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Literature Review

Three Dimensional Printing – From A Pediatric Dentist's Perspective

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ABSTRACT

In the digital era, the conventional techniques of manufacturing have been replaced by additive manufacturing using the digital data captured. This advent of manufacturing has been trending in medical field in the early beginning of the 20th century and now it's trending in all biomedical and allied healthcare including dentistry. Three dimensional printing or additive manufacturing has found its usage in most of the dental procedures. The object is "printed" in the additive manufacturing process by adding the building material in increments. In pediatric dentistry,3D printing has gained its way by its child friendly practice tool with the advent of intra oral scanners. This 3D printing has various roles in taking pediatric dentistry to its next era – digital era –leading to customised, child friendly, painless holistic pediatric dental practice.

Keywords: Additive manufacturing; Pediatric Dentistry; 3D printing

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INTRODUCTION

A rapid amelioration in technical aspects of 3D printing has led to digital workflow in all aspects in the field of dentistry. The drive behind such upgrade emerges from the improvements in personalised medicine and possibilities of digital analysis and accessibility of patient image and data. This narrative review highlights the application of 3D printing in Pediatric Dentistry.

3D printing- what is all about?

3D printing or Additive manufacturing is a process, that allows for the creation of objects with precise geometric shapes using Computer Aided Design (CAD-CAM) scanners or 3D object scanners. These are built layer by layer, as opposed to traditional manufacturing, which frequently requires machining or other techniques to remove excess material. In simpler terms, 3D printing creates less material wastage. Three-dimensional printing (3D printing) involves controlled materials together printed layer by layer in a processed manner much similar to ink spraying on paper. However, this occurs by crystallizing, solidifying or joining a liquid material or powder at any point during contact of the printing object aided by CAD (computer-aided design).[1,2,3]

HISTORICAL PERSPECTIVE

The first evidence of 3D printing dates back to 1980 when Dr. Kodama from Japan invented this technology as rapid prototyping (RP). It was called so because the technology was designed for rapid and frugal construction and mass production of a prototype. Following this, Chuck Hull patented the invention of stereolithography (SLT) device in 1986. At the same time, Carl Deckard who was studying at the University of Texas performed the process of RP with selective laser sintering (SLS) in 1987. In the same year, 1989, Scott Crump, announced the patenting of his melting layer modelling machine and the technology was called selective laser melting. In the beginning of the 21st century, several developments took place which encouraged the use of 3d printing in healthcare. In 2008, the first 3D printed prosthetic leg was made which in turn made huge leaps in allied healthcare also. In 2012, the first 3D printed jaw was made. The bioresorbable scaffold for periodontal repair in 3D was first implanted in the University of Michigan in 2015.[4,5]

STAGE OF PROCESSING IN 3D PRINTING

The printing of 3D objects, involves a certain controlled set of processing stages[6] in **Figure 1** as follows:
Stage 1: Creation of a three dimensional file using CAD software
Stage 2: Conversion of 3D file into STL file format to be recognized by the printer
Stage 3: The STL file is imported to a program that slices file layers and is called slicer. The slicer receives the model and converts it to a G-code that contains instructions for CNC machines and 3D printers. The third step is related to model printing.
Stage 4: The step wise printing of 3D model layer by layer
Stage 5: Processing

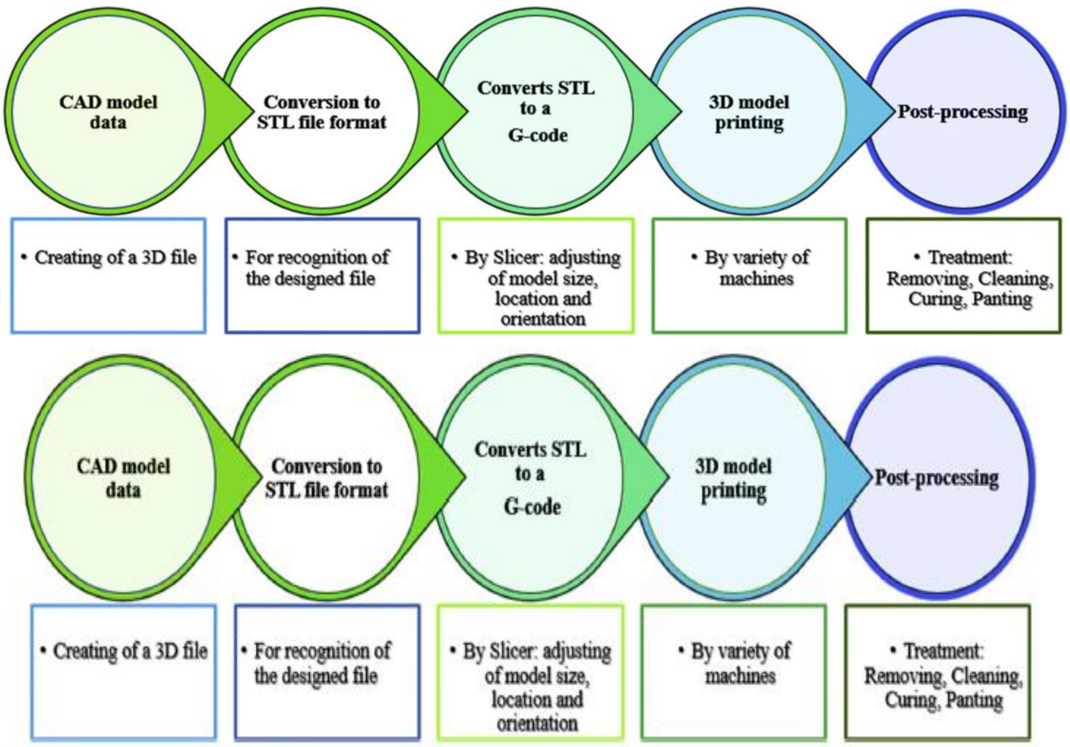

Figure 1: Stages of 3D printing. Source: Eshkalak et al.(2020)

BIOMATERIALS IN 3D PRINTING

Biomaterials is synonymous with natural or synthetic materials utilized to replace any biological organ or compensating injured tissues in the body in a natural way by interacting biologically with human liquids. Moreover, biomaterials aid clinicians in customization of individualized products via 3D printing. Based on the chemical composition of the biomaterials; they are classified as metals, ceramics, polymers and composites. Metallic and polymeric biomaterials are mostly used in dentistry or orthopaedic applications with the advantages of optimum mechanical and elastic qualities along with good stability. Polymers have found their application in prosthetics, implants, controlled drug delivery as well. The most common biomaterial polymers used in healthcare are tabulated below as given in **Figure 2** as stated by Eshkalak et al.[6]

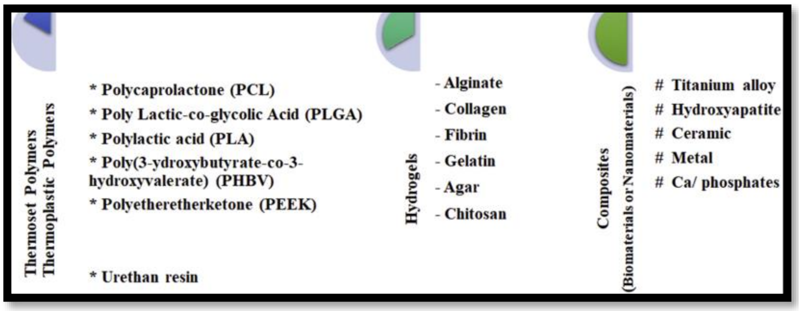

Figure 2: Most common used biomaterials in healthcare

BIOPRINTING

The 3D printing technology involving the cells is termed “bioprinting”, and the hydrogels, in which cells reside for the printing purpose, are termed “bioinks”. Hydrogels are preferred due to adaptable chemical composition, and adjustable mechanical and biodegradation qualities with good biocompatibility, low cytotoxicity, and high water content. Examples: alginate is combined with calcium, and fibrinogen with thrombin. Laser-assisted bioprinting (LAB) is based on a laser pulse that causes local heating of a cell-containing solution, resulting in the orderly dropping of cells on the other side of a platform/substrate. Laser-direct-writing, a type of LAB, has been used successfully in tissue engineering to deposit various cell types and biomaterials.[5]

3D PRINTING IN DENTISTRY

3D printing in the dentistry dates back to almost 10 years back. The first of its usage in dentistry was guided implant drills for implant surgery procedures and laser–sintered alloys.

DIGITAL WORKFLOW:

The evolution of digital imaging and the use of CAD/CAM technology enabled the emergence of digital dental treatment. Plastic imprints have been replaced by intraoral scanning in the production of computer-aided manufactured (CAM) digital physical models. As a result, throughout the three processing steps, manual handling is being replaced, and this novel approach has been dubbed "digital workflow”. The initial stage is to collect data using various scanning technologies. Computerized tomography (CT), cone beam computed tomography (CBCT), magnetic resonance imaging (MRI), and laser digitising with extraoral or intraoral scanning equipment are the most commonly used procedures.

The second stage is to process the data and design the model using computer-aided design (CAD) software. The generated STL file is loaded into the printer software. The building variables and segmentation parameters are then supplied, along with the support structures, to generate the information required to drive the 3D printer. The processed data is further used in the third step to produce structures with the specified material using the CAM step.[6]

3D PRINTING TECHNIQUES IN DENTISTRY:

Fused deposition modelling (FDM), selective laser sintering (SLS), stereolithography (SLA), polyjet printing, and bioprinting are the most often used 3D printing processes in dentistry. In fused deposition modelling (FDM), the spooled material is fed into a hot nozzle, which melts and extrudes it in the customised input dimensions one layer at a time before the nozzle is elevated or the print bed is dropped, as shown in **Figure 3**. It is the printer of choice for producing easily accessible anatomical models in-house.[7]

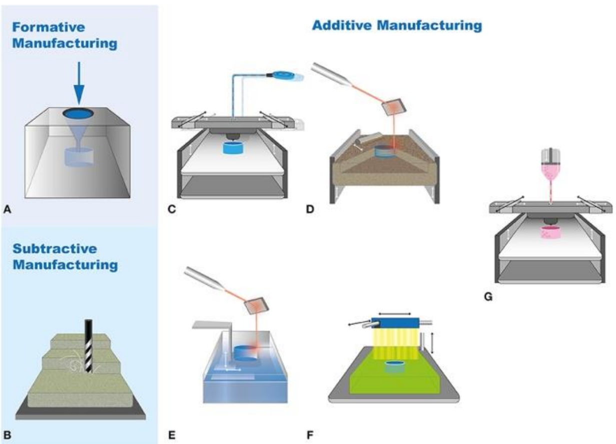

Figure 3: Conventional and different types of 3D manufacturing.A)depicts the conventional formative manufacturing using casting moulds.B)Subtractive manufacturing with the loss of material lead to finished product.C) Fused deposition modeling (FDM), (D) Selective laser sintering (SLS), (E) Stereolithography (SLA), (F) Polyjet and (G)Bioprinting. Source: Oberoi et al.(2018)

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SLA(Stereolithography) is a method of hardening the surface of a photosensitive polymer by pointing a laser or a light source onto it. The constant vertical raising of the container with a polymer results in the substance subsequently hardening and the creation of a 3D object. SLA has been utilized for the production of biodegradable polymers, ceramic acrylate, and hydroxyapatite for bone repair.[5]

For the manufacture of zirconia implants, another 3D printing technology, digital light processing (DLP) based on photopolymerization, was used.[6] The selective laser sintering (SLS) and powder fusion printing (PFP) techniques employ a laser to fuse grains of metal, resin, or plastic layer by layer. This technology was utilised to create scaffolds for bone regeneration using tricalcium phosphate and hydroxyapatite. The ability to print molten metals such as titanium, magnesium, or cobalt chromium, which are used in medicine and dentistry, is a benefit of PFP techniques.[5]

The polyjet printer **(Figure 3)** has the highest resolution since the 3 dimensional model is formed increment wise by the printer heads jetting layers of liquid photopolymer onto a build tray, followed by UV light curing. The benefits of polyjet printers include a wide range of printing materials with varying density, hardness, flexibility, and porosity, resolution as fine as 25 microns, a quick printing process, and the replication of complex shapes. The downsides are the post-print model processing steps, such as rigorous washing and support material removal. It is used in surgical planning on patient-individualistic 3D models with complicated geometries, surgical stents and guides, phantoms for orthopaedic and cardiac surgeries, and scaffolds for bio-engineering. [8] The various techniques of printing and its uses are summarized in **Table 1**.

Table 1: Various Techniques of printing and its uses

3D Printer	Materials	Potential application in dentistry
Fused Deposition Modeling (FDM)	Thermoplastic polymers such as polylactic acid (PLA), acrylonitrile butadiene styrene (ABS), polycarbonate (PC), polyether ether ketone (PEEK), etc.	In-house production of basic proof-of-concept models, low-cost prototyping of simple anatomical parts
Stereolithography (SLA)	A variety of resins for photopolymerization, ceramic filled resins, etc.	Dental models, surgical guides and splints, orthodontic devices (aligners and retainers), castable crowns, and bridges.
Selective Laser Sintering (SLS)	Powder such as alumide, polyamide, glass-particle filled polyamide, rubber-like polyurethane, etc.	Hospital set up for metal crowns, copings and bridges, metal or resin partial denture frameworks
Polyjet printing	A variety of photopolymers	Hospital set-up manufacturing of craniomaxillofacial implants, sophisticated anatomical models, drilling and cutting guides, facial prosthesis (ear, nose, eye)
Bioprinter	Cell-loaded gels and inks based on collagen, photopolymer resins, agarose, alginate, hyaluronan, chitosan, etc.	Cell-laden scaffolds for hard and soft tissue printing

APPLICATION IN CLINICAL PEDIATRIC DENTISTRY

3D Printing In Pediatric Oral And Maxillofacial Procedures

Patients with orofacial defects can be reconstructed with customized allogenic implants and scaffolds for bone and tissue regeneration with bio-materials using 3D printing technology. With additives such as calcium phosphate biomaterials in the form of hydroxyapatite, -tricalcium phosphate to polyglycolic acid and polylactic acid, and even bioactive magnesium-calcium silicate/poly—caprolactone, it is possible to obtain the desired dimensions and customised properties of biomaterials in terms of porosity, surface texture, and design. Osteoinductive substances, such as bone morphogenetic proteins (BMP-2 and BMP-7) that stimulate osteogenic differentiation, could be added preferentially to the printed scaffolds to improve cell adhesion, proliferation, and vascularisation.[9]

3D Printing Application In Autotransplantation

Autotransplantation of impacted permanent tooth or loss of tooth due to trauma as well as in congenital hypodontia cases could be easily performed with help of 3D printing. A recipient socket must be made for the placement of the donor tooth in autogenous tooth transplantation. The transplanted tooth is extremely vulnerable, especially during the testing of its fit inside the new alveolar bed, when periodontal ligament injury is likely. Furthermore, wherever possible, the donor tooth's extraoral handling time should be kept to a minimum, as it has a negative impact on the tooth's viability.[10,11]

To minimise damage to the donor tooth, helical CT/cone beam computed tomography is used in tandem with computer-aided rapid prototyping, which allows the printing of dental replicas for use as guides during surgery, thereby minimising extra-oral time and limiting possible damage to the donor tooth's periodontal tissue. All of this promotes the formation of a new recipient socket, so eliminating dangers to the donor tooth and, more broadly, aiding in the standardisation of the technique.[11] In a case report, autotransplantation of the teeth was performed by taking a replica of the teeth using Polyjet 3D printing and surgical guides were customised to minimise the trauma to the bone and periodontium.[11] The Objet30 Prime® printer provided the dental replica and the Sigmar R19 (BCN 3D® Technologies) the mandibular segment, using PolyJet and FDM technologies respectively. Med610 material (Stratasys®) was used for 3D printing of the dental replica and polylactic acid (PLA) for the printing of the mandibular segment and adjacent teeth similar to **Figure 4**. This could be very useful in cases of avulsed permanent cental incisor in young patients with minimal damage to alveolar bone and periodontium enhancing the success of transplanted tooth. The design of surgical guides and templates for better precision of the operation is critical for digital surgical planning and execution. They are based on data from CT imaging and computer software analysis of the maxillomandibular abnormality. It is also possible to create a digitally planned and printed surgical drilling or cutting guide using a variety of commercial software packages. This technique has fewer flaws with better margin control, and fewer bone compromises. On screen, a developed virtual 3D plan is sent to the operator site. As a result, it serves as a link between the virtual plan and the physical patient. This guide will be similar to as shown in **Figure 5.**

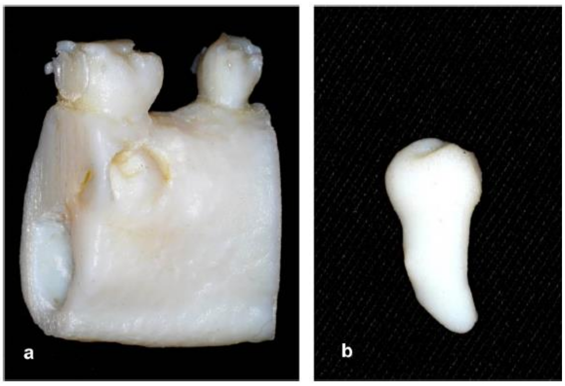

Figure 4: PLA and MED610 printing material and FDM and Polyjet technology. a) Replica of the mandibular segment; b) Replica of tooth 35 (Cahuana-Bartra et al., 2020)

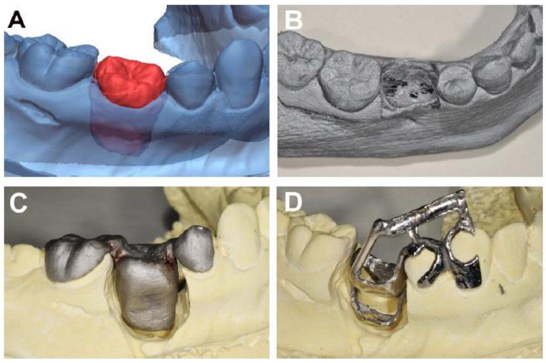

Figure 5: Surgical guider for autotransplantation. A. Simulation of transplanted tooth with scanning and 3D imaging computer software. B. 3D printing model of recipient site showing socket for transplantation. C. 3D printing model of surgical guider. D. Surgical guider for drilling depth made by 3D printed wax pattern and metal casting (Hu et al., 2017)

3D Printing In Behaviour Management Of Uncooperative Children And SHCN

Intra oral scanners have become a boon in the management of uncooperative children and SHCN in the fabrication of space maintainers and habit breaking appliances. Millennial kids are not excited about a mouthful of "Play-Doh" even dressed up with euphemistic phrases. The intraoral scanner is a game changer for fearful children or those with strong gag reflexes in pediatric clinical practice. Scanning of arches can be done with pauses and breaks and can be started from the area which is more acceptable in young children and children with special health needs. This gives an edge over the conventional impression technique where it could be rarely possible to pause or stop, risking having to start all over again. The term "magic wand" can be used as an euphemism to take a full scan of their teeth that they can view in 360 degrees on a colourful touch screen. Thus intra oral scanners and digital workflow could be used to educate patients and help them understand why they are receiving a certain appliance or space maintainer increasing the acceptability in clinical practice.

3D Printing In Interceptive Orthodontic Procedures

A novel method was proposed employing 3D face scans and 3D printing to create perfect anatomical dental arches of patients along with orthodontic brackets, some years ago.[12] As a result, patient-specific modifications are feasible now virtually to depict the alterations made by braces in advance using this computer-aided technique. 3D printing is now being used in animal models to adjust mandibular growth and modulate tooth mobility in order to gain a better understanding of cartilage and bone growth physiology. Some of these discoveries will help in growth modification, acceleration of orthodontic tooth movement, and enhancing anchorage of teeth.[13] 3D printing may change the current

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concepts of interceptive orthodontic treatment modalities in young patients to customised precise functional appliances using the growth models of young patients and can be effectively to modulate growth in the future.

3D Printing In Fixed Orthodontics

Presently, 3D printing in orthodontics is largely employed for the creation of aligners for the correction of malaligned teeth. Teeth are digitally implanted in the optimum position using computer software. Following the presentation of the 3D model, a customized casting mould is made. The mould is printed using the stereolithography method, which involves building up the product layer wise during the printing process. Orthodontic aligner is then silicone-cast from the completed mould.[14]

3D printing reduces the lengthy treatment time of fixed orthodontics. This clinically favours young patients thus minimising the chances of tooth demineralization, orthodontic white spot lesion and root resorption.[15] It gives a possibility of the fabricating 3D-printed brackets. By digital planning of orthodontic treatment and using 3D printing to construct customised brackets and properly positioning them, it is feasible to accomplish the desired treatment outcomes while expediting the entire procedure. Furthermore, printing of guides for the placement of temporary anchorage devices or indirect bonding guides for precise bracket positioning may play a significant role in orthodontics in the future as shown in **Figure 6**. Also, auxiliary orthodontic devices such as Herbst, Andresen, and sleep apnea appliances can be manufactured by CAD/CAM technology leading to an excellent intraoral fit.[16]

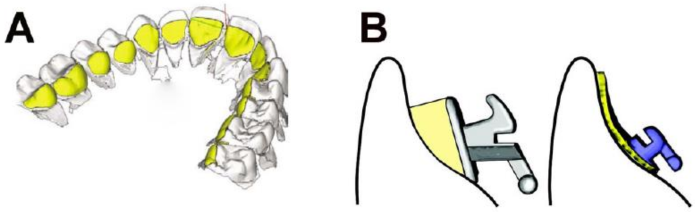

Figure 6: Digital setup with individually defined bracket bases, B. Conventional lingual bracket (left) and customized bracket (Right). cited on Am J Orthod Dentofacial Ortho, 124:593-599, 2003.

3D Printing In Regenerative Endodontics

The shift to digital workflow has changed the precision in regenerative and conventional endodontics in an unparalleled manner with greater exactitude, and better patient comfort. Furthermore,it has provided a path breaking advancement in regenerative endodontics by improving operator skills.[17,18] In endodontics, the notion of additive manufacturing can be used to provide stem cells, pulp scaffolds, injectable calcium phosphates, growth hormones, and gene therapy.[17].This could help with dentin-pulp complex renewal with the rise of novel bioactive materials. According to research, applying 3Dprinted polycaprolactone covered with freeze-dried platelet-rich plasma to dental pulp cells improves osteogenic activity *in vitro*. Also, utilising 3D printed polyepsilon-caprolactone and hydroxyapatite scaffolds, anatomically formed tooth-like tissue was created.[19]

Clinically, additive manufacturing in endodontics is used in apicectomy and access cavity preparation. Evidence has demonstrated the superiority of guided access cavity preparation over conventional method.[20] Such guided endodontic operations could be extremely beneficial in difficult teeth with root canal anatomical anomalies. Case studies have demonstrated the potential importance of 3D printing in this field by creating models with internal root anatomy using CBCT that can be utilised as a base to print a guide for the endodontic treatment of such difficult scenarios.[21] Furthermore this technique can even be used on primary and immature permanent molars with complicated root canal anatomies.[22]

3D-printed models and computer software, such as haptic simulators, aid in the development of endodontic skills by providing the user with sensory proprioception promising a future in advancement of surgical and non-surgical pediatric endodontics in training and education during the post COVID era.

3D Printing In Fabrication Of Crowns And Space Maintainers

In the additive manufacture of dental prostheses and crowns, metallic and polymer-based materials are commonly used. Many in vitro investigations have revealed that ceramics produced using lithography, in which the object is printed layer wise, have mechanical qualities comparable to milled ceramics. However, further research is needed in the manufacturing process, as well as strength and fracture toughness. Most 3D printing processes utilised today, such as selective laser sintering, selective laser melting, and stereolithography, produce porous materials, whereas ink-jet printing produces complicated thick ceramic-like structures.[23]

Recent equipments such as intra oral scanners (iTero® system) promote the quick fabrication of customised chair side space maintainers such as band and loop space maintainers. Recently, the usage of 3d printed chairside space maintainers was reported emphasising the impact of 3d printing in preventive orthodontics.[24] Another 3D printed band and loop space maintainer was successfully placed indicating the game changing potential of digital workflow in preventive orthodontics and pediatric dentistry.[25] Functional space maintainers will be the future of pediatric dentistry with the advent of this technology. In challenging cases with short clinical crowns,3D printing give an edge over conventional prefabricated zirconia crowns with the placement of customised short post retained zirconia crowns and

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celluloid strip crowns as well as shown in **Figure 7.**

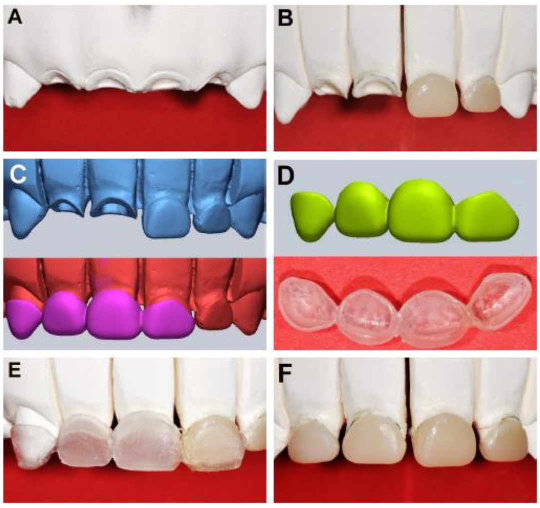

Figure 7: Fabrication of short post crowns for primary anterior teeth. A. Preparation of teeth for short post crown. B. Zirconia short post crown made with CAM/CAD system. C. 3D scanning model (upper) and stent for strip crown designed by 3D imaging software (lower). D. 3D stent image (upper) and printed material of stent (lower). E. Checking the stent on working model before placement of composite resin. F. Placement of short post crown, Left central and lateral primary incisors: Zirconia crowns fabricated by CAM/CAM system, Right central and lateral primary incisors: Resin crowns fabricated by 3Dprinting technology (Source: S Lee et al.).

CONCLUSION

With the advent of technological leap in additive manufacturing and the introduction of intra oral scanning, 3D printing will become an indispensable tool in every day to day practice and digital workflow will replace conventional work flow in due course of time. This digital game changer in pediatric clinical practice will transform prefabricated crowns to customised crowns and customised space maintainers and functional and fixed appliances, thus providing personalised and holistic pediatric dentistry.

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