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RESEARCH ARTICLE

3D PRINTING IN DENTISTRY

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Abstract

Manufacture of 3D objects is of most extreme significance in different medical fields counting dentistry. Its appearance started when Charles Hull printed, for the first time, in 1984, a 3D object using the first 3D printer. 3D printing is well gotten by dental experts because of its capability to create complex parts with ease, accuracy, ease of fabricating and decreased chair time permitting the dental practitioner to supply more successful treatment. 3D printing is an additive manufacturing process in which a 3D object is created by the establishment of successive material layers. There are various 3D printing techniques, mainly stereolithography, selective laser sintering, fused deposition modeling in dentistry, which is mainly used in teaching and or managing cases involving implants, different surgeries, periodontal treatment, crowns and bridges, endodontic and orthodontic appliances. This article is focused around the various technologies of additive manufacturing, its developing applications, advantages and limitations in the field of dentistry.

Introduction:-

There has been a wide growth of 3D printing in medicine and dentistry.3D printing isnew and has captured a lot of attention in the public sector. 3D printing is the process in which multiple layers of materials are added one by one under computer control to create a three-dimensional object. It is also known as additive manufacturing or layered manufacturing or rapid prototyping. It has been useful in medical and dental fields for educational, training and research purposes, treatment and surgical planning [1]. This article sets out to explore why 3D printing is important to dentistry, and why dentistry motivates development in 3D printing applications.

History

In 1981 the history of 3D printing began with Dr. Hideo Kodama, describing a rapid prototyping system. In 1984 a 3D printing object was first invented by Charles Hull. He named it "Stereolithography". Further in 1988 Hull founded the 3D system company which introduced the first commercially available 3D printer named "SLA-1" [2].Later on, Carl Deckard brought a patent for SLS(selective laser sintering) technology while in the meantime;Scott Crump filed a patent for FDM(fused deposition modeling).

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Process Of 3D Printing

1. Creation of CAD file: **In the first step design of an object is created using CAD (**computer-aided design) software. Through this the exact dimensions of the object is determined to see how the object will behave under different conditions.
2. Creation of STL file: **In this step CAD file is converted into specific file format i.e. into STL (ST**ereoLithography). This STL file is transferred into a slicer program in which it gets translated into G-code [3].
3. **Transfer of STL file:** Now that the STL file is ready, theuser needs the 3D printer. In this printer the user will have to set the parameters of the object such as orientation and size to be printed, just like in a 2D printer.
4. **Set up of the machine:** As now everything about the digital file is ready,users have to prepare the printer by checking properly the polymers, binders and other materials necessary for printing. As the printing begins most of the machines do not require monitoring instead follow G-code instructions given to the printer.
5. **Build up:** In this stage the printer builds the object layer by layer and each layer is approximately 1mm thick[4]. This entire process takes time depending upon the factors like complexity of object, machine and the materials used. The machine is to be checked in between the entire process from time to time to avoid any errors.
6. **Removal of the 3D object:** The object is now removed from the printer. Depending on the technology, removal of finished parts may be either easy or difficult and may require professional skills and specialized equipment [5].
7. **Post-processing:** Once the 3d object is ready the user needs to handle it carefully, but if the user doesn't do so then all the hard work is going to be wasted. This step is important regarding the aesthetics and function of the object. Finally sanding, painting, polishing, and other post-processing methods like tumbling, high-pressure air cleaning, and coloring are applied to create a final 3D printing model.
8. **Application:** 3D printing model is now ready for use.

Technologies In 3d Printing

Depending on various process technologies are divided as **:-**

Working on Vat Polymerization-Stereolithography(SLA), Digital Light Processing (DLP), Masked Stereolithography (MSLA)Material used- Liquid photopolymer resin

Stereolithography (SLA)

Process- Initially the perforable platform is placed just near the vat of liquid polymer resin. Later a laser beam is directed over the platform which solidifies it. As the first layer gets solidified the platform is lowered down to form the second layer of polymer. This process repeats until a complete 3D object is produced. Stereolithography always requires support structure for undercuts. Finally the 3D object is cured in a UV oven [6]. The build material gets cured and the support structures are removed manually while surfaces require post processing.

Digital light processing (DLP)

Process- Digital light processing is a similar process to stereolithography. Major difference is the light source. Digital light processing uses a more conventional light source.Digital light processing makes use of micromirrors called a digital micromirror device (DMD). Digital light processing can achieve faster print as compared to stereolithography because an entire layer is exposed all at once, rather than tracing the cross-sectional area with the point of a laser. Like stereolithography this process also requires support structure and surface requires post processing.

Masked stereolithography (MSLA)

Process- Masked stereolithography is similar to stereolithography and digital light processing. The difference is that masked stereolithography uses an LED array as the source of light with an LCD photomask. This LED photomask gives the shape to the light image coming from the LED array [7]. In this process all the layers are exposed at once instead of the cross section area with a laser point, which results in the formation of the entire 3D object in a single exposure.

Working on Material Extrusion-Fused Deposition Modelling (FDM) / FusedFilament Fabrication (FFF)Material used- Thermoplastic filament

Fused Deposition Modelling (FDM) / FusedFilament Fabrication (FFF)
Process- In 3D printer a coil of filament is loaded and fed through to a printer nozzle in the extrusion head. Then the nozzle is heated to the desired temperature whereon through the heated nozzle a motor pushes the filament, causing it to melt. Along with specified coordinates the printer moves the extrusion head, the molten material is placed onto the build plate where it cools down and solidifies. Once a layer is complete, the printer proceeds for another layer. Until the object is fully formed this process of cross-sections is repeated, layer by layer. Support material is required for undercuts. Post processing is generally required for finishing of the smooth surfaces.

Working on Polymer Powder Bed Fusion- Selective Laser Sintering (SLS)Material used- Polymer powder

Selective Laser Sintering (SLS)
Process- A high power laser is operated using a mirror consisting of a fine layer of powder. When the beam hits the powder it is converted into a melt pool and powder particles fuse together. After scanning each layer a new layer of material is applied on top. This process continues until the 3D object is complete. No support structure is required in this process because overhangs and undercuts are supported by the solid powder bed.

Working on Metal Powder Bed Fusion- Selective Laser Melting (SLM) / Direct Metal Laser Sintering (DMLS), Electron Beam Melting (EMB) Material used- Metal powder

Selective Laser Melting (SLM) / Direct Metal Laser Sintering (DMLS)
Process- Both direct metal laser sintering and selective laser melting produce objects in a similar way as selective laser sintering. The main difference is that these technologies are used for the production of metal parts. Direct metal laser sintering doesn't melt the powder but instead heats it to a point, whereas selective laser melting uses the laser to achieve a full melt of the metal. This leadsto a part that has a single meltingtemperature. The difference between direct metal laser sintering and selective laser melting is that the former produces parts from metal alloys, while the latter forms single element material like titanium. Both the process requires supporting structure.

Electron Beam Melting (EMB)
Process- Electron beam melting is similar to selective laser melting. Unlike selective laser melting the metal powder is deposited on the platform but uses a targeted electron beam instead of laser to scan the layer of powder that results in melting and solidification of a specific area which develops into a solid 3D object. The entire process is carried in vacuum and only with conductive metal powder [8].

Working on Material Jetting- Polyjet / Material Jetting (MJ) , Drop On Demand (DOD)Material used- Polymer resin

Polyjet / Material Jetting (MJ)
Process- Polyjet is similar to standard inkjet printers. But the difference is that Polyjet builds multiple layers one over the other to form a 3D object rather than a single layer of ink on a piece of paper [9]. Hundreds of small droplets of photopolymer are spread by the printer head on the platform and gets solidified by UV light layer by layer. The build platform is lowered down as the first layer get cured and the second layer gets deposited. This process is repeated until the 3D object gets developed. Polyjet always requires a support structure which is water soluble and gets easily dissolved at the time of post processing.

Drop On Demand (DOD)
Process- This technology uses a pair of ink jets. The first deposits the build materials. Second is used for dissolvable support material. Drop on demand printers follow a predetermined path to jet material in a point wise deposition, creating the cross-sectional area of an object layer by layer.

Working on Binder Jetting- Binder JettingMaterial used- Sand / Metal particles

Binder Jetting (BJ)
Process- In this method powder is spread on the platform and binder droplets are spread by the print head that moves over the powder surface thus binding with the powder to form the layer of 3D object. As the first layer is printed the powder bed gets lowered down for the next layer to form. This process is repeated till the 3D object is formed. For curing and gaining strength, the object is then left in the powder. Finally the object is taken out from the powder bed and compressed air is used to remove any unbounded particles.

Applications Of 3D Printing

In orthodontic perspective

Orthodontists produce beautiful smiles and producing smile is a time-consuming process. But nowadays because of this technology, it has become easy. As soon as the 3D scan is done, it is transferred to the computer so that we get 3D images of the patient's teeth. These files can be sent out for fabrication either in an office set up where this 3D CAD file is pulled into the printer or in the labs. 3D printing is used in various removable appliances, functional appliances, arch expansion appliances, clear aligners, retainers, arch wire, brackets, auxiliaries, trays for indirect bonding, set up models which will make lingual orthodontics and mock surgeries fast and easy, also study models [10]. The primary benefit of using 3d printing in all this process is speed. This technology also makes each product more accurate and custom.

Surgical guides

Dental drilling requires a high degree of precision and dental 3D printing has made precision simple as hitting the wrong nerve can lead to a high degree of pain for the patient and can cause partial facial paralysis in the worst possible way. Dental surgical guide resin increases patient satisfaction and overall process efficiency. This is entirely sterilizable and used to build practical guides for surgeons. A sample of the patient's teeth is taken and guides are then produced in the model to accommodate metal drilling inserts. During surgery, the guides are positioned over the teeth of the patient's and used to align thedrill [11].

Dental Implant

3D printing technology increases the ease of implant surgery. 3D printed models help the dentist to determine the depth and width of the bone, exact sizing for implants and determine the position of sinus and nerves prior to the surgery. It also helps to produce surgical drill guides and templates for implants [12]. Firstly a surgical guide is createdthat will properly fit over the gums and teeth. Dentists then collect the data by cone beam to plan the position of the implant depending on the quality and density of bone, soft tissue, nerves and their locations. Lab then converts this guide into a 3D printed guide which helps the dentist to know the position of the implant more accurately. 3D printed surgical drill guides help the dentist to increase the surgical safety by guiding the surgeon in determining the exact location and the depth of the drill.

Veneers

3D printed veneers are manufactured with great precision within a fraction of time. These are easily grindable and polishable with the standard tools and provide excellent aesthetics due to balanced ratio of opacity and translucency. Due to low water absorption there is less tendency of plaque accumulation. 3D printed veneers provide great comfort to patients as these are less sensitive to heat and cold. Moreover dentists can create an aesthetic mockup, basically a mouthpiece that fits over a patient's teeth and permits the patient to see their smile which will look like after the treatment that will help them to make better decisions and boost their morale [13].

Root canal

A novel treatment approach for root canal treatment of teeth with calcified pulp canal and apical pathology was introduced using special drills and surgical models. In such cases CBCT and intraoral scanning was performed and combined using software for virtual implant planning. A special root canal location drill was developed. It was designed for its place,a virtual template was exported as a STL file and sent to a 3D printer. The template was placed on the affected area, a special drill was used to penetrate through the root canal's obliterated portion and obtain minimally invasive access to the apical part. Root canal was accessible at a distance of 9mm from the apex, and further preparation of the root canal was performed using endodontic rotary instrumentation method. This study concluded that a controlled endodontic approach appears to be a safe, clinically possible method for locating root canal and avoiding perforation in teeth with calcification of the pulp canal. The challenges associated with this technology are the space required for the template and the difficulty of instrument positioning in the posterior region. It can only be used in straight canals and up to the straight parts of apically curved canals.

Crowns and bridges

For the correction of damaged or missing teeth, the most common procedure is the use of crowns or bridges. At very high resolution in labs castable resin can print digital crown or bridge models. It would then be able tocast in the metal based on your personal preference through a process known as investment casting. The printed part is utilized in a mold and afterward burned out to make a hollow negative. The metal is then cast to make a crown or bridge. Checking the fit of prosthodontics before establishing them to a patient's teeth is often critically important [14].

With the help of intraoral optical scanners, dental model resin allows you to produce a 3D model of the patient's teeth to test the fit of prosthodontics treatment.

Removable Partial Denture

A 3D scan of the partially edentulous patient's cast was performed which hence permitted the computerized structuring of the RPD's parts. Owing to its excellent corrosion resistance, stainless steel was chosen in the 1st experiment making it ideal for dental application and cobalt chromium alloy was picked in the 2nd experiment using selective laser melting. While comparing both the RPD frameworks, both showed precise fit on the patient's cast, but after repeated insertion and removal, the retentive part(clasp) of the stainless steel framework showed deformation. But the cobalt chromium alloy doesn't show any sign of deformation hence this proved to be more efficient than stainless steel. This study shows that, compared to manual work and casting methods, the time required to plan and the probability of mistakes, 3D printing is superior to construct RPD frameworks.

Fixed Partial Denture

For the fabrication of FPD, the'robocasting' method is used. Robocasting is a 3D printing manufacturing process whereby an object is printed directly from a digital file in a layer by layer fashion onto a flat substrate. The paste is used in robocasting which is capable of producing fine filaments and drying with minimal shrinkage.

Oral and Maxillofacial Surgeries

3D models play an important role in decision making in oral and maxillofacial surgeries. 3D models help to differentiate easily between traumatic and pathological defects and thus help in diagnosis and treatment planning. These are precise and accurate in explaining head and neck anatomy and thus helpful during surgeries. It is also used in osteogenesis and treatment of craniofacial deformities. 3D printing fulfills better aesthetics and functional facial prosthesis than traditional prosthesis [15]. The 3D printed model based on MRI plays a vital role in the diagnosis of the temporomandibular joints by disclosing the morphological features of the joint which helps in distinguishing different patterns of TMJ pathologies. 3D printed models also minimize the operative complications and help the patient to understand about surgical details, different results and potential obstacles.

Sinus and bone augmentation

Loss of vertical bone height is a common sequel after tooth extraction which ultimately affects the treatment of partially dentate patients, particularly for placement of implants requiring adequate bone height and width. The maxillary sinus position also restricts the available bone height. Recent technological advancements have introduced the role of 3D printing in bone and sinus augmentation, and have shown promising results. Some of the benefits of 3D printing is the ability due to the additive manufacturing method to replicate the bony architecture and form macroporous internal grafting structure with minimal material wastage. Certain advantages include no ethical issues, adequate availability due to alloplastic material, less chance of transmission of infection and less chair side surgery time. There is a lack of randomized control trials [16].

Socket preservation

Removal of the tooth results in loss of alveolar ridge width and height due to the normal resorption process. Recent technical advancements have allowed the use of 3D printed scaffolds to preserve the socket and maintain the extraction socket dimensions. Long term follow up clinical trials are lacking and require attention.

3D printed bioresorbable scaffold for guided bone and tissue regeneration

Recent tissue-engineering developments have led to the production of "3D printed" scaffolds. These scaffolds are intended to facilitate the formation of bone,periodontal ligament, cementum, and the re-establishment of the connection between them. Due to its reported positive outcomes in bony regeneration, polycaprolactone was widely used as a scaffold material among various materials. Such scaffolds have the advantages of 3D architecture that closely resembles extracellular matrices, resulting in better regenerative capabilities. There is a lack of randomized control trials and clinical studies with long term follow-up.

Orthognathic surgery

The success of orthognathic surgery relies on exact planning based on accurate diagnosis. CT and CBCT are gaining more significance in pre-operative planning compared to conventional radiographic imaging techniques providing the acquired dataset's 3 dimensionality. Digital study models in the treatment planning for malocclusion patient's prove to be a better alternative to conventional plaster study models. Orthognathic surgical planning may be done by controlling the digital orthodontic model. Subsequently 3D printed surgical wafers are produced by computer. After the technician and clinician have approved the virtual wafer design, the surgical wafers are printed using a 3D printer, and the surgery is completed.

Regenerative dentistry

The 3D printer can print bone tissue customized to the patient's requirement to serve as a biomimetic scaffold. There are 3D printed alginate peptide hybrid scaffolds these days which act as a stable medium for optimum stem cell growth. It is possible to print calcium sulfate, calcium phosphate and composite powders which act as material for the augmentation.

Custom Impression trays

3D custom trays can be made either by available materials or by computerized scan of impression / models and printed. There are two methods of developing a model. First method involves directly screening the impression and transferring it into the program. Second method involves taking an impression with a stock or custom tray and pouring it with stone, this stone prototype is then scanned or directly used in manufacturing protocol [17]. The CAD design of custom trays provides the homogeneous space for the impression materials and decreases the manual procedure. 3D custom trays are mostly used in cases of complete edentulous patients complete arch implant impression technique.

Study Models

3D study models provide accurate anatomical details which provide exceptional measurements, patient's education and laboratory collaboration. The color options provided permits the clinician to opt the shade that will provide details more clearly. The materials used in making 3D study models are non toxic and are not brittle. These models act as a powerful tool for the dentist as they allow them to check their work before surgically implanting into the patient [18].

Diagnostic wax-up

Diagnostic wax-up models as compared to traditional wax-up savesvaluable time and provides consistent results between imaging, wax-up, mock-up, provisional and final restorations. Diagnostic wax ups act as a tool for diagnostic and treatment planning in the field of dentistry. 3D wax up models help in designing of gingival height recontour with a great precision. Diagnostic wax-ups are important for smile makeover. It acts as a source of communication between the clinician, technician and patient explaining the treatment plan three- dimensionally and permitting modification in a reversible way. It is useful to educate the patient and help them to accept and approve the indicated treatment[19].

Product designing and instrument manufacture

Many surgical instruments can be printed by 3D printing technology. This helps the dentists as they can design the instruments themselves saving the cost and time on tool replacement. Instruments can be made faster than the traditional method. This technology increases the accuracy, reliability and repeatability of the device. 3D printed tools can be either easily disposed of or sterilized for reuse.

Bioprinting

It is a form of 3D printing which involves cells and tissues. Bioprinting refers to the printing of living cellular material that is mixed with polymer. This develops the complex tissues similar to that present in the body. 3D printed objects are rapid, regenerate or replace damaged tissues of the body. Bioprinting provides additional plus points to the traditional regenerative method like high precise cell placement and high digital control of speed, resolution, cell concentration, drop volume and diameter of printed cell [20]. Development of 3D printed tissues solves the problem of organ donor shortage.

Auto-transplantation

Successful auto-transplantation needs the survival of the PDL cells and adequate adaptation to the recipient site of the transplanted tooth. During the procedure, extra oral time and damage to the PDL have a significant effect on outcomes. Conventional approaches use the transplant tooth as a template to prepare the receiver site, often requiring multiple 'fitting' attempts with adjustments to the alveolar bone that increases extra-oral time and threaten PDL injury [21]. In this field 3D printing technology was introduced. Computer aided rapid prototyping (CARP) is used to print replicas of teeth so that manipulation of the recipient bone sites could be done without PDL disruption from repeated insertion and removal prior to extraction of the transplanted teeth.

Forensic Dentistry

3D printing helps in forensic science in various ways. 3D printed bite marks analysis is compared to the suspect's dentition to rule out inclusion or exclusion. In case of cheiloscopy, palatoscopy, tongue print pattern, finger prints, foot prints analysis where impressions are difficult to take with traditional technique, 3D printing technology is useful in such conditions. Facial reconstruction by 3D printing technology plays an important role in identifying cranium or skull. 3D model of dentition and mandible helps in age estimation. 3D printing also helps in sex determination, population identification and to illustrate the bone injury pattern. Anatomical 3D models are useful in analysis of crime investigations [22]. 3D printed evidence is easily transportable and can be examined by multiple experts without any ethical issues or deterioration. Post mortem profiling is done by identifying the key elements on the 3d printed parts. Thus 3d printing technology is noninvasive reconstruction of detailed anatomical structures which helps to solve the cases, to provide education and training.

Advantages Of 3d Printing

1. Some of the greatest benefits of 3D printing is certainly that it saves both patient anddentist time [23].
2. 3D printing is an extremely cost-effective method for dental laboratories.
3. A 3D model is a more stable, convenient, reliable andprecise alternative compared to a plaster model.
4. Digital workflow finishing with a 3D print also leads to a more faster andaccurate end result [24].
5. Complex geometric shapes andinterlocking pieces can be printed which do not require any assembly.
6. 3D printing significantly reduces the amount of manual work andlabor-intensive activities involved in the dental manufacturing process [25].
7. 3D printing thereby increasing the treatment efficiency andensuring a more comfortable environment for the patient.
8. 3D printing is aesthetically superior.
9. 3D printed prosthesis lasts longer than conventional ones.
10. Reduction of the material loss associated with the output [26].
11. 3D printing provides the technician with a safe workplace, without having to deal with plaster or grinding dust inhaled.
12. Surgery can be less invasive andmore predictable using surgical guides.
13. 3D printing provides the opportunity to print on demand, meaning we can only print it when we need it andin the same amount, so no storage cost is required [27].
14. As 3D printing expands andbecomes more popular, so does its accessibility.
15. 3D printing is useful in preoperative planning i.e it predicts anatomical problems in the direct visualization of malformations.
16. 3D printing reduces the occurrence of complications such as blood loss, infection etc.
17. It increases information flow to the patients andbetter patient contact.
18. The widespread use of 3D printing technology would undoubtedly increase the demandfor engineers required to design andproduce these printers [28].
19. Customized human body parts andorgans can now be manufactured with the development of technology, this process is known as bioprinting.

Disadvantages Of 3D Printing

1. 3D printers consume more energy as compared to traditional methods.
2. Materials used in 3D printing technology are limited.
3. Due to specialized equipment and parts used it is difficult to handle [29].
4. The investing cost is high.
5. Post processing requires specialized skills.
6. Resin on contact and inhalation may lead to inflammation and irritation [30].
7. A 3D printing machine produces potentially toxic emissions and carcinogenic particles .
8. Manufacturing jobs are decreasing due to 3D printing technology

Conclusion:-

"3D printing" or "Rapid prototyping" technology is a boon to the field of dentistry. It increases the confidence and satisfaction of the patient towards the treatment to be done thus improving the patient dentist relationship. It acts as an important tool for educating dentist, students and patients about the treatment plan. It reduces the risk of failure and complications by guiding the dentist in a proper way before implementing the procedure into the patient. It helps the dentist to design the instrument according to the need of the treatment. It requires special skill and saves the valuable time of the dentist and patient during the treatment. Along with all these advantages health and safety protocols should be strictly followed. Thus,the combination of scanning, visualization, CAD, milling, 3D printing technology and skill makes the dentistry curious and creative. In the future 3D printing has huge scope in the field of research and treatment planning.

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