Journal Homepage: -www.journalijar.com

INTERNATIONAL JOURNAL OF ADVANCED RESEARCH (IJAR)

Article DOI:10.21474/IJAR01/19939
DOI URL: http://dx.doi.org/10.21474/IJAR01/19939

ISSN NO. 2320-5407

RESEARCH ARTICLE

3D PRINTING IN PEDIATRIC DENTISTRY

Dr. Bhargab Roymedhi, Dr. Manohar Bhat, Dr. Abhishek Khairwa, Dr. Rajesh Sharma, Dr. Bidisha Borah and Dr. Diksha Sharma

……………………………………………………………………………………………………....

Manuscript Info

……………………….

Manuscript History
Received: 15 September 2024
Final Accepted: 26 October 2024
Published: November 2024

Abstract

…………………………………………………………………

Background: The emergence of three-dimensional (3D) printing technology has brought about significant advancements in dentistry, particularly in pediatric dentistry. Dentists are increasingly adopting digital approaches, moving away from traditional treatment methods towards fully digital treatment plans to enhance patient care.

Methods: 3D printers utilize computer-aided design (CAD) software or 3D scanners to produce physical representations of objects. Various technologies such as selective laser sintering (SLS), stereolithography, fused deposition modeling, and laminated object manufacturing are employed to print a range of dental products including individual impression trays, orthodontic models, gingiva masks, and prosthetics. These 3D printed products facilitate diagnostics, evaluation of maxillofacial growth, correction of facial asymmetry, and fabrication of aligners for children with malocclusions.

Results: The versatile applications of 3D printing in dentistry have enabled the development of novel and efficient manufacturing methods for dental products.

Conclusion: In conjunction with computer-aided design and computer-aided manufacturing (CAD-CAM), intra-oral scanning, and cone beam computed tomography (CBCT) data, 3D printing has the potential to revolutionize pediatric dentistry. The future trajectory of 3D printing in dentistry will likely involve advancements in materials and technologies, indicating a promising future for this innovative technology in the field.

……………………………………………………………………………………………………....

Introduction:-

The introduction of 3D printing technology in dentistry has provided practitioners with capabilities that were once limited to dental laboratories. In the past decade, this technology has become increasingly accessible to clinicians, enabling them to offer treatments that are more precise, affordable, and time-efficient for patients.[1,2]

Three-dimensional (3D) printing, often referred to as additive manufacturing, is a groundbreaking technology that involves depositing materials to create 3D objects. It utilizes a range of materials such as plastic polymers, metals, ceramics, and even living cells. Additive manufacturing has garnered significant interest and found various applications in the medical and dental fields.[3,4]This revolutionary technology enables the fabrication of working models,prosthodonticrestorations,appliances for orthodontic treatment,implant placementsurgical guides,andmaxillofacial prostheses.[5,6]

Corresponding Author:- Dr. Bhargab Roymedhi

History

3D printing was invented by Charles Hall, which he originally termed "stereolithography," in the early 1980s.[7] Carl Deckard in the year 1986 invented the selective laser sintering methodology. In the year 1999, Wake Forest University designed the first 3D-printed organ for transplantation. In the year 2003, the first inkjet bioprinter was designed. Organovo Company(2009) designed the first 3D-printed blood vessels. In the year 2019, the University of Tel Aviv designed the first 3D-printed heart that contracts with blood vessels.In 2020, Fab Rx developed a 3D printer specifically for personalized medicine.[8] Initially, 3D printers were predominantly employed for rapid prototyping during the 20th century. However, advancements in technology rapidly progressed in subsequent years.Following the expiration of the fused deposition modeling (FDM) patent in 2009[9], 3D printers started to make their way into the consumer market. Subsequently, this technology was adopted by dental laboratories, leading to the development of smaller and more affordable printers tailored for dental applications.The variety of materials that can be printed has grown to include plastics, metals, ceramics, and even biological tissues.[10]

Technologies Involved In 3d Printing

The following techniques are used for 3D printing in various dental applications:
Stereo lithography (SLA).
Fused Deposition Modelling (FDM).
Selective Laser Sintering
Photopolymer Jetting
Electron Beam Melting (EBM)
Power binder printers
Direct light processing

Stereo lithography (SLA)

Stereolithography stands out as one of the first and most widely used techniques in the field of 3D printing.[11] The invention of the first 3D model using a stereolithography apparatus is credited to Charles Hull. This method operates on the principle where a photosensitive monomer resin undergoes polymerization and solidification upon exposure to UV light. Sequential curing ensures that each layer adheres to the previous one, gradually building a solid object from the bottom up.[12] (Fig-1(a))

Fused Deposition Modelling (FDM)

Schott C Rump developed Fused Deposition Modelling.[13]**Fused Deposition Modeling (FDM)** is a 3D printing technique where layers of molten thermoplastic material are extruded from a nozzle and deposited onto a build platform. This material solidifies rapidly, typically within 0.1 seconds, allowing the printer to build up the object layer by layer.[14,15] Its advantage mainly include easy installation, cost effective and easy availability.[16] But the disadvantage of FDM is that its accuracy is less.[11](Fig-1(b))

Selective Laser Sintering

Selective Laser Sintering (SLS)is a 3D printing technique that has been utilized since the mid-1980s. The technology was originally created by Dr. Carl Deckard and his team at the University of Texas.Structures are gradually built up by selectively melting fine powder with a scanning laser. As the powder bed descends, a new layer of fine powder is spread evenly over the surface.This process allows for a high resolution of up to 60 micrometers. Because the surrounding powder supports the printed structures, no extra support materials are required.[17] Polymer scaffolds, such as polyamide or polycaprolactone, are utilized in the production of facial prostheses. Selective Laser Sintering (SLS) is employed to create anatomical study models, guides for cutting and drilling, dental models, as well as prototypes for engineering and design.[18] Its advantages are materials used in the process are easily autoclavable, the printed objects exhibit complete mechanical functionality and when produced in huge amounts, the materials become more cost-effective.Disadvantages are the use of powders can be messy and poses a risk of inhalation, high cost andthe process demands specific climatic conditions, such as compressed air, to operate effectively.[18,19](Fig-1(c))

Photopolymer jetting

This method employs photopolymer or light-cure resin materials along with multiple print heads. The print heads deposit successive layers of the material, with each layer being cured immediately after it is applied.[20]This technology can operate with either a fixed platform and a moving print head or a moving platform and a fixed print head.[21]This technique can print a diverse range of materials, including resins, waxes used for casting, silicone rubber, and substances that require intricate geometry and fine details.[22]It offers a resolution of around 16 micrometers, enabling the rapid and cost-effective production of implant drill guides with minimal bulk.[12]Advantages are that the technique is rapid in producing results and offers a good balance between cost and output.The process also delivers materials with excellent resolution and a high-quality finish.Disadvantages are that it can be challenging to completely remove the material, the cost of materials can be relatively high, risk of skin irritation and sterilization Issues is that the materials cannot be sterilized using heat.[23] (Fig-1(d))

Electron beam melting-

This method employs an electron beam as the energy source rather than using a laser.[24]The electron beam melts the metal powder layer by layer within a high-vacuum chamber, resulting in the complete liquefaction of the material.[25]This technology is utilized in orthopaedics and oral and maxillofacial surgery to create customized implants designed as porous scaffolds.[26,27]

Power binder printers

This device employs a modified inkjet head, a pigmented liquid (typically water), and a powder (often plaster of Paris). It deposits a single layer of powder, which is then penetrated by liquid droplets. This process is repeated incrementally, layer by layer. The final model is constructed from multiple layers, with a new layer of un-infiltrated powder on top of each. This un-infiltrated powder functions as a support material.[28,21]The benefits of this technique include low material and machine costs, fully coloured printed models, faster processing times, and safety during use.[29]Disadvantages include limited accuracy, low resolution, reduced strength, and fragility, with models that cannot be sterilized.[30] (Fig-1(e))

Direct light processing

A projector serves as the light source, and the photosensitive resin is applied and solidified in layers using the projector.[31]The object is built on a lifting platform with layers being formed from the top down. The printing process happens layer by layer, with each layer being solidified as the resin cures.[32]

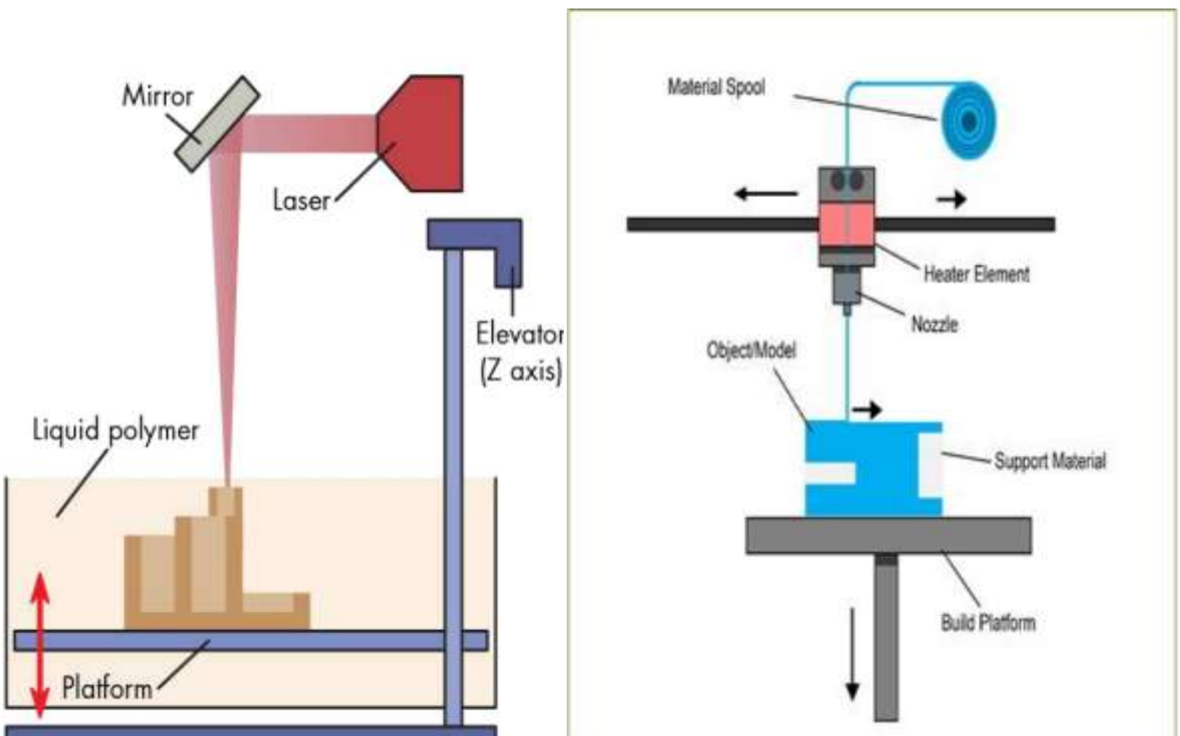
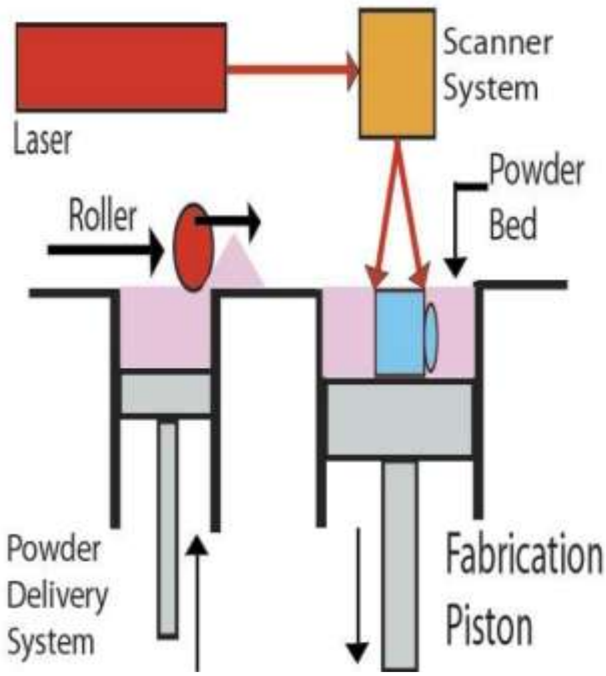


Fig. 1:-(a)Stereo lithography (SLA)[13]**Fig. 1:-**(b)Fused Deposition Modelling[13]



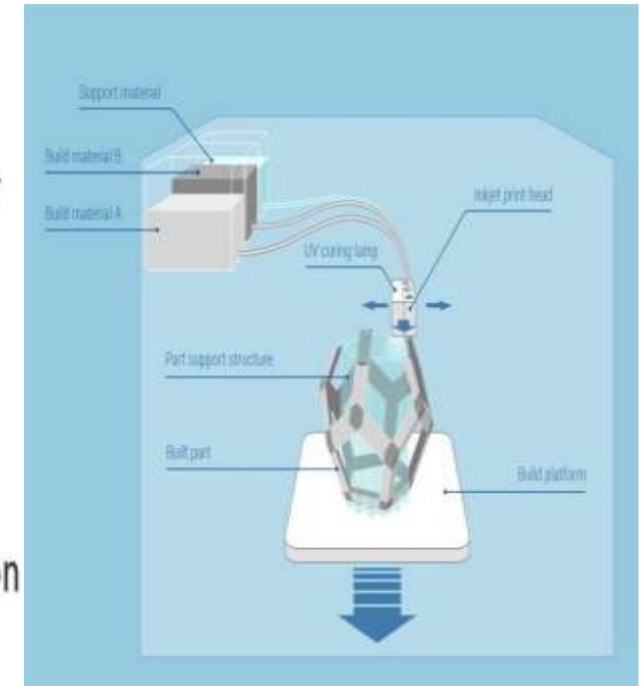


Fig. 1:-(c)Selective Laser Sintering[13] **Fig. 1:-**(d)Photopolymer Jetting[13]

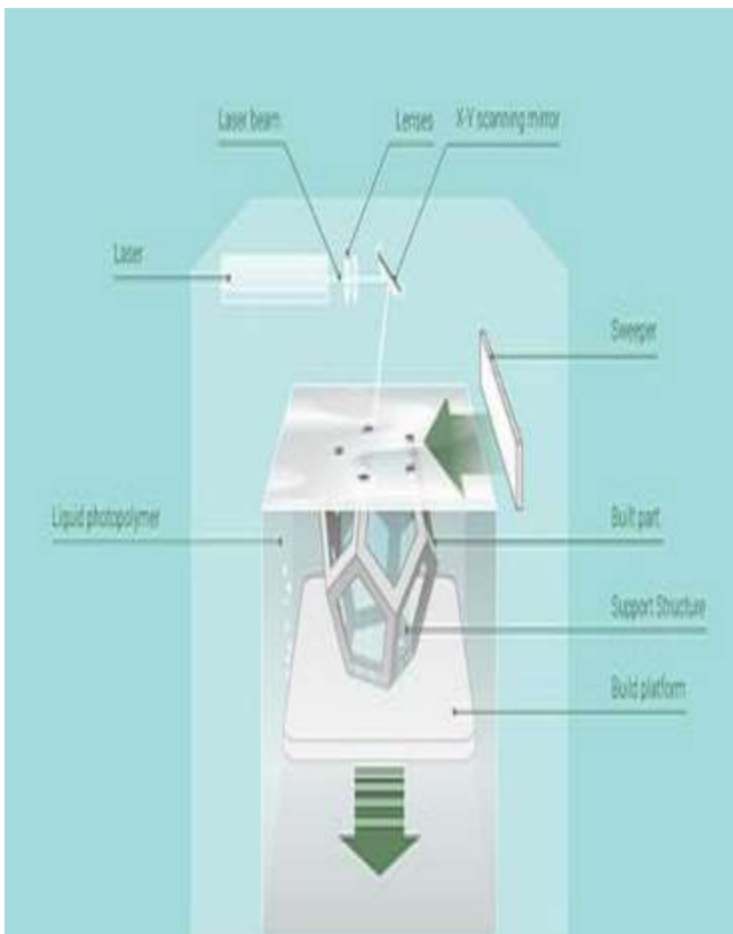


Fig. 1:-(e)Powder Binder Printer[13]

3D Printing Procedure

From a mechanical standpoint, 3D printers are straightforward robotic devices. However, they rely heavily on computer-aided design (CAD) software, which is essential for creating the objects to be printed. CAD software plays a crucial role in designing the objects before they are produced.CAD software is extensively used in industrial design and engineering, and it is increasingly becoming a key tool in dental surgeries as well. In the fields of surgery and dentistry, there is easy access to volumetric data through CT scans, CBCT scans, and intraoral scans.[12]The 3D printing process involves several key steps: first, obtaining a 3D patient model, which can be either physical or digital. Next, the design is created using CAD software, and the model is prepared for 3D printing. This is followed by the actual 3D printing of the model using an additive manufacturing technique, and finally, post-processing is carried out.[33]

Advantages

When comparing 3D-printed restorations to those made using conventional methods, the superior precision, accuracy, detail capture, and high-quality finish of 3D printing technology often make it the preferred choice in dentistry over other available processing methods.[33]The importance of 3D printing in dentistry is underscored by its higher efficiency, resolution, and flexibility. Additionally, its ease and rapid fabrication, reduced material waste due to additive techniques, and enhanced diagnostic and learning capabilities contribute to its significance in the field.

Disadvantages

3D printing technology, while advanced, can be costly. It also has drawbacks, such as the potential for skin irritation, messiness, and inflammation from contact with or inhalation of powders, as well as the need for support materials. Despite these issues, ceramics remain one of the most commonly used materials in dentistry.[12]Due to high porosity during fabrication, ceramics currently lack the capability to be effectively 3D printed[33].However, with ongoing research and the development of advanced techniques in the future, these limitations of 3D printing may be addressed and improved.[12]

Application Of 3D Printing In Pediatric Dentistry

Pediatric dentistry is a distinctive field within dentistry that focuses on treating patients within a specific age range. Due to this specialization, pediatric dentists must possess a wide range of skills. They are required to handle various aspects of dental care, including behaviour management, oral surgery, preventive and interceptive orthodontics, as well as conservative, endodontic, and prosthodontic procedures. Since their patients are children, who represent the future, pediatric dentists face numerous challenges and must be adept in multiple areas to effectively address their needs.

A) Space maintainer fabrication-

The digital 3D model, stored in STL format, is sent to a 3D printing service, where the object is built layer by layer. Initially, an impression is taken to create a cast, which is then scanned using a 3D digital dental scanner. This scanned data is used to design the band and loop. After the printed space maintainer (SM) is positioned in the patient's mouth and its fit is verified, it is secured with glass ionomer cement (GIC).[15]

B) Custom tray fabrication-

Custom trays can be either fabricated manually or 3D printed using computerized scans of impressions or models. Direct 3D printing of models from intraoral scans facilitates the rapid production of prostheses.[15]

C) Fabrication of Fixed and Removable Appliances-

In fixed and removable prosthodontics, CAD software can be utilized to design restorations, and 3D printers can be employed to create crowns, bridges, copings, abutments, and many more components[15].This approach helps prevent unnecessary discomfort from gag reflexes, lengthy lab procedures, and extended appointments. It is particularly beneficial for children, teens with gag reflexes, and individuals with special needs, who often struggle with traditional impression methods for crowns, fillings, and other dental restorations. Scanning and 3D printing treatments are not only faster but also more patient-friendly and comfortable.[34]

D) Pediatric crown fabrication-

In a 2016 study by Sangho Lee et al., the process of fabricating anterior short crowns for primary teeth was detailed. Four primary anterior crowns were needed: the left maxillary central and lateral incisors were created using CAD-CAM technology. A digital scanner was then used to scan the model, and a stent for the strip crown was designed for the right central and lateral incisors. The stent was subsequently tried in place and cemented using composite resin.[35]

E) Pediatric Oral Medicine and Radiology

Requirement of early referral and management of adenoid hypertrophy in children is well-supported in literature. Pediatric dentists are key in detecting nasopharyngeal obstructions, and combining CBCT with 3D printing enhances obstruction identification with more detailed visualization than clinical assessment alone.[36]

F) Pediatric Endodontic and Restorative therapies

In-vivo tooth auto-transplantation is a procedure employed to restore teeth lost due to traumatic dental injuries in children and adolescents. Usually, pedodontists must wait for a period of 3 to 4 months to ensure complete healing before performing any reshaping to enhance the teeth's appearance.However, this delay can be minimized by utilizing 3D printing technology to create chair-side temporary veneers with a DLP printer (Ray dent RAM500, 16 Ray Medical, Seoul, South Korea). Studies have reported that the marginal and internal adaptation values of these temporary veneers are within clinically acceptable ranges.[37]

Tooth anomalies like dilaceration, pulp stones, and dens in dente, which can be challenging to manage during endodontic procedures, can benefit from 3D printing technology. By combining 3D printing with CBCT, a translucent model of the tooth's complex internal anatomy can be created. This, along with a customized guide, helps achieve a safe working length and significantly enhances the quality and precision of treatments for such anomalous teeth.[38,39]3D-printed tooth restorations can be created using materials that feature continuous self-folding properties, allowing them to transition from the center to the edges. This approach helps prevent micro-leakage while enhancing aesthetics, strength, and biocompatibility, and eliminates the need for etching and bonding, relying instead on mechanical retention.[40]Guided endodontics is an advanced approach uses 3D-printed templates to treat teeth with calcified canals or complex restorations, guiding burs accurately to difficult areas. This technique reduces the risk of iatrogenic damage and preserves tooth structure.[41]In endodontic surgeries such as root-end resections and osteotomies, precise control of bur positioning, angulation, and depth is essential to avoid errors and complications such as improper angulation or excessive osteotomy diameter. These issues can lead to increased healing time and postoperative discomfort. 3D-printed surgical stent guides enhance accuracy and precision, making procedures more localized and minimally invasive.[42]

Autotransplantation success is enhanced by 3D printing technology. Computer-aided rapid prototyping (CARP) creates a precise tooth replica, allowing for modifications to the recipient bone site before extraction, thus avoiding damage to the periodontal ligament from repeated adjustments. This method facilitates immediate crown preparation and placement of a temporary crown after the tooth is positioned, reducing extraoral time and minimizing the risk of errors during the procedure.[43]3D bioprinting can facilitate pulp regeneration by dispensing a hydrogel with odontoblastic cells on the edges, fibroblasts in the core, and a supporting network of vascular and neural cells.Researchers continue to explore revascularizing and reinnervating pulp tissue as a promising approach.[44]

G) Pediatric Oral Surgery

3D printing improves surgical planning for oral cancers and mandibular fractures by offering detailed models for accurate procedure execution. It aids in wire placement, tumor resections, and helps surgeons and patients evaluate treatment options through visual aids.[45,46]

A patient-specific digital cap splint for pediatric mandibular fractures reduces the need for sedation, shortens surgery time, and requires no intraoperative adjustments. It fits precisely, restores mandibular arch alignment, and is more aesthetically pleasing than traditional acrylic splints.[47]Another application is customizing titanium alloy restorations for prefabricated skull defect and is highly effective but requires careful technique selection and teamwork across departments.[48]

H) For the Purposes of Education

Dental students can better understand the size, extent, and details of decayed lesions and tooth variations through models made from patient radiographs. This allows instructors to adjust the models to fit specific teaching goals.[49]

I) Orthodontics for children and adolescents

In the coming years, 3D printing and AI will soon revolutionize patient care by allowing patients to virtually view and handle 3D models of their corrected arches and facial changes.[50]

Stereolithography enables the 3D printing of tailored braces with precise tip and torque specifications or custom clear aligners for patients.[51]Additive printing technology can create custom splints for young patients with TMJ dysfunction.[52]Soon, 3D printing will allow the creation of precise myofunctional appliances like Herbst, Activator, and twin block devices for growing patients. This will enhance fit, compliance, and treatment outcomes. It will also enable printing of specialized appliances for sleep apnea, obturators, and feeding for cleft lip and palate patients.[53]Bioprinting intricate oral tissue structures can aid in studying how biological tissues respond to the forces applied during orthodontic treatment.[49]

Future Projections

4D printing, an emerging technology, allows materials to change shape in response to environmental conditions. Developed by Skylar Tibbitts and his team, this method transforms static 3D-printed objects into dynamic structures. In restorative dentistry, 4D-printed materials can move as programmed, potentially eliminating the need for etching and bonding by using mechanical retention.[54]

Future applications may include:

1. 4D-printed filling materials in dental practice thathave the ability to changeshape and position from the center to the margins over time, potentially preventing fractures and marginal leakage.

It is possible to design orthodontic appliances with controlled, self-folding movements that guide teeth into the desired position and angulation.If leveraged effectively, this technology could advance like CAD-CAM and 3D printing, potentially transforming the field of dentistry.[55]

Conclusion:-

3D printing holds transformative potential in pediatric dentistry, offering precise, customized solutions for various treatments. It enhances diagnostic accuracy, enables the creation of tailored orthodontic appliances, and improves the fit and functionality of restorative devices. By advancing patient care through innovative, patient-specific models and reducing procedural complexities, 3D printing is set to significantly impact pediatric dental practices.

Reference:-

1. Kessler A, Hickel R, Reymus M. 3D printing in dentistry—State of the art. Operative dentistry. 2020 Jan 1;45(1):30-40.
2. Turkyilmaz I, Wilkins GN. 3D printing in dentistry–exploring the new horizons. Journal of Dental Sciences. 2021 Jul;16(3):1037.
3. Cousley RR. Introducing 3D printing in your orthodontic practice. Journal of orthodontics. 2020 Sep;47(3):265-72.
4. Kačarević ŽP, Rider PM, Alkildani S, Retnasingh S, Smeets R, Jung O, Ivanišević Z, Barbeck M. An introduction to 3D bioprinting: possibilities, challenges and future aspects. Materials. 2018 Nov 6;11(11):2199.
5. Yoo SY, Kim SK, Heo SJ, Koak JY, Kim JG. Dimensional accuracy of dental models for three-unit prostheses fabricated by various 3D printing technologies. Materials. 2021 Mar 22;14(6):1550.
6. Sherwood RG, Murphy N, Kearns G, Barry C. The use of 3D printing technology in the creation of patient-specific facial prostheses. Irish Journal of Medical Science (1971-). 2020 Nov;189:1215-21.
7. Ventola CL. Medical applications for 3D printing: current and projected uses. Pharmacy and Therapeutics. 2014 Oct;39(10):704.
8. Nesic D, Schaefer BM, Sun Y, Saulacic N, Sailer I. 3D printing approach in dentistry: the future for personalized oral soft tissue regeneration. Journal of clinical medicine. 2020 Jul 15;9(7):2238.
9. Crump SS, inventor; Stratasys Inc, assignee. Apparatus and method for creating three-dimensional objects. United States patent US 5,121,329. 1992 Jun 9.
10. Schweiger J, Edelhoff D, Güth JF. 3D printing in digital prosthetic dentistry: an overview of recent developments in additive manufacturing. Journal of clinical medicine. 2021 May 7;10(9):2010.

11. Kim GB, Lee S, Kim H, Yang DH, Kim YH, Kyung YS, Kim CS, Choi SH, Kim BJ, Ha H, Kwon SU. Three-dimensional printing: basic principles and applications in medicine and radiology. Korean journal of radiology. 2016 Apr 1;17(2):182-97.
12. Neha N, Dr. Jayalakshmi Somasundaram, Dr. Subhabrata Maiti, Dr.Jessy P. 3d printing - a new dimension in dentistry. European Journal of Molecular & Clinical Medicine. 2020;7(1): 1482-97
13. Jain R, Supriya BS, Gupta K. Recent trends of 3-D printing in dentistry-a review. Ann Prosthodont Rest Dent. 2016 Oct;2(1):101-4.
14. Shaikh S, Nahar P, Ali HM. Current perspectives of 3d printing in dental applications. Brazilian Dental Science. 2021 Jul 1;24(3).
15. Tiwari S, Parimala Kulkarni DS, Abraham JM, Agrawal N, Kumar A. 3D printing: A silver lining in pediatric dentistry. NVEO-NATURAL VOLATILES & ESSENTIAL OILS Journal| NVEO. 2021 Dec 18:11582-91.
16. Huang TC, Lin CY. From 3D modeling to 3D printing: Development of a differentiated spatial ability teaching model. Telematics and Informatics. 2017 May 1;34(2):604-13.
17. Pattanayak DK, Fukuda A, Matsushita T, Takemoto M, Fujibayashi S, Sasaki K, Nishida N, Nakamura T, Kokubo T. Bioactive Ti metal analogous to human cancellous bone: Fabrication by selective laser melting and chemical treatments. Acta biomaterialia. 2011 Mar 1;7(3):1398-406.
18. Chen J, Zhang Z, Chen X, Zhang C, Zhang G, Xu Z. Design and manufacture of customized dental implants by using reverse engineering and selective laser melting technology. The Journal of prosthetic dentistry. 2014 Nov 1;112(5):1088-95.
19. Xiong Y, Qian C, Sun J. Fabrication of porous titanium implants by three-dimensional printing and sintering at different temperatures. Dental materials journal. 2012 Oct 2;31(5):815-20.
20. Van Noort R. The future of dental devices is digital. Dental materials. 2012 Jan 1;28(1):3-12.
21. Dawood A, Marti BM, Sauret-Jackson V, Darwood A. 3D printing in dentistry. British dental journal. 2015 Dec 11;219(11):521-9.
22. Ibrahim D, Broilo TL, Heitz C, de Oliveira MG, de Oliveira HW, Nobre SM, dos Santos Filho JH, Silva DN. Dimensional error of selective laser sintering, three-dimensional printing and PolyJet™ models in the reproduction of mandibular anatomy. Journal of Cranio-Maxillofacial Surgery. 2009 Apr 1;37(3):167-73.
23. Jacquet JR, Ossant F, Levassort F, Grégoire JM. 3-D-Printed phantom fabricated by photopolymer jetting technology for high-frequency ultrasound imaging. IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control. 2018 Apr 5;65(6):1048-55.
24. Sawhney H, Jose AA. 3D printing in dentistry-sculpting the way it is. Turkish journal of biology= Turk biyolojidergisi/the Scientific and Technical Research Council of Turkey. 2018 Jun;8(1):01-4.
25. Gali S, Sirsi S. 3D Printing: the future technology in prosthodontics. Journal of Dental and Orofacial Research. 2015;11(1):37-40.
26. Hung KC, Tseng CS, Dai LG, Hsu SH. Water-based polyurethane 3D printed scaffolds with controlled release function for customized cartilage tissue engineering. Biomaterials. 2016 Mar 1;83:156-68.
27. Osman RB, van der Veen AJ, Huiberts D, Wismeijer D, Alharbi N. 3D-printing zirconia implants; a dream or a reality? An in-vitro study evaluating the dimensional accuracy, surface topography and mechanical properties of printed zirconia implant and discs. Journal of the mechanical behavior of biomedical materials. 2017 Nov 1;75:521-8.
28. Qingbin Liu · Ming C. Leu · Stephen M. Schmitt. Rapid prototyping in dentistry: technology and application.Int J Adv Manuf Technol (2006) 29: 317–335
29. Ciuffolo F, Epifania E, Duranti G, De Luca V, Raviglia D, Rezza S, Festa F. Rapid prototyping: a new method of preparing trays for indirect bonding. American Journal of Orthodontics and Dentofacial Orthopedics. 2006 Jan 1;129(1):75-7.
30. Chia HN, Wu BM. Recent advances in 3D printing of biomaterials. Journal of biological engineering. 2015 Dec;9:1-4.
31. Zaharia C, Gabor AG, Gavrilovici A, Stan AT, Idorasi L, Sinescu C, Negruțiu ML. Digital dentistry-3D printing applications. J Interdiscip Med. 2017 Mar 1;2(1):50-3.
32. Nayar S, Bhuminathan S, Bhat WM. Rapid prototyping and stereolithography in dentistry. Journal of Pharmacy and Bioallied Sciences. 2015 Apr 1;7(Suppl 1):S216-9.
33. Prasad S, Kader NA, Sujatha G, Raj T, Patil S. 3D printing in dentistry. Journal of 3D printing in medicine. 2018 Aug 14;2(3):89-91.
34. Pawar BA. Maintenance of space by innovative three-dimensional-printed band and loop space maintainer. Journal of Indian Society of Pedodontics and Preventive Dentistry. 2019 Apr 1;37(2):205-8.

35. Lee S. Prospect for 3D printing technology in medical, dental, and pediatric dental field. Journal of the Korean academy of pediatric dentistry. 2016 Feb 29;43(1):93-108.
36. Thereza-Bussolaro C, Lagravère M, Pacheco-Pereira C, Flores-Mir C. Development, validation and application of a 3D printed model depicting adenoid hypertrophy in comparison to a Nasoendoscopy. Head & face medicine. 2020 Dec;16:1-8.
37. Al-Rimawi A, EzEldeen M, Schneider D, Politis C, Jacobs R. 3D printed temporary veneer restoring autotransplanted teeth in children: design and concept validation ex vivo. International Journal of Environmental Research and Public Health. 2019 Feb;16(3):496.
38. Kfir A, Telishevsky-Strauss Y, Leitner A, Metzger Z. The diagnosis and conservative treatment of a complex type 3 dens invaginatus using cone beam computed tomography (CBCT) and 3D plastic models. International endodontic journal. 2013 Mar;46(3):275-88.
39. Byun C, Kim C, Cho S, Baek SH, Kim G, Kim SG, Kim SY. Endodontic treatment of an anomalous anterior tooth with the aid of a 3-dimensional printed physical tooth model. Journal of endodontics. 2015 Jun 1;41(6):961-5.
40. Ayar MK. Is a three-dimensional-printed tooth filling possible?. Dental Hypotheses. 2016 Apr 1;7(2):53-5.
41. Zehnder MS, Connert T, Weiger R, Krastl G, Kühl S. Guided endodontics: accuracy of a novel method for guided access cavity preparation and root canal location. International endodontic journal. 2016 Oct;49(10):966-72.
42. Murray PE, Garcia-Godoy F, Hargreaves KM. Regenerative endodontics: a review of current status and a call for action. Journal of endodontics. 2007 Apr 1;33(4):377-90.
43. Obregon F, Vaquette C, Ivanovski S, Hutmacher DW, Bertassoni LE. Three-dimensional bioprinting for regenerative dentistry and craniofacial tissue engineering. Journal of dental research. 2015 Sep;94(9_suppl):143S-52S.
44. Sureshchandra B, Roma M. Regeneration of dental pulp: A myth or hype. Endodontology. 2013 Jan 1;25(1):139-54.
45. Lee AY, Patel NA, Kurtz K, Edelman M, Koral K, Kamdar D, Goldstein T. The use of 3D printing in shared decision making for a juvenile aggressive ossifying fibroma in a pediatric patient. American Journal of Otolaryngology. 2019 Sep 1;40(5):779-82.
46. Dong Z, Li Q, Bai S, Zhang L. Application of 3-dimensional printing technology to Kirschner wire fixation of adolescent condyle fracture. Journal of Oral and Maxillofacial Surgery. 2015 Oct 1;73(10):1970-6.
47. Chakravarthy C, Gupta NC, Patil R. A simplified digital workflow for the treatment of pediatric mandibular fractures using three-dimensional (3D) printed cap splint: A case report. Craniomaxillofacial Trauma & Reconstruction Open. 2019 Jan;3(1):s-0039.
48. Wang Y, Qi H. Perfect combination of the expanded flap and 3D printing technology in reconstructing a child’s craniofacial region. Head & Face Medicine. 2020 Dec;16:1-5.
49. Sikdar R, Bag A, Shirolkar S, Gayen K, Sarkar S, Roychowdhury S. 3D printing: Its application in pediatric dental practice. Acta Scientific Dental Sciences (ISSN: 2581-4893). 2022 Feb;6(2):103-11.
50. Jheon AH, Oberoi S, Solem RC, Kapila S. Moving towards precision orthodontics: An evolving paradigm shift in the planning and delivery of customized orthodontic therapy. Orthodontics & craniofacial research. 2017 Jun;20:106-13.
51. Martorelli M, Gerbino S, Giudice M, Ausiello P. A comparison between customized clear and removable orthodontic appliances manufactured using RP and CNC techniques. Dental Materials. 2013 Feb 1;29(2):e1-0.
52. Salmi M, Paloheimo KS, Tuomi J, Ingman T, Mäkitie A. A digital process for additive manufacturing of occlusal splints: a clinical pilot study. Journal of the Royal Society Interface. 2013 Jul 6;10(84):20130203.
53. Al Mortadi N, Eggbeer D, Lewis J, Williams RJ. CAD/CAM/AM applications in the manufacture of dental appliances. American journal of orthodontics and dentofacial orthopedics. 2012 Nov 1;142(5):727-33.
54. Tibbits S. 4D printing: multi-material shape change. Architectural design. 2014 Jan;84(1):116-21.
55. Haleem A, Javaid M. 4D printing applications in dentistry. Curr Med Res Pract. 2019;9:41-2.