3D PRINTING: ITS APPLICATIONS IN PEDIATRIC DENTAL PRACTICE

Abstract

Additive manufacturing, which uses digital data for production, has supplanted traditional manufacturing techniques in the digital age. The medical industry was first affected by this manufacturing revolution in the early 20th century and has since extended its influence to encompass all areas of biomedical and allied healthcare, including dentistry. Additive manufacturing is rapidly emerging as a valuable tool in various branches of dentistry. What sets it apart from traditional formative and subtractive manufacturing methods is that it constructs objects layer by layer through the addition of building materials. Because of its kid-friendly methodology, 3D printing has becoming more popular in pediatric dentistry, especially when intraoral scanners were introduced. This technology plays a multifaceted role in advancing pediatric dentistry into the digital era, ushering in a new era of customized, child-friendly, and painless holistic dental practices.

Keywords: Additive manufacturing, 3D printing, dentistry, pediatric

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I. INTRODUCTION

. Significant advancements in 3D printing technology have brought about a complete digital transformation across all facets of the dental field. This shift is primarily fueled by the progress made in personalized medicine and the potential for digital sharing and processing of patient images and data. This narrative study offers a thorough synopsis of the 3D printing procedure and its numerous uses in different facets of pediatric dentistry.

II. ADDITIVE MANUFACTURING

Additive manufacturing, commonly known as 3D printing, is a manufacturing process that enables the precise shaping of objects using Computer-Aided Design (CAD-CAM) scanners or 3D object scanners. In contrast to conventional manufacturing techniques, which frequently call for milling or other procedures to eliminate extra material, 3D printing constructs things layer by layer. To put it another way, 3D printing reduces material waste. In a manner akin to spraying ink onto paper, it entails the carefully managed deposition of ingredients, layer by layer. However, in 3D printing, this occurs in three dimensions through the crystallization, solidification, or bonding of liquid material or powder at various points during the printing process, guided by CAD (Computer-Aided Design)..[1,2,3,4]

III. HISTORY OF 3D PRINTING

The early stages of 3D printing technology date back to 1980 when Dr. Kodama from Japan introduced the concept, initially known as rapid prototyping (RP). This term was coined because the technology aimed to swiftly and cost-effectively produce prototypes for mass production. In 1986The stereo lithography (SLT) device was patented by Chuck Hull. Then, in 1987, Carl Deckard of the University of Texas used selective laser sintering (SLS) for RP at the same time. The term "selective laser melting" originated in 1989 when Scott Crump patented his melting layer modeling equipment.

Early in the twenty-first century, a number of developments supported the use of 3D printing in the medical field. An important turning point in the field of allied healthcare was reached in 2008 with the creation of the first 3D-printed prosthetic leg. The first successful 3D-printed jaw was produced in 2012. Furthermore, in 2015, the University of Michigan introduced the first implanted 3D-printed bioresorbable scaffold for periodontal repair. These milestones marked crucial progress in the integration of 3D printing technology into healthcare.[5,6]

IV. STAGE OF PROCESSING IN 3D PRINTING

The process of 3D object printing consists of a specific sequence of controlled processing stages, as illustrated in Figure 1, which are as follows:[7,8,9]

- **Stage 1:** Generating a three-dimensional file utilizing CAD software.
- **Stage 2**: converting the 3D file into an STL file format that the printer can read.
- **Stage 3:** The STL file is imported into a slicing program, often referred to as a slicer, Which divides the model into layers and generates G-code instructions for CNC machines and 3D printers. This step is crucial for the actual printing of the model.

- **Stage 4:** The layer-by-layer printing of a three-dimensional model
- **Stage 5:** Processing

V. BIOMATERIALS IN 3D PRINTING

Biomaterials encompass both natural and synthetic materials employed for the replacement of organs or the repair of injured tissues within the body, facilitating biological interactions with bodily fluids. Furthermore, biomaterials offer healthcare professionals the ability to customize products for individuals through 3D printing technology. These biomaterials can be classified into four main types based on their chemical composition: metals, ceramics, polymers, and composites. Within the field of dentistry and orthopedics, metallic and polymeric biomaterials find prominent use, offering advantageous mechanical properties, stability, and elasticity. Polymers, in particular, have found widespread application in various biomedical contexts, including prosthetics, implants, and controlled drug delivery systems, among others. A list of commonly used biomaterial polymers in healthcare is provided below. Table 1 by Eshkalaket al.(2020)

VI. BIOPRINTING

Cell-based 3D printing is known as "bioprinting," and the hydrogels that are used to contain the cells during printing are known as "bioinks." Hydrogels are preferred because of their great biocompatibility, low cytotoxicity, high water content, and modifiable mechanical and chemical composition. They are also biodegradable. For example, alginate and calcium can be blended, and fibrinogen and thrombin can be combined. The theory behind laser-assisted bioprinting (LAB) is that a laser pulse causes localized heating in a solution containing cells, which allows for the exact deposition of cells onto a substrate or platform. One sort of LAB that has been successfully applied in tissue engineering is laser-direct-writing, which allows for the deposition of different cell types and biomaterials.6,10

1. **3D Printing In Dentistry:** The dental industry has been using 3D printing for more than ten years. Using laser-sintered alloys and guided implant drills for implant surgery operations were two of the first uses of additive fabrication technologies in dentistry.

2. **Digital Workflow:** The progress in digital image acquisition and the adoption of CAD/CAM technology have paved the way for a completely digitalized approach to dental treatment. Intraoral scanning has replaced conventional plastic molds to produce computer-aided manufactured (CAM) digital physical models. This shift is gradually eliminating manual intervention across all three stages of the process and is commonly referred to as the "digital workflow.[12]Data collection utilizing various scanning technologies is the initial step. Using either extraoral or intraoral scanning equipment, commonly utilized techniques include computerized tomography (CT), cone beam computed tomography (CBCT), magnetic resonance imaging (MRI), and laser digitizing.

   Using computer-aided design (CAD) software, data processing and model design are done in the second step. Next, the printer software imports the generated STL file. Creating the required instructions for the 3D printer to operate requires the provision of building variables, segmentation parameters, and support structures. The third stage in the CAM process uses the analyzed data to create structures using the chosen material.[12]

VII. 3D PRINTING TECHNIQUES IN DENTISTRY

The most often used 3D printing techniques in dentistry are polyjet printing, bioprinting, stereolithography (SLA), selective laser sintering (SLS), and fused deposition modeling (FDM).

In **fused deposition modelling (FDM),** The material on the spool is introduced into a heated nozzle, where it melts and is extruded in the specified dimensions, one layer at a time. Once a layer is completed, the nozzle is lifted, or the print bed is lowered, as illustrated in Figure 2. This type of printer is preferred for creating readily available anatomical models in-house.[13]

SLA (Stereolithography) Applying a laser or other light source to a photosensitive polymer surface is one way to harden its surface. This process entails continuously raising a container containing the polymer, causing the material to harden progressively and forming a 3D object. SLA technology has been used to produce hydroxyapatite for bone healing, ceramic acrylate, and biodegradable polymers. Another 3D printing method known as **digital light processing** (DLP), which relies on photopolymerization, has been employed in the fabrication of zirconia implants. Layer by layer, metal, resin, or plastic grains are fused together using a laser in the selective laser sintering (SLS) and powder fusion printing (PFP) processes. These techniques have been applied to the manufacture of tricalcium phosphate and hydroxyapatite scaffolds for bone regeneration. An advantage of PFP techniques is their capability to print molten metal's like titanium, magnesium, or cobalt chromium, which are utilized in medical and dental applications.[6]

The polyjet printer (shown in Figure 2) boasts the highest resolution among the available options. It achieves this by building the 3D model layer by layer using printer heads that jet layers of liquid photopolymer onto a build tray, which are then solidified by UV light curing.14 Polyjet printers offer several advantages, including the capacity to employ a broad variety of printing materials with different properties, such as porosity, flexibility, hardness, and density. They feature a quick printing process and can produce a precise resolution as low as 25 microns. They are also capable of replicating complex shapes. However, there are some downsides, such as the need for post-print model processing steps like thorough washing and the removal of support materials.

Significant uses for these printers can be found in a number of areas, such as surgical planning with patient-specific 3D models with intricate geometries, the production of surgical stents and guides, the development of phantoms for cardiac and orthopedic procedures, and the scaffolding for tissue engineering. The following sections provide an overview of these different printing methods and their uses.

VIII. APPLICATION IN CLINICAL PEDIATRIC DENTISTRY

3D printing in Pediatric Oral and Maxillofacial Procedures: Patients with orofacial defects can benefit from personalized allogenic implants and scaffolds designed for bone and tissue regeneration, made possible by using biocompatible materials through additive manufacturing. It is possible to achieve the required dimensions and customized properties of biomaterials by adding additives like calcium phosphate biomaterials, such as hydroxyapatite and tricalcium phosphate, into materials like polyglycolic acid, polylactic acid, and bioactive magnesium-calcium silicate/poly-caprolactone. These characteristics include surface roughness, porosity, and design.

Moreover, specific additions of osteoinductive materials, such as bone morphogenetic proteins (BMP-2 and BMP-7), which stimulate osteogenic differentiation, can be made to the printed scaffolds to improve vascularization, cell adhesion, and proliferation.[15]

IX. 3D PRINTING APPLICATION IN AUTOTRANSPLANTATION

The utilization of 3D printing proves to be highly beneficial in cases of autotransplantation involving impacted permanent teeth, tooth loss due to trauma, and congenital hypodontia. In autogenous tooth transplantation, it is essential to create a recipient socket for the placement of the donor tooth.

During the procedure, great care must be taken as the transplanted tooth is particularly fragile, especially when assessing its fit within the new alveolar bed, as this can lead to potential injury to the periodontal ligament. Additionally, every effort should be made to minimize the extraoral handling time of the donor tooth, as prolonged handling can have adverse effects on the tooth's viability.[17,18] Computer-aided fast prototyping is used in conjunction with either cone beam computed tomography or helical CT (computed tomography) to minimize damage and preserve the donor tooth. This method allows for the production of surgical guides in the form of dental replicas, so cutting down on the amount of time that is spent outside the mouth and minimizing the risk of damage to the periodontal tissue of the donor tooth. By facilitating the development of a new recipient socket, these procedures help to standardize the procedure and reduce risks to the donor tooth.[17]

In a case study conducted by Bartra et al. (2020)17, autotransplantation of teeth was carried out with the aid of Polyjet 3D printing to create replicas of the teeth, and customized surgical guides were employed to minimize bone and periodontium trauma. The mandibular section and surrounding teeth were printed using PolyJet and FDM technologies with the Sigmar R19 (BCN 3D® Technologies) printer, whilst the dental duplicate was generated using the Objet30 Prime® printer. The dental model was 3D printed using Med610 material (Stratasys®), while the mandibular portion and surrounding teeth, as seen in Figure 3, were printed using polylactic acid (PLA). This approach holds significant promise for cases involving avulsed permanent central incisors in young patients, as it minimizes damage to the alveolar bone and periodontium, thereby enhancing the success of the transplanted tooth.

The development of surgical guides and templates to enhance the precision of surgical procedures is a crucial aspect of digital surgical planning and execution. These guides are created using data obtained from CT imaging and analyzed through computer software to assess maxillomandibular abnormalities. Various commercial software packages can be utilized to design and produce digitally planned surgical drilling or cutting guides, which have shown to exhibit fewer imperfections, improved margin control, and reduced impact on bone integrity. A virtual 3D plan is generated on-screen, which is then transmitted to the operating site, acting as a link between the real patient and the virtual plan. Nineteen This instruction will like the one displayed in **Figure 4**.

X. 3D PRINTING IN BEHAVIOUR MANAGEMENT OF UNCOOPERATIVE CHILDREN AND SHCN

When fabricating space maintainers and habit-breaking appliances, intraoral scanners have shown to be immensely helpful in managing uncooperative children and individuals with special health care needs (SHCN). Even with a euphemistic description, modern kids might not find traditional dental impressions very appetizing. The intraoral scanner has revolutionized pediatric clinical practice, especially for children who experience fear or have a strong gag reflex. Arch scanning can be performed with pauses and breaks, commencing from areas that are more comfortable for young children and those with special health needs. This offers a significant advantage over traditional impression techniques, where pausing or stopping is rarely feasible, potentially necessitating a complete restart. To make the experience more child-friendly, the term "magic wand" can be playfully used to describe the process of taking a comprehensive scan of their teeth, which they can then view in 360 degrees on a colorful touch screen. Consequently, intraoral scanners and digital workflows can be employed not only for clinical purposes but also for patient education, helping them comprehend the necessity for a specific appliance or space maintainer, thereby increasing their acceptance of the treatment.

XI. 3D PRINTING IN INTERCEPTIVE ORTHODONTIC PROCEDURES

In the world of orthodontics, 3D printing has ushered in a new era of precision and individualized dentistry. The idea of using 3D face scans and 3D printing to make orthodontic brackets and anatomically precise, perfect dental arches for patients was first presented by Normando et al. a few years ago. This breakthrough has enabled the virtual representation of patient-specific modifications, allowing orthodontists to visualize the anticipated changes brought about by braces through computer-aided techniques. In addition, 3D printing is currently being employed in animal models to fine-tune mandibular growth and control tooth mobility, providing valuable insights into cartilage development and bone biology. Some of these breakthroughs are expected to translate into clinical applications within orthodontics, particularly in terms of modifying growth patterns, expediting orthodontic tooth movement, and improving tooth anchorage or retention. As a result, 3D printing has the potential to reshape the existing approaches to interceptive orthodontic treatments for young patients, ultimately leading to the creation of precise, custom functional appliances based on young patients' growth models, with the potential to modulate growth in the future.

XII. 3D PRINTING IN FIXED ORTHODONTICS

At present, 3D printing is predominantly utilized in orthodontics to produce customized orthodontic aligners, primarily for the purpose of realigning misaligned teeth. This process begins by digitally positioning the teeth into their desired locations using computer software. Once the 3D model is prepared, a personalized casting mold is created for the patient. The mold is generated using the stereolithography technique, which involves layer-by-layer construction during the printing procedure. Subsequently, the orthodontic aligner is cast from silicone material using the finalized mold.[16]

in clinical practice, fixed orthodontic treatments can be time-consuming, but 3D printing offers the potential to minimize treatment duration. This is particularly beneficial for young patients, reducing the risk of tooth demineralization, orthodontic white spot lesions, and root resorption. A novel approach involves the creation of 3D-printed brackets. By digitally planning tooth movement and using 3D printing to craft brackets customized for specific tooth surfaces and correct placement, treatment goals can be achieved more efficiently. Furthermore, in orthodontics, the printing of guides for the exact installation of temporary anchorage devices or indirect bonding guides for bracket positioning accuracy may become more and more important. Additionally, to ensure a perfect intraoral fit, CAD/CAM technology makes it possible to manufacture auxiliary orthodontic devices including Herbst, Andresen, and sleep apnea appliances[23]

XIII. 3D PRINTING IN REGENERATIVE ENDODONTICS

The transition from manual to digital workflow has significantly enhanced precision in both regenerative and conventional endodontics, offering greater accuracy and improved patient comfort. Additionally, it represents a groundbreaking advancement in regenerative endodontics, fostering the development of operator skills through training and education..24,25

The concept of 3D printing in endodontics holds promise for a number of applications, including the provision of stem cells, pulp scaffolds, injectable calcium phosphates, growth hormones, and gene therapy. Given the advent of novel bioactive materials, this may be especially advantageous for the regeneration of the dentin-pulp complex. Research suggests that applying freeze-dried platelet-rich plasma coated 3D-printed polycaprolactone to dental pulp cells improves osteogenic activity in vitro. Additionally, the production of tooth-like tissue with anatomical shape has been made possible by the use of 3D-printed polyepsilon-caprolactone and hydroxyapatite scaffolds.[26]

In clinical practice, additive manufacturing has found applications in endodontics, specifically in surgically guided endodontic procedures like apicoectomy and endodontic access cavity preparation. Numerous published studies have established the advantages of guided access cavity preparation compared to conventional methods. This approach proves particularly beneficial in cases involving challenging teeth with unique root canal anatomical variations. Case reports have underscored the significant role of 3D printing in this field by creating additive tooth models with intricate internal root canal structures using CBCT scans. These models serve as a foundation for producing guides tailored to the specific requirements of endodontic treatment in such complex cases. Moreover, considering that radiographs only offer 2D information of the root canal, potentially missing auxiliary and lateral canals, this technique can be applied effectively to primary and immature permanent molars with intricate root canal anatomies.[29]

Endodontic skills can be improved by the use of 3D-printed models and computer software, such as haptic simulators, which provide users with tactile, visual, and audio feedback. Consequently, we anticipate that 3D printing will continue to play a highly promising and advancing role in both pediatric endodontics, including surgical and non-surgical, with a focus on education and training in the wake of COVID-19.

XIV. 3D PRINTING IN FABRICATION OF CROWNS AND SPACE MAINTAINERS

Metallic and polymer-based materials are commonly used in the additive fabrication of dental prostheses and crowns. Numerous in vitro studies have demonstrated that ceramics created through lithography, a layer-by-layer printing method, exhibit mechanical properties on par with milled ceramics. Nevertheless, additional research is essential to delve into the manufacturing process, strength, and fracture toughness. Porous materials are frequently produced by currently available 3D printing methods, such as stereolithography, selective laser melting, and selective laser sintering. On the other hand, thick, complicated structures that resemble ceramics are produced via ink-jet printing.[31]

Recent advancements, facilitated by intraoral scanners like the iTero® system, have made it possible to leverage 3D printing for crafting personalized functional and passive space maintainers, such as band and loop space maintainers. A case study conducted in 2021 by Suhani et al. highlighted the utilization of 3D printed chairside space maintainers, underscoring the profound impact of 3D printing on preventive orthodontics. Furthermore, another instance of a 3D printed band and loop space maintainer was successfully employed and documented by Pawar et al. in 2019, underscoring the transformative potential of digital workflows in preventive orthodontics and pediatric dentistry. With the advent of this technology, functional space maintainers are poised to become the future of pediatric dentistry.

In complex scenarios involving short clinical crowns, 3D printing offers distinct advantages compared to conventional pre-made zirconia crowns. As seen in Figure 6, it permits the insertion of custom-made celluloid strip crowns and short post-retained zirconia crowns.

XV. CONCLUSION

As technology advances in additive manufacturing and the integration of intraoral scanning, 3D printing is poised to become an essential tool in everyday dental practice. In time, digital workflows are expected to replace traditional methods. This digital transformation in pediatric clinical practice will revolutionize the production of customized crowns, space maintainers, functional appliances, and fixed devices, ushering in a new era of personalized and comprehensive pediatric dentistry.

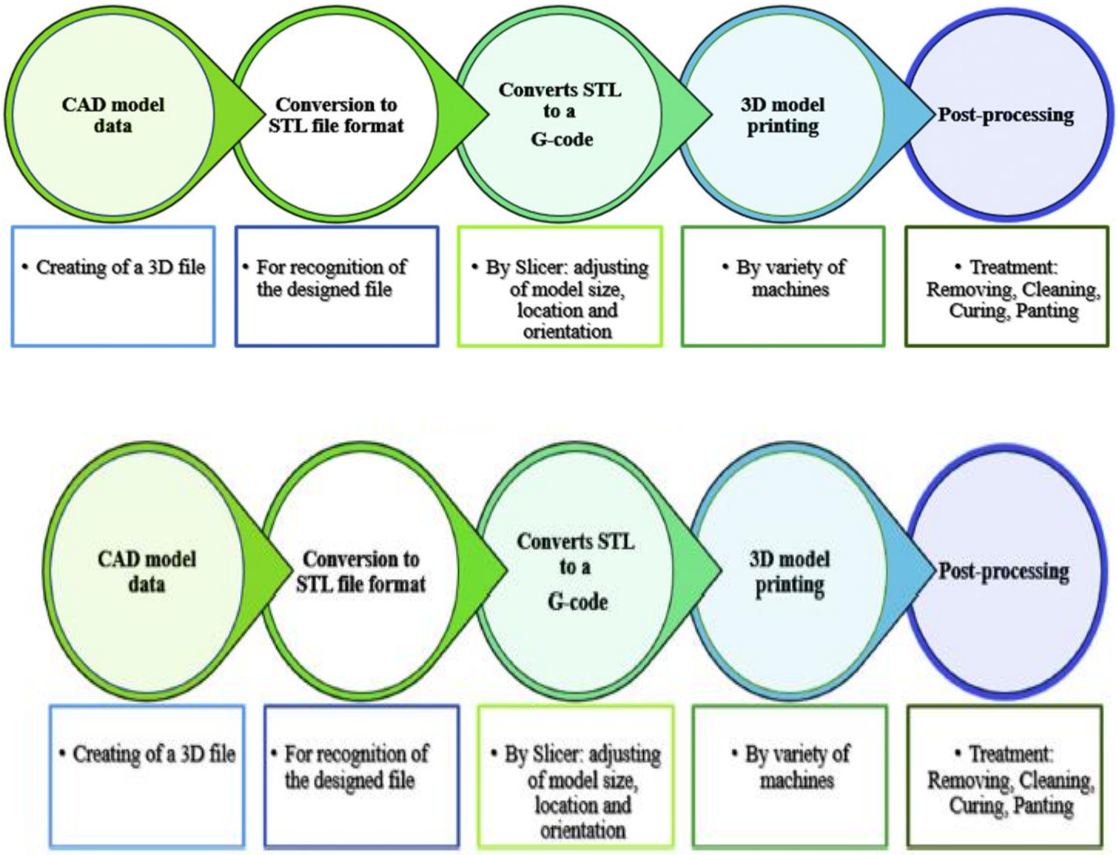

Figure 1: Stages of 3D printing. Source: Eshkalaket al.(2020)

Table 1: Most Common Used Biomaterials in Healthcare

Thermoset Polymers / Thermoplastic Polymers		Hydrogels		Composites (Biomaterials or Nanomaterials)	
	* Polycaprolactone (PCL) * Poly Lactic-co-glycolic Acid (PLGA) * Polylactic acid (PLA) * Poly(3-ydroxybutyrate-co-3-hydroxyvalerate) (PHBV) * Polyetheretherketone (PEEK) * Urethan resin		- Alginate - Collagen - Fibrin - Gelatin - Agar - Chitosan		# Titanium alloy # Hydroxyapatite # Ceramic # Metal # Ca/ phosphates

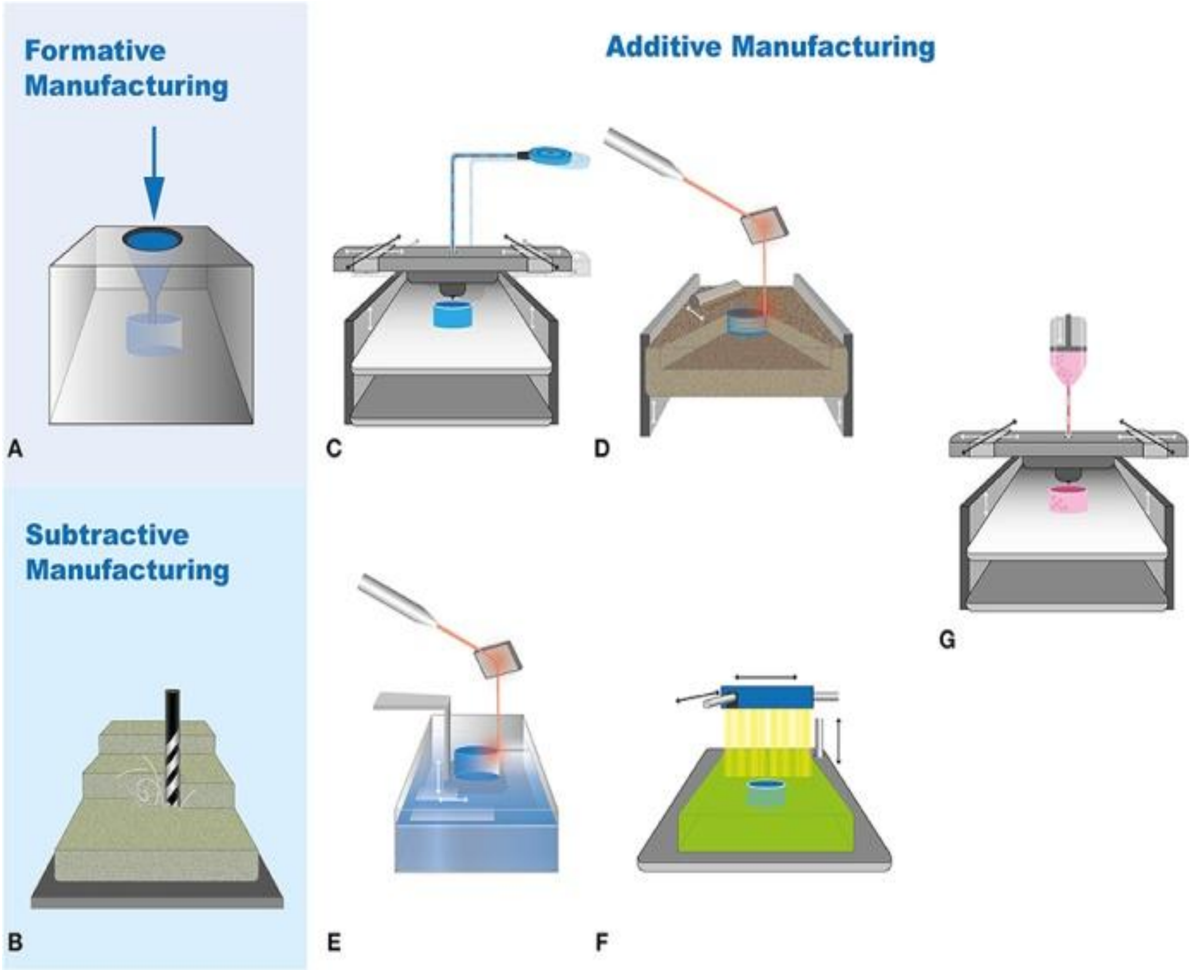

Figure 2: illustrates various methods of 3D manufacturing. A) Represents conventional formative manufacturing utilizing casting molds. B) Depicts subtractive manufacturing, which involves material loss to create the final product. C) Shows Fused Deposition Modeling (FDM), while D) showcases Selective Laser Sintering (SLS). E) Represents Stereolithography (SLA), F) Polyjet printing, and G) Bioprinting. Source: Oberoi et al. (2018).

Table 2: Applications and Different Types of 3D Printing Techniques in Dentistry. (Oberoi Et Al., 2018)

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

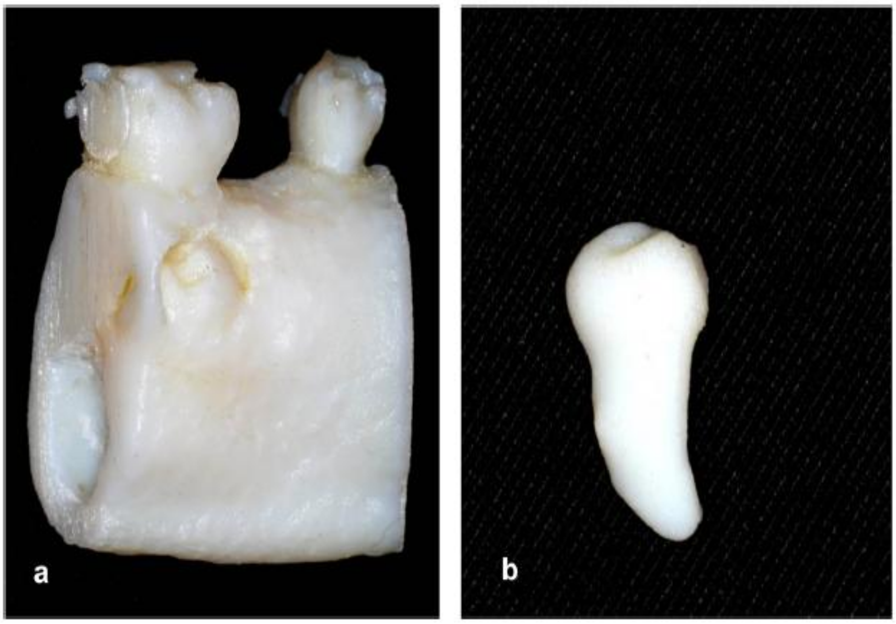

Figure 3: Technology: FDM and Polyjet; printing materials: PLA and MED610. Mandibular segment replica (a) and tooth 35 replica (b) (Cahuana-Bartra et al., 2020)

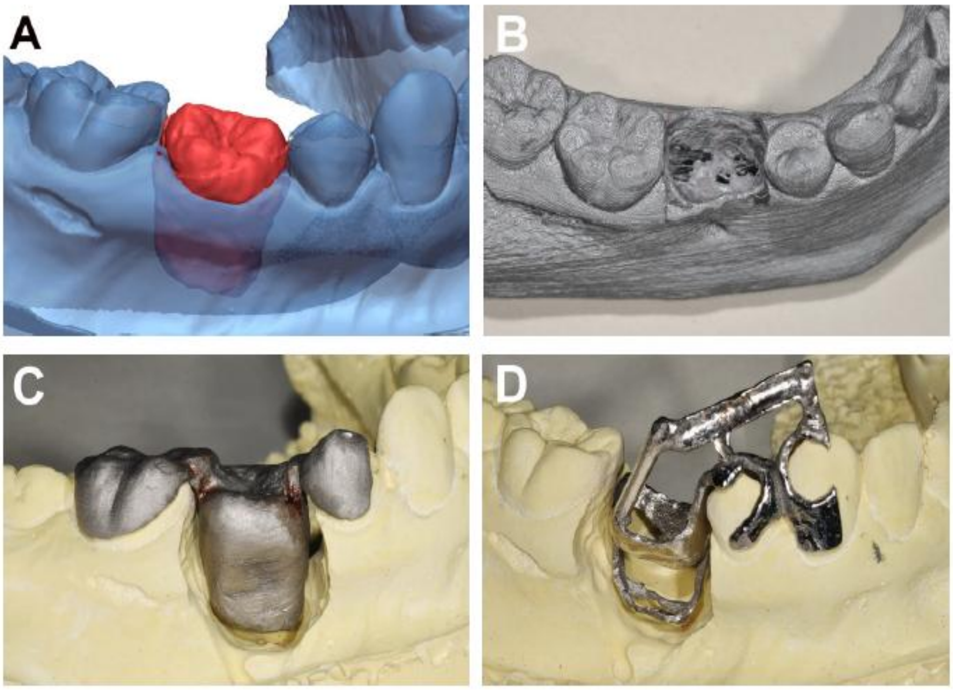

Figure 4: provides an autotransplant surgical guidance. A) Uses computer software for scanning and 3D imaging to simulate a transplanted tooth. B) Shows the transplant socket in a 3D printed model of the recipient location. C) Displays a surgical guide model created via 3D printing. D) Exhibits the surgical guide for drilling depth that was made by Hu et al. (2017) utilizing a metal casting and a 3D printed wax pattern.

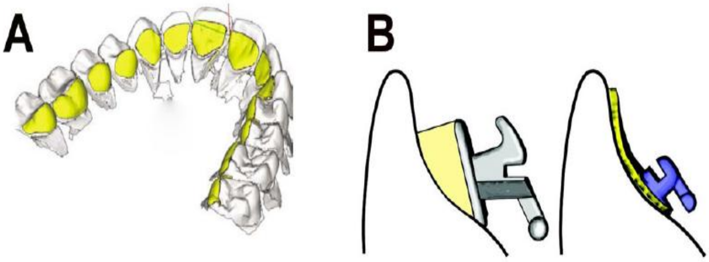

Figure 5: depicts a digital configuration with separately defined bracket bases. B) It contrasts a customized bracket on the right with a traditional lingual bracket on the left. The American Journal of Orthodontics and Dentofacial Orthopedics, Volume 124, pages 593-599, 2003, has a citation for this source.

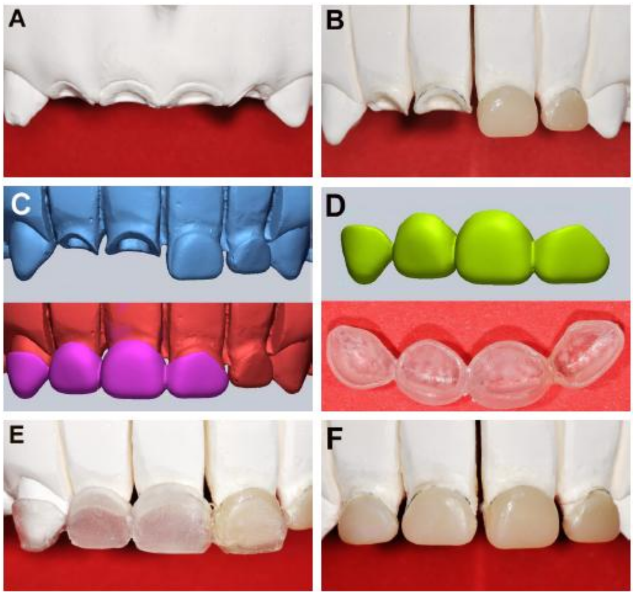

Figure 6: illustrates the process of fabricating short post crowns for primary anterior teeth. A) The teeth are prepared for the short post crown. B) A zirconia short post crown is created using a CAM/CAD system. C) The upper part shows a 3D scanning model, while the lower part displays a stent designed for strip crown placement using 3D imaging software. D) The upper part shows a 3D stent image, and the lower part displays the printed stent material. E) The stent is checked on a working model before the placement of composite resin. F) The central and lateral primary incisor zirconia crowns made with the CAM/CAM system are on the left, while resin crowns made with 3D printing technology are on the right. Source: Lee, S. et al.

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