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3D Printing In Endodontics

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Introduction

In endodontics, radiographic imaging is a primary and essential step in the diagnosis, treatment planning and follow up of all the cases. Diagnostic imaging is an important adjunct in clinical assessment of the patient. Radiology has played a crucial role in dentistry. An intraoral radiography system is based on the transmission, attenuation and recording of x-rays on a film or digital receptor and the images produced by a conventional periapical radiograph are a two dimensional (2D) representation of a three dimensional (3D) area of interest that possess inherent limitations of magnification, distortion and superimposition.[1] These constraints paved way for the advanced techniques of cross sectional imaging which revolutionised the concept of diagnosis and treatment planning in dentistry.[2,3]

3D printing has been used increasingly since the 1980s. In 1983, for the first time, a three-dimensional object was printed by Charles Hull, in which the technique of stereo lithography is used, as well as the first program for virtualization. It can be used in areas that require millimetric precision. So, it has drawn the attention of specialists in general medicine, which started to implement it since the 1990s. [4]

Methods of 3d Printing

Dental applications of 3D printing adopt one or more of the following common technical type classifications:

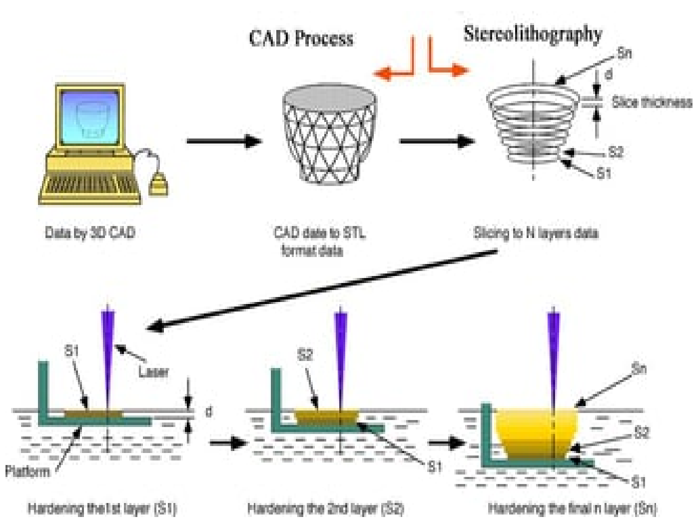
1. Stereo lithography apparatus (SLA),
2. Fused deposition modelling (FDM),

3. MultiJet printing (MJP),
4. PolyJet printing,
5. Powder Binder Printer,
6. Electron Beam Melting (EBM),
7. ColorJet printing (CJP),
8. Digital light processing(DLP),
9. Selective Laser Sintering (SLS) also known as Selective Laser
10. Melting (SLM) (Torabi et al. 2015, Kimet al. 2016),
11. Inkjet 3D printing,
12. Laminated Object Manufacturing (LOM).

Stereo lithography (SLA)

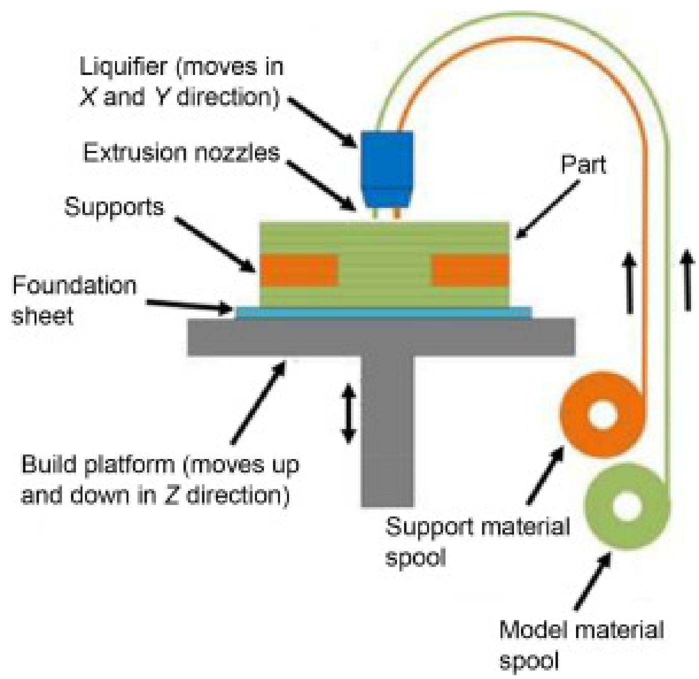
1. Stereo lithography (SLA)

Stereolithography device was invented by Charles Hull in 1980s. It is a form of additive manufacturing that converts liquid material into solid parts, layer by layer by curing them using a light source through photopolymerization. SLA is that the first so-called "rapid prototyping" process. The resolution of the built item is higher when more layers are used and therefore the number of layers may range from five to twenty per millimeter. SLA models are currently used for planning constructing highly accurate replicas of human anatomy, customized implants, onlays and surgical guides for implant placement. [5]



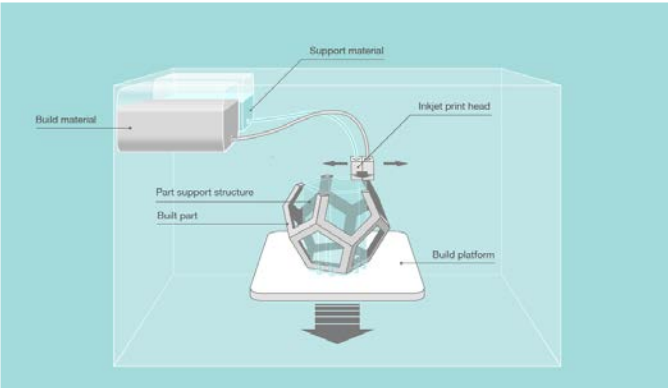
2. Fused Deposition Modelling (FDM)

S. Scott Crump introduced the technology of fused deposition modelling towards the end of 1980s and was popularized by Stratasys, Ltd in 1990. It is the most popular and affordable printing method. FDM employs the "additive" method of laying down thermoplastic material in layers. In this process the material is melted and extruded through a nozzle to 3D print a cross section of an object each layer at a time, building them from bottom to top. Materials used in this method are Thermoplastic polymers such as polylactic acid (PLA), acrylonitrile butadiene styrene (ABS), polycarbonate (PC), polyether ether ketone (PEEK), etc.[6,7]



3. MultiJet Printing

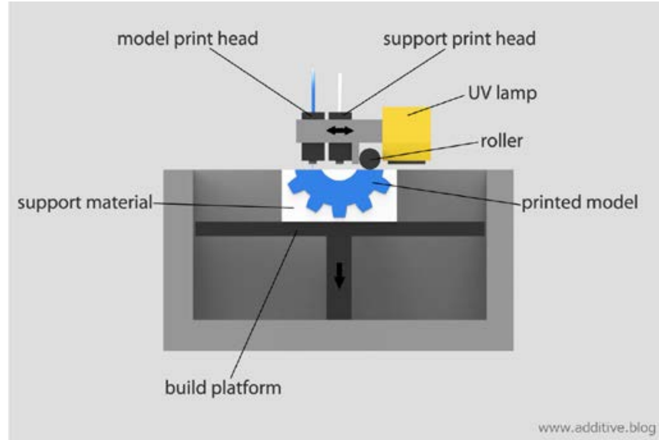
MultiJet Printing is an inkjet printing process. It uses piezoprint head technology to deposit either photocurable plastic resin or casting wax materials layer by layer. MJP is used to build patterns, parts and molds with accurate detail to address a wide range of applications. These high-resolution printers are economical and easy to operate and use a separate, meltable or dissolvable support material to make postprocessing a breeze. It is beneficial as the removal of support material is virtually a hands-free operation. It allows thorough cleaning of complex internal cavities and even the most delicate features without damage.[8]



4. Photopolymer Jetting

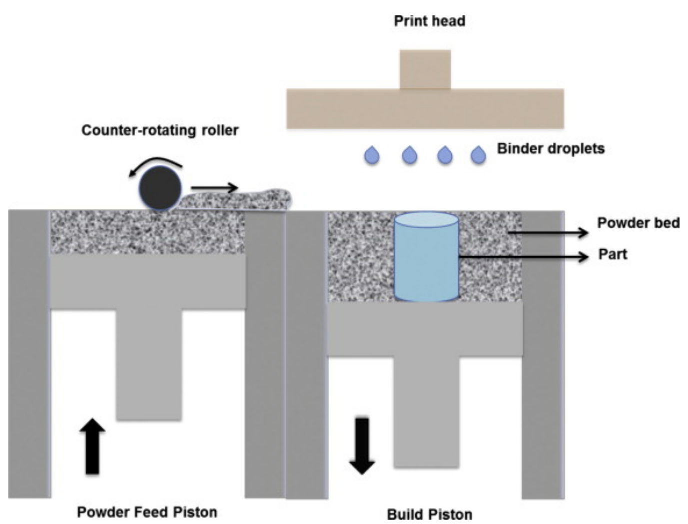
This machinery utilizes either a dynamic print head and stationary platform or a dynamic platform and stationary print head. Onto a build platform, light sensitive polymer is shooted by an inkjet type print head, which further cured layer by layer on an incrementally descending platform with a support structure that is established in a friable support material. A wide variety of casting waxes and resins, some silicone-like rubber materials can be printed. This technology gives the resolution of approximately 16 microns and provides the straightforward access for creating complex and fine detailed objects. [9]

This printers are used most commonly in printing dental or anatomical study models and Implant drill guides which will be quickly and cheaply produced with this technology as they're less bulky. 3D Jet printers may have a single print head like a computer printer, or they may have multiple heads to cover the width of the working platform.[10]



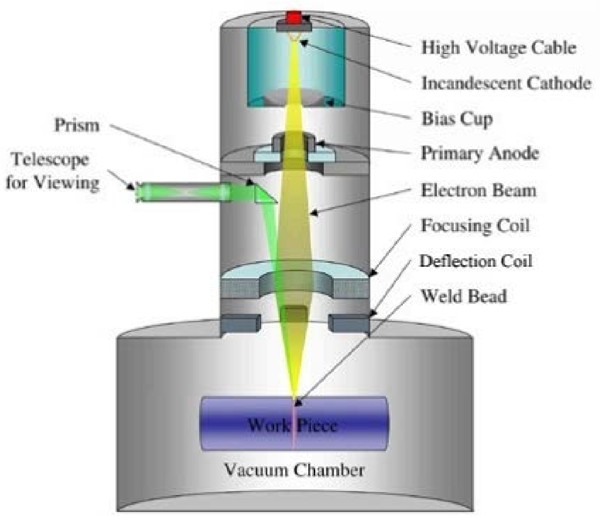
5. Powder Binder Printer

This apparatus uses a modified inkjet head to print. Liquid droplets are made to infiltrate a uniform and single layer of powder one after the other. Powder bed drops incrementally and a final model is ready which is built of many layers and a new fine layer of powder is swept over the surface. The uninfiltrated powder supports the model, and so no support material is essential.[11]



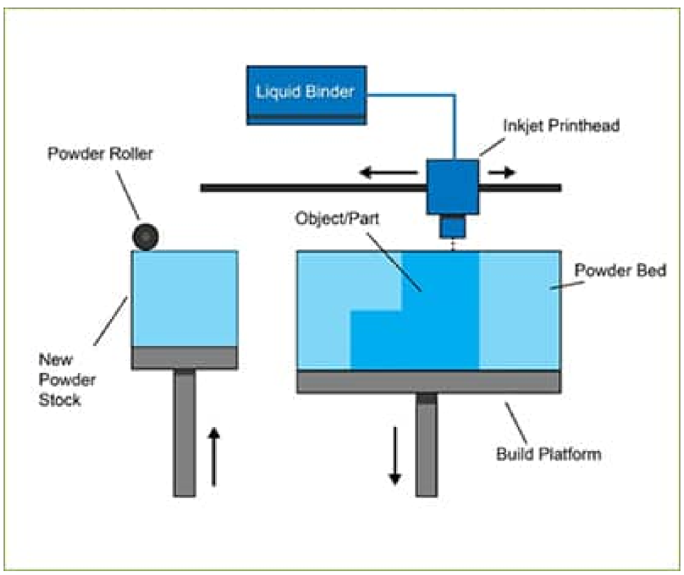
6. Electron Beam Melting (EBM)

Electron beam melting (EBM) uses "additive" type of manufacturing for laying down successive layers and creating near-net-shape or highly porous metal parts that are strong enough, free of void and fully dense. The EBM technology uses the energy source of an beam , as against a laser. The EBM technology uses the energy source of an electron beam, as opposed to a laser.[12]



EBM is able to form extremely porous mesh or foam structures in a wide range of alloys including stainless steel, titanium, and copper.

7. ColorJet Printing (CJP)



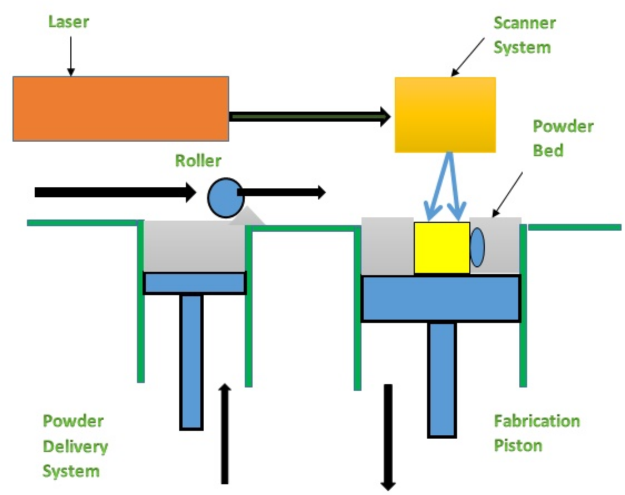
It is an additive manufacturing technology which involves two major components– core and binder. The core material is spread in thin layers over the build platform with the help of a roller. After each layer is build evenly, color binder is selectively shooted from inkjet print heads over the core layer, which causes the core to solidify. as the build platform lowers with every subsequent layer which is spread and printed, it will result in a full-color three-dimensional model.[13]

8. Digital Light Processing

A projector light is employed to cure the liquid resin during a layered fashion. On an elevating platform, the object is constructed and an upside down layer is created. The polymer is layered pending the thing is made and therefore the residual liquid polymer is drained.[13]

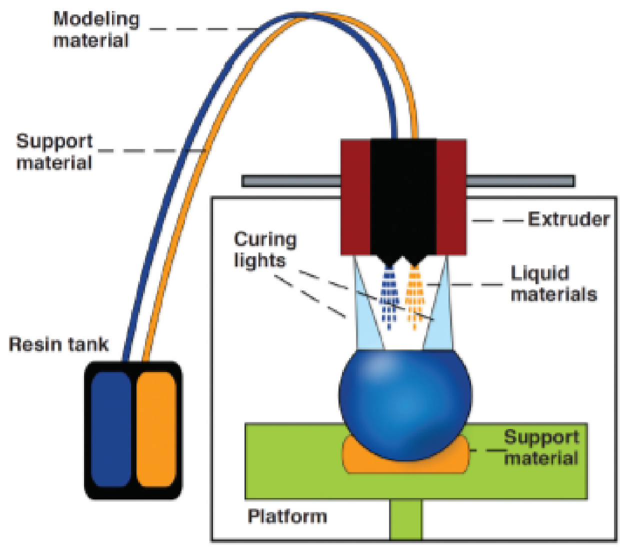
9. Selective Laser Sintering

This method was developed by university of Texas. A very fine material powder is fused by laser scanning and structures are build up incrementally. when a powder bed drops down, a new fine layer of material is roll out uniformly over the surface. A high (60µm) level of resolution could also be obtained. No support material is required as the structures that are printed are supported by the surrounding powder.[14]



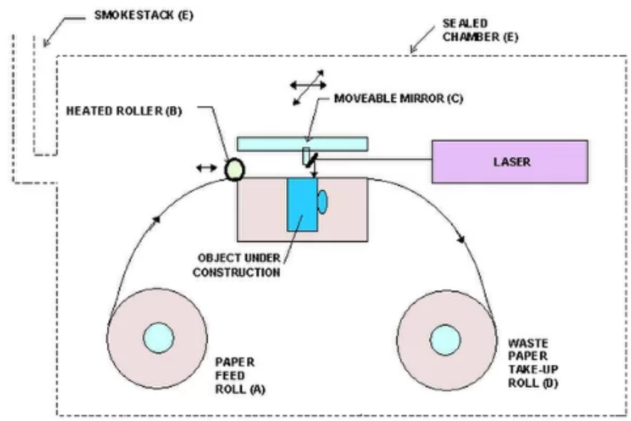
10. Inkjet 3D printing

The inkjet printing technology utilizes a nozzle. this nozzle "prints" a pattern on a thin layer of powder substrate by moving a liquid binding agent.[15] The small ink droplets are forced by pressure, heat, or vibrations through the orifice. The object is built by a incremental addition process layer by layer with each layer of material adhered to the last. when droplets are deposited upon the substrate by UV curing light, drying, reaction , or heat transfer , phase transformation from liquid to solid occurs immediately. [15,16].



11. Laminated Object Manufacturing (LOM)

In this process, additive and subtractive techniques are used to build an object. It functions by adding successive layering sheets of material one on another and binding them together with the help of adhesive, pressure, and heat application. After completion of this process, objects are cut to desired dimensions with a knife, a laser, or can be modified by machine drilling. As no chemical reaction is needed, the technology is able to produce relatively large parts. The most commonly used materials are paper, plastics, composites, ceramics and metals. Throughout the process, materials can be mixed in various layers which give them more flexibility in the final outcome of the objects. If paper models are used, than they have a wood-like texture and characteristics and can be finished accordingly. [16]



Laminated Object Manufacturing

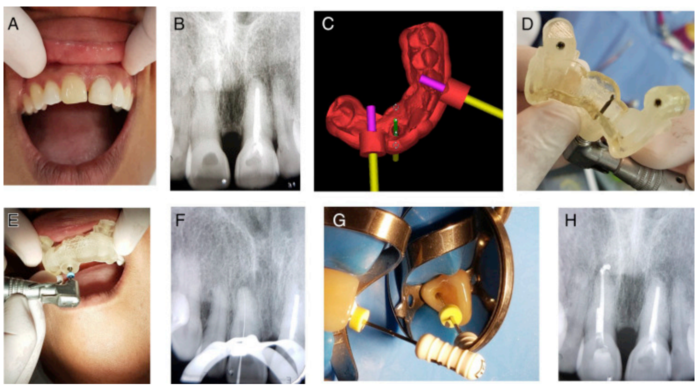
Limitations of 3d Printing

- It has high cost
- An inherent weakness is its staircase effect, created by successive deposition of material on top of the first layer.
- this methods requires supportive materials that are difficult to remove later.
- Finishing the final product is time-consuming.
- Technique sensitive
- Inflammation, irritation can be caused by resin on contact or inhalation.
- Stereolithography can only be done with light-curable.
- Additional treatment like sintering might be required for additional strength. An inherent weakness is its staircase effect, created by successive deposition of material on top of the first layer. [17]

Application in Endodontics

Guided Endodontic Access

In calcified root canal cases, it's a novel treatment approach for gaining access using 3D printed templates. Trauma, caries, aging or orthodontics causes progressive narrowing of root canals and during attempted location and negotiation of calcified canals perforations or gauging are implicated. In order to avoid this complications, 3D guided access stents or templates are digitally designed to target burs in elusive canals. CAD software Digital impressions are merged with CBCT scans, this forms DICOM data which is then allowed to create STL file containing bony architecture for pulp canal obliterated teeth. The structures are sliced, and the sliced data is sent to the printer and the final printed guides are obtained. 3D printed access guides are efficient and safe means for addressing challenging endodontic scenarios like malpositioned teeth or teeth with extensive restoration enabling conservation of tooth structure and minimizing chances of iatrogenic errors.[18,19,20]



Guided endodontic access of calcified anterior teeth

Auto transplantation

Chances of the tooth-saving procedure increases with 3D printing in auto transplantation. With the help of computer-aided rapid prototyping (CARP), a replica of the tooth can be printed such that modification of recipient bone site is done before extraction without PDL damage from repeated insertion and removal. With this recipient, the tooth can be prepared for the crown, and a temporary crown can be placed immediately after placing the tooth in the desired tooth site. This method minimizes extra oral time and chances of any error during auto transplantation.[21,22]

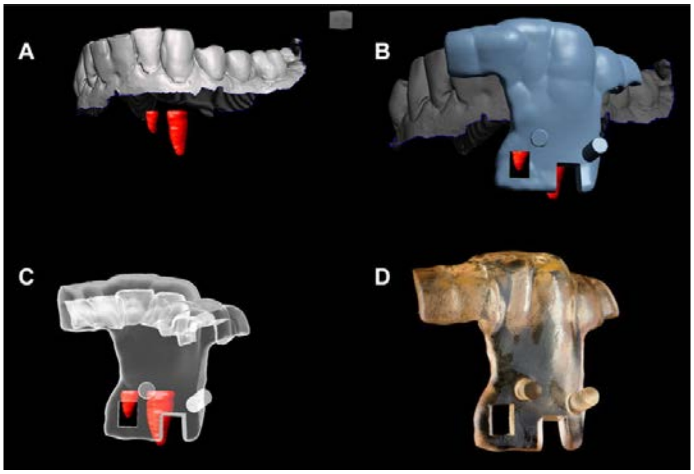
Educational 3d Models

Plaster models can serve as educational tools for students as well as for patients. 3D printed models and their digital counterparts can fulfill the functions of plaster models. Depending on the 3D printing process used, models can be fabricated in multiple textures, colors, transparencies and/or mechanical properties suitable for simulation or sterilization.23,24 3D printed models fabricated using SLG, DLP, MJM and PBP have more compatibility with plaster models. In endodontics, 3D printed models can be used as a teaching aid for trainees to improve understanding of tooth, root canal morphologies, to improve management of endodontic procedures by enabling duplication and maintenance of accurate records, patient education, aiding treatment planning through improved visualization and determination of important anatomical landmarks or pathosis such as internal/ external root resorption and allowing the fabrication of laboratory-manufactured directional or surgical guides.[25,26]

Endodontic teeth root canal model

Surgical Guides

In endodontic microsurgery, root-end resection and osteotomy procedures are done based upon on CBCT measurements or X-Ray. Surgical stent-like guides are designed that reproduces preplanned osteotomy site which can diminish risk through avoiding encroachment upon neurovascular structures or adjacent teeth and also avoiding perforations at osteotomy sites. With these stents, more accurate, precise, localised, less invasive microsurgeries can be performed.[20]



STL of teeth merged with the segmentation of the roots (a). 3D guide design (b). Transparent view of the guide (c). 3D-printed guide (d)

Dental Pulp Regeneration and Fabrication of Scaffolds

The pulp tissue can be replaced by utilizing a 3D cell printing technique. To recreate the structure of pulp tissue, an ink jet device is used by dispensing layers of cells that are suspended in hydrogel. This helps us to precisely position cells and this mimics the natural pulp tissue of the tooth. In order to simulate the pulp of natural tooth a systematic positioning of cells is required that includes positioning of fibroblasts with in the core with a supportive network of vascular and neural cells and the odontoblastic cells at the periphery. However careful orientation of the cells is required, and research is in focus to in vivo create a functional tissue like pulp.[27] Using 3D printing, various types of calcium phosphate cements have been developed to form porous customized scaffolds for regeneration of pulp dentin complex by Rapid prototyping or solid free form fabrication techniques. Polyethylene oxide and polyethylene glycol dimethacrylate photo-polymerisable hydrogels are used to fabricate scaffolds of various geometric shapes through customized tissue engineering. These 3D scaffolds are useful in repairing the defects caused by accidents, surgery or during birth.[28]

Conclusion

3D printing could establish itself as a milestone within the field of endodontics thanks to its accuracy, efficacy, potency and minimal time consumption within the fabrication process. Its utility in treatment planning and analysis of treatment outcomes extemporizes the quality of treatment provided by the dentist to the patient enhancing the patient statisfaction. Nevertheless, like every newly originated technology 3D printing has its own provocations to overcome such as cost, lack of trained personnel and limited choice of materials that are biocompatible. Hence more research is required during this field to determine itself as a reliable technology and studies should be directed to watch clinical treatment outcomes employed by 3D printed objects.

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