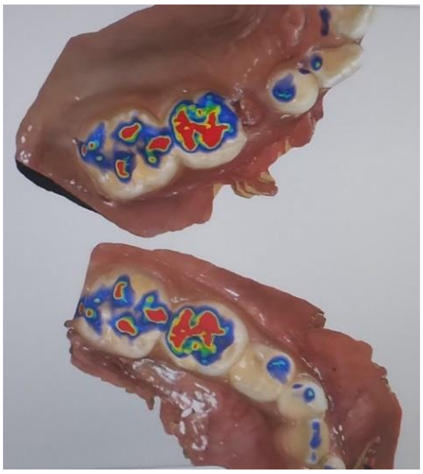

Figure 1

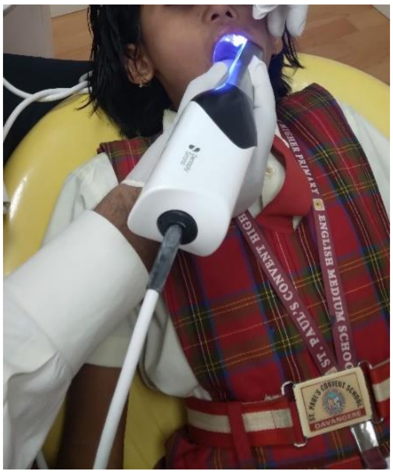

Figure 2

Figure 3 and 4 (scanning for CAD NAM).

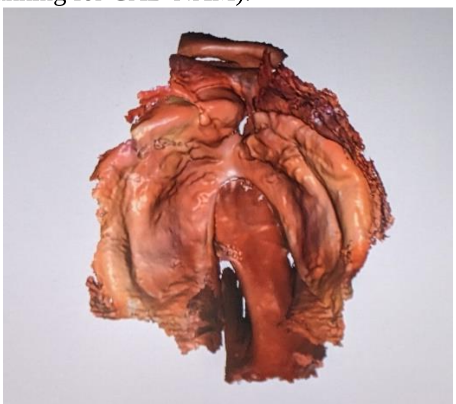

Figure 3

Figure 4

Subtractive manufacturing - PMMA milled Crown (Figure 5).

Figure 5.

Additive manufacturing - Band and loop space maintainer (Figure 6), Lingual holding arch space maintainer (Figure 7), 3-D printed Nasoalveolar moulding appliance (Figure 8), DLP printed crown (Figure 9).

Figure 6.

Figure 7.

Figure 8.

Figure 9.

CONCLUSION

Based on current review article, it can be concluded that various digital techniques have the potential to revolutionize pediatric dental practice by offering various advantages like reduced chairside time, reduced fabrication time of dental appliance, increased patient comfort, increased accuracy and fit of the appliance. It can also motivate the dental patients and can ingrain positive and cooperative behaviour towards pediatric dentistry. However, there is scarcity of literature incorporating digital workflow in day-to-day dental practice. Hence, further clinical research/studies are required to assess the different clinical aspects and factors of the digital dentistry involving IOS, CAD-CAM, 3D printing in various pediatric dental procedures.

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