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3D Printing: An Appealing Milestone in Endodontics

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ABSTRACT: Three-dimensional printing is an assuring new technology in the field of dentistry. It is an additive manufacturing method where a 3D object is created by laying down successive layers of material. It is a technology that can design and produce 3D models and is Proifying to improve the standards of treatment to patients as it is less technique sensitive and be more clearly.It is a technology that can design and produce 3D models and demonstrates improved treatment standards for patients as it is a sensitive precision. Many 3D printing methods such as Stereolithography (SLA), Inkjet based system, Selective Laser Sintering (SLS) and Fused Deposition Modeling (FDM) allow for rapid prototyping. 3D printing can be combined with oral scanning and CAD / CAM design to produce crowns, bridges, stone models and various orthodontic equipment. Improved success in dental implants is due to advances in digital technology and 3D printing. Written solutions for endodontic challenges include: targeted access to obliterated pulp canal , application for autotransplantation, pre-surgical planning and educational modeling and accurate location of osteotomy sites. This document provides an overview of 3D printing and its various uses in Operative Dentistry and Endodontics to predict future research indicators and clinical use within specialties.

Keywords: 3D Printing, Additive Manufacturing, Autotransplantation, Computer Aided Designing, Guided Access, Guided Endodontic Surgery, Rapid Prototyping, Stereolithography

I. INTRODUCTION

3D printing is an emerging technology that has a wide variety of applications in the field of dentistry. 3D printing usually describes the production process that creates an object by creating a single layer while adding multiple layers that lead to the construction of the object. 3D printing can be accurately described as Additive manufacturing or Rapid prototyping. Dental restoration is produced using fast prototyping and is flexible and faster in production compared to those restoration performed by dentists. Nowadays, this technology ensures the accuracy of quality dental care making it the preferred treatment option.

3D printing began in the 1980s when Charles Hull printed a three-dimensional object in 1983. He then created the first 3D printer using stereolithography. Initially the focus was on the construction, aerospace and telecommunications sectors. Later its use in general medicine began to attract professional attention in the 1990s which led to an increase in research and better results in the field.

There has been a dynamic growth in 3D medical and dental printing with the help of CAD CAM technology.[1] 3D printing uses 3 dimensionla CAD data sets to produce 3D body models.[2] This approach is referred to as additive manufacturing (AM) which means building materials such as metals, polymers or expanding layers using CAD / CAM (Computer Aided Design / Computer Aided Manufacturing) digital scanning for the dual purpose of product production and control of the production process. Additive manufacturing is a new feature over subtractive manufacturing (SM) where an object is cut from a material block. AM allows for greater complexity, reduced debris and a wider selection of items over SM.[3]

All CAD / CAM programs consist of three steps: digital data acquisition using an internal scanner and / or CBCT (cone beam computed tomography, data processing and design within a software application, and by milling or printing.[4]

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The process of 3D printing initiates by designing object's virtual image after which there is a conversion of image into digital file. The printer follows the virtual design provided by the 3D modeling program.For this, a CAD software is required that enables to produce objects from the scratch.[5]

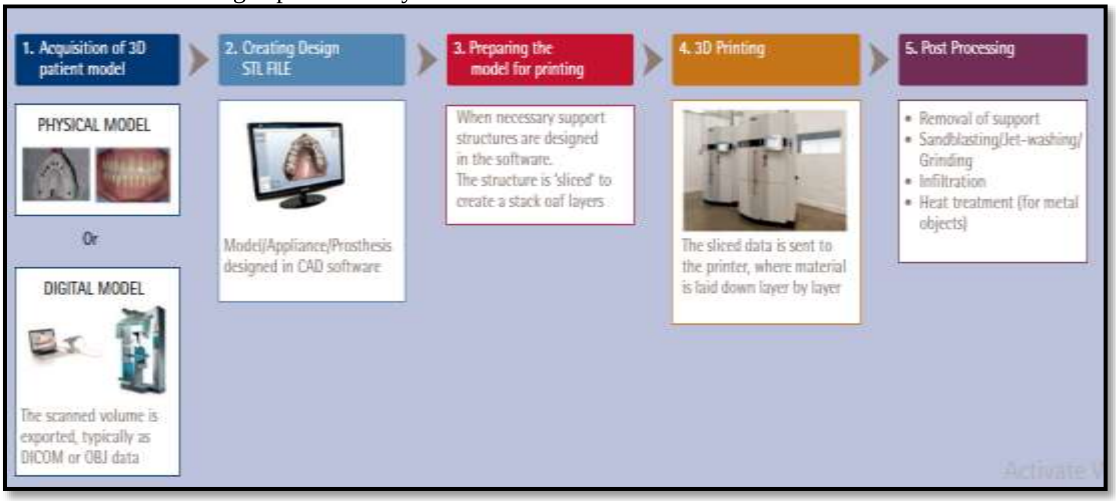

Figure 1: 3D PRINTING PROCESS (picture taken from - A. Dawood et al, british dental journal volume 219 no.11) [1]

The advantage of 3D printed model/restoration is that it can be printed on the selected option based on the application location. 3D objects help to study reconstruction, patient jaw or dental morphology over the table. Therefore, it enables better preclinical training, case analysis and pre-operative planning as it is done digitally with greater accuracy and reduced time. This article reviews the latest developments in the use of 3D printing in endodontics.

II. 3D PRINTING TECHNIQUES

Methods used for printing 3D models are :

- Stereolithography
- Fused Deposition Modeling
- Multijet Printing
- Photopolymer Jetting
- ColorjetPrinting
- Digital Light Processing
- Selective laser sintering also known as selective laser melting

STEREOLITHOGRAPHY (SLA)

It was found by Charles Hull in the 1980s and became the first commercially available printer for rapid prototyping. UV light is concentrated on the surface of a vat filled with liquid photopolymer and as the beam draws the substance to the surface of the liquid each time the resin layer is polymerized.[4] It is useful in making surgical stent and implant guides.[6]

Advantages: high accuracy, high mechanical strength and good surface finish

Disadvantages: equipment costs, back treatment requirement and can only be used for polymers.[7]

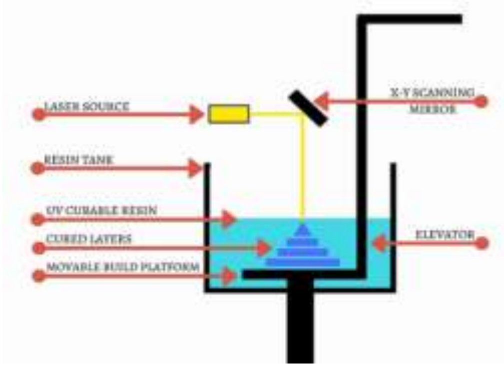

Figure 2: Diagramatic Representation of Stereolithography (Image taken by Manufactur3D) [25]

FUSED DEPOSITION MODELING (FDM)

Built by Scott C rump. In this model, the object is constructed in a layered way with the inclusion of thermoplastic polycarbonate. As the layers of molten plastic come together at once, the production of complex parts is easier to produce. The basic structure of the machine incorporates nozzles where the inputs are laid on a layer that is later fused together.[4,8,9]

FDM uses biocompatible glass composite, biocompatible polymers, Poly Methyl Methacrylate (PMMA). The whole process takes place in a chamber where the temperature is set just below the melting point of the thermoplastic substance.[4] Accuracy depends on the speed of the extruder's

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movement, the material flow and the size of each step.
It enables the printing of raw anatomical models without the complexity as an edentulous mandible printing.
Advantages: This process is used by most low cost 3D printers.
Disadvantages: Can only be used with thermoplastic materials. It has a rough surface finish and does not have one hundred percent density.[7]

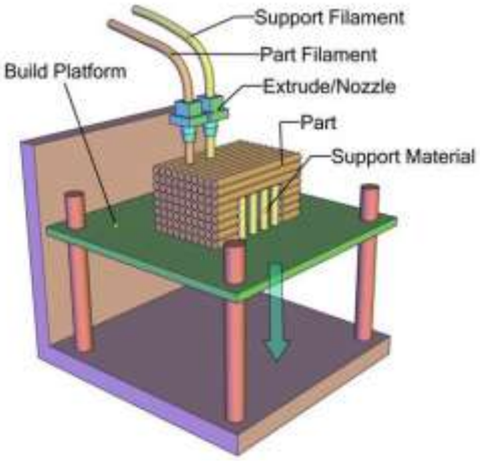

Figure 3: Fused Deposition Modeling (FDM)(Picture courtesy: Principle of 3d printing-FDM)[26]

MULTIJET PRINTING (MJP)

MJP or MultiJet printing is an inkjet printing process using piezo printhead technology for the use of photocurable plastic resin or casting wax material in layers. MJP is used to create parts, patterns and molds with fine feature details to handle many different applications.
Benefits:
These high-quality printers save money and use alternative, meltable or dissolvable support material to make postprocessing a breeze.
Another great advantage is that removing the support material is virtually a hands-free operation and permits even the most delicate features and complex internal cavities to be thoroughly cleaned with no damage.

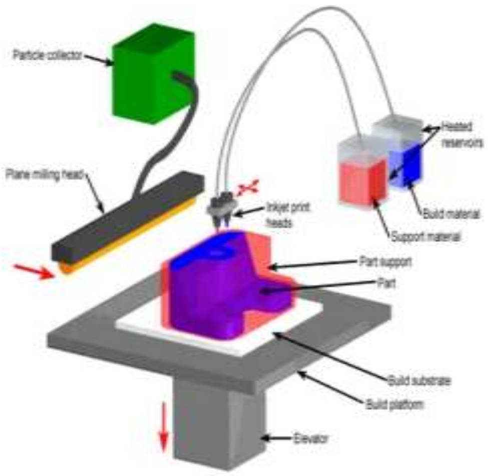

Figure 4: Inkjet and Multijet Printing(Kyle Stetz, Inkjet and MultiJet Printing-2008)[27]

PHOTOPOLYMER JETTING

This method uses a stable platform with a dynamic print head or a stationary print head with a dynamic platform. A light sensitive polymer is jetted on a construction platform from an inkjet-type print head with a cured layer on a step-down platform. Photopolymer jetting can be used to print a variety of resins and waxes on castings and for silicone-like rubber materials. The 16 microns resolution is provided by this technology and provides easy access to complex and beautiful details. It can be used to make drill guides for implants and production of indirect orthodontic bracket splints.[1]3D Jet printers can have a single print head as a computer printer or they can have multiple heads to cover the width of the working platform. A UV lamp or light source is used by 3D applications and printers to make resin or wax hard after each layer is applied.
Advantages: Fast and less expensive and can provide high quality resolutions and good finishes.
Disadvantages: Solid backing materials can be difficult to remove completely, can cause skin irritation and cannot be heat sterilized.

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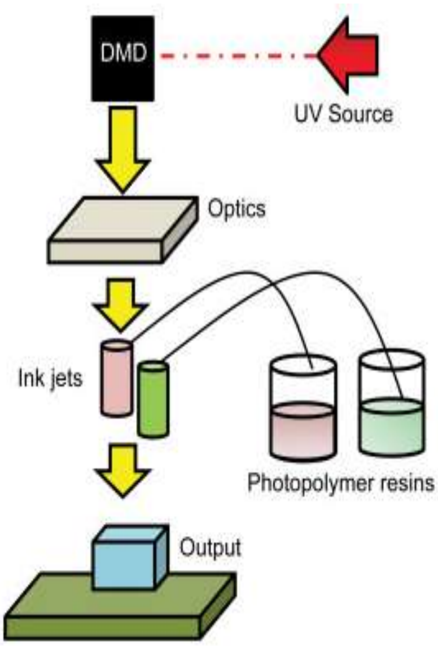

Figure 5: Photopolymer Jetting (Image taken from Encyclopedia of Modern optics, Photopolymer, 2016)[28]
DMD*Direct Metal Deposition

Table 1: Principle differences in the stereolithography and PolyJet 3D printing technology (Photopolymers, 2016)[28]

Features	Stereolithography	PolyJet
Curing method	UV lasers directed via dynamic mirrors onto a bed of liquid photopolymers for curing	Curing of materials after deposition of liquid photopolymer on build platform
Object recovery	Hand sanding, light bead blasting	Water blasting, some residue removal by hand
Resolution	Good @ 0.005–0.002”	Excellent @ 0.00063”
Ideal size	Large prototypes and master patterns	Small designs with highly detailed prototypes and master patterns
Optical property	Generally opaque	Opaque, multicolor, transparent

COLORJET PRINTING

ColorJet Printing (CJP) is an additive manufacturing (AM) technology that includes two main components - the core and the binder. Core ™ materials are still distributed in small layers with a roller over the build platform. After the distribution of each layer, the color binder is jetted selectively from the inkjet print heads over the core layer, causing the layer to harden. The build platform descends with all the next layer spread and printed, resulting in a 3D model full of colors. Colorjet and polyjet are similar technologies, owned by two different companies. Since they could not copy, they made another method.

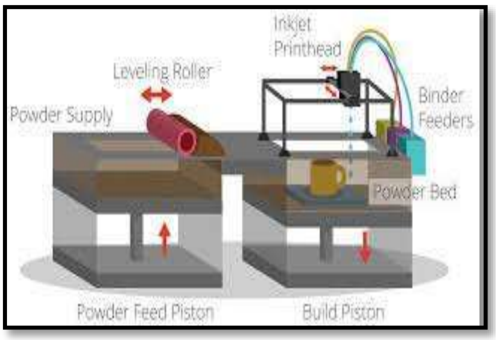

Figure 6: Colorjet Printing (Picture from Dr. Pradnyav.Bansode, "3D Printing”, 2019)[24]

DIGITAL LIGHT PLANNING

The liquid resin layers in this, is cured using the projector light source. The object is built on an elevating platform and a layer is made upside down. The polymer is layered while the object is formed and the residual liquid polymer is drained off .[10]

SELECTIVE LASER SINTERING

This technology was developed at the University of Texas and has been in use since 1980. One of the most promising technologies to solve various problems encountered during casting alloys.[11]The fine powder of the material is combined by laser scanning to form more structures inrementally. A fine new layer of material spreads in the same way on the surface as the powder bed goes down. It involves the fabrication of a metal frame with a selective laser, melting in an increment manne that produces 3D fragments by reinforcing selective and successive layers of powdered material, one above the other, using heat generated by computer-controlled laser beams.[12]The printed structures are supported by the surrounding powder. The production of facial prosthesis is done using polymers scaffolds. Selective Laser Sintering/Milling can be used in the production of anatomical learning models, dental models, cutting and drilling guidelines and engineering / design prototypes. The materials used can be titanium, cobalt chrome, stainless steel etc. It has a variety of applications in areas that require high durability and mechanical strength such as metal implants that aid bone ingrowths and regeneration.

Advantages: Used materials can be autoclaved, printed objects have full mechanical function and the use of cost effective materials in abundance.

Disadvantages: Powder is contaminated with the risk of inhalation, technology is high priced and requires compressed air.

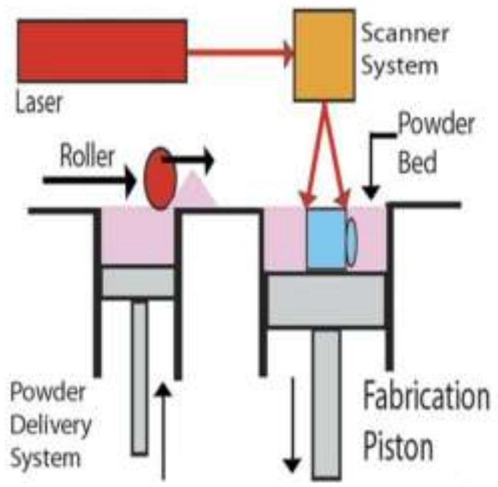

Figure 7: Selective Laser Sintering(Photo taken from: Summative Engineering™)

III. APPLICATIONS IN OPERATIVE DENTISTRY AND ENDODONTICS

The use of 3D printing and digital technology has greatly increased the level of success and improved the quality and accuracy of dental work. Also, it will affect the clinical performance of how the surgeon will be able to work faster and more efficiently. This new technology allows for a more comfortable diagnosis and faster results.

Reconstruction of 3D Models

3D printing can be used to take a 3D dental image and upload it to an available computer program and the desired model can be adjusted or modified as needed and can be printed in a few hours. This model can be hand-held and can replicate the area of interest for high observation.

Preclinical Training

3D printing will allow students to discover and develop clinical skills in contrast to the current use of extracted teeth used for learning purposes. Multiple copies of dental models can be printed from any selected micro CT scan (Computed Tomography) that can be used by dentists and dental trainees, as only limited tooth extracts are available. Also, 3D printed dental models can mimic conditions such as pulp stones, internal and external root resorptions, dens in dente and much more that can help them visualize, develop and advance science and the art of endodontics.[13] One of the most important uses of 3D printing at the dentist creates digital scanning of full or partial arches into a durable plastic model casts. This reduces the effort and distraction on the operator and the patient in the use of impression materials to

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record impressions followed by the casting of stones.

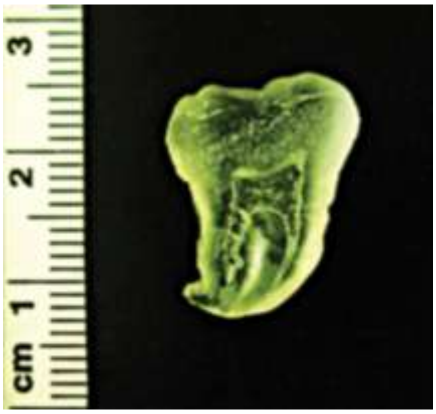

Figure 8: Cross-section view of a model tooth with pulpal and canal spaces present (picture taken by Gregory S. Jacob, Inside Dentistry, 2016)[29]

Fabrication of Tooth Restorations

3D printing can be used for dental fillings that will reduce the cost of treatment compared to CAD-CAM (Computer Aided Design/Computer Aided Manufacturing) and reduce the sensitivity of the placement process. It can be used to restore a complex cavity that includes multiple surfaces that can be directly restored. The steps for making a 3D printed restoration are as follows[14]:

- Tooth preparation according to the cavity is done, it can be two or three surface preparations.
- Scanning of preparation and uploading data to a computer.
- Printing the filling with appropriate restorative material.
- Finally, cementation of the prepared 3D filling into the scanned cavity with suitable adhesives.

3D printed guides and models assist the clinician in planning aesthetic treatment and assist them with minimal interventions and skill gains.

Template

For restoration of fractured anterior teeth 3D printed templates can be prepared which facilitates easy placement and integration of composite.

Reconstruction of tooth models (Atypical anterior tooth)

In the case of atypical anterior teeth, a dental model is developed to guide the effective treatment process. A translucent dental model is developed that contains information about the internal structure of the root canals. This is done through a 3-step process:

- Data collection by CBCT scanning (Cone Beam Computed Tomography).
- Virtual modeling by image processing.
- Manufacturing with 3D printers.

The custom guide jig is designed to find a safe and accurate way to the root canal and is followed up by a few months for complete periapical healing..

Night Guard Trays

Scanned images are used to create a 3D dental model where the tray can be adjusted.

Guided Endodontic Access

Pulp canal obliteration (pco) creates a clinical condition in which the canals should be found in the apical parts of the roots that continue to be narrowing due to age-related dentin apposition, caries, orthodontics, systemic disease or trauma.[15]

RD printed templates that can be used to gain guided access to root canals and various in vitro research studies have proven that accurate access u to apical third of the root can be achieved through Endodontic procedures led by a 3D template.[16] This will be useful for the clinicians while dealing with canal morphology challenges. This investigation suggests that 3D printed access guides represent efficient and safe ways to deal with challenging endodontic conditions, enabling both chemomechanical debridement and tooth structure conservation. Dental treatment with pulp canal obliteration, extensive restoration or malposition may be most effective with the intended access guidelines. Further clinical research in the area is worthwhile.

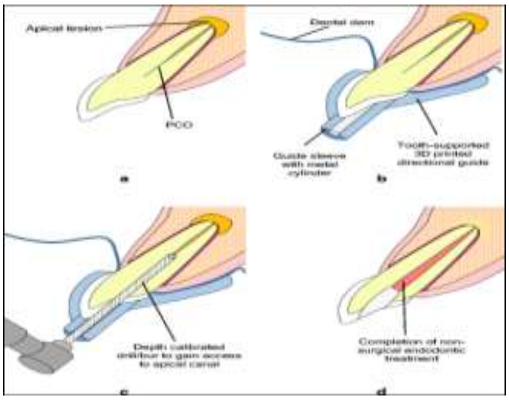

Figure 9: Guided Endodontic Access (Picture by: Shah, P., Chong, B.S. 3D imaging, 3D printing and 3D virtual planning in endodontics,2018)[31]

Auto transplantation

Effective autotransplantation requires the maintenance of periodontal ligament (PDL) cells and adequate repair of the transplanted tooth at the recipient site.[17] 3D printing can help in this as the image of the tooth can be scanned before extraction and the recipient's tooth can be adjusted accordingly and inserted into the extraction socket. The recipient's tooth can be prepared for the crown and a temporary crown can be placed immediately after inserting the tooth in the desired location. This reduces the chances of errors during translanting.

A systematic review by Verweij et al.[18] achieved a total success rate of 80-91% when using rapid prototyping showing success in the preparation of the recipient site prior to the transplanted tooth extraction, in some cases allowing less than 1 minute oral time.

Surgical Guides

Endodontic microsurgery (EMS) requires targeted osteotomy and root end resection based on anatomic landmarks and X-ray or CBCT of preoperative measurements. Osteotomy can deviate from the ideal as a result of human error in clinical situations where proper orientation, depth and angulation of preparation is a challenge. 3D printed stents can reduce the risk by avoiding entry into nearby neurovascular structures and teeth, and by pointing to osteotomy perforation sites. During the CAD phase, the 3D rendering of the surgical site is used to design a custom stent that generates access to a planned osteotomy. Strbac et al. (2016)[19] created a stent describing the upper and lower extremities of osteotomy, as well as a site of root resection and angulation, which has led to increased clinical efficacy and accuracy, reducing the risk of sinus perforation. Patel et al. (2017)[20] demonstrated the usage of 3D printed custom tissue retractor to improve the perception and management of soft tissue during EMS in the maxillary incisor. These articles suggest exciting opportunities for future use of 3D printing within the modern concept of EMS.

Repair of Bony/Soft Tissue Defects

Accidents, surgery or birth defects can be corrected by making 3D scaffolds of various geometric shapes using customized tissue engineering. Rapid prototyping or solid free form fabrication techniques are very helpful in forming custom-designed scaffolds. Scaffolds fabricated from Polyethylene oxide and polyethylene glycol dimethacrylatephotopolymerisable hydrogels were used to form constructs comparable soft tissues in relation to the elasticity and function of high cell viability and high density constructs.[21]

Dental Pulp Regeneration

The 3D cell printing process can be used toreplace pulp tissue. Tissue formation can be replicated using an ink jet device by moving layers of suspended cells into a hydrogel. This helps to correctly position the cells and this mimics the natural tissue of the tooth. This is achieved by the orderly positioning of cells involving the placement of odontoblastic cells at the edges and fibroblasts within the core through a network of vascular and neural cells. The research study focuses on in vivo to create functional tissues like pulp.[22, 23]

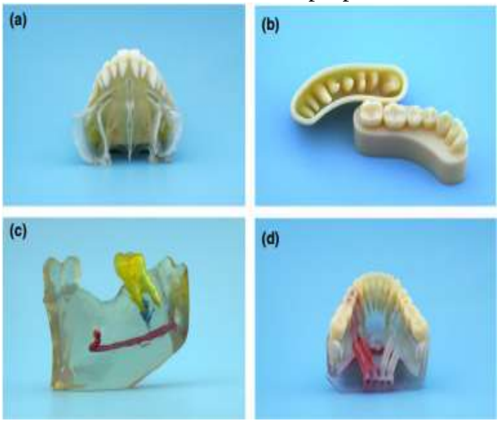

Figure 10: Endodontics Residency 3D printing applications: (a) Surgical model used for pre-surgical treatment planning and simulation. (b) Instructional models. (c) Large-scale model of periapical lesion adjacent to mandibular canal. (d) Regenerative endodontics model with open apices and ports for simulated apical haemorrhage. (image interpreted from 3D Printing in Endodontics Anderson et al)[32]

Instruments

3D printed materials are now available. They are currently being used in the medical field. Sodental instruments can also be seen soon.

IV. BENEFITS

Conventional subtractive manufacturing (SM) techniques such as milling are known for creating high wastes that can be reduced using techniques in conjunction with additive manufacturing (AM). 3D printing is obviously the best digital processing solution for this purpose.[24] Its high efficiency, durability, flexibility and high material use make it unique to other techniques. Also, it is time-saving, minimal sensitivity and many models can be customized using this method.

V. LIMITATIONS

The limitations of 3D printing are its high cost, the emergence of a staircase effect (made up of layered deposition), incompatible reproduction and the requirement of hard support items which is not easy to remove post processing. Other injustices are a requirement for a qualified person and there is no gold standard and no moral and legal permit at present.[24]

VI. CONCLUSION

3D printing can establish itself as a milestone in the field of dentistry because of its accuracy, efficiency, power, and minimal time in the process. With the help of 3D Imaging and CAD / CAM Technology 3D printing is at the forefront which has a huge impact on all aspects. Its use in treatment planning and analysis of treatment outcomes improves the quality of treatment provided by the dentist to the patient and improves patient satisfaction. 3D printing transforms digital dentistry by providing greater opportunities for diagnosis, treatment and education. Endodontic applications for rapid prototyping of anomalous teeth, stent-directed EMS, , autotransplantation and educational model are listed within the literature. 3D printing emerges as an appealing technology, with the natural curiosity and ingenuity of the dentist, making this the most exciting time in the industry. In the future, the widespread use of 3D printing technology in endodontics will be possible as further research and development takes place. Further research in this regard will transform digital dentistryand have a positive impact on patient care.

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