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3D PRINTING- THE FUTURE IS NOW

Dental Science

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ABSTRACT

"3D PRINTING" an umbrella term for host of processes and technologies that offer a full spectrum of capabilities for the production of parts and products in different material. It is generally used to describe a manufacturing approach that builds objects one layer at a time, adding multiple layers to form an object. This process is more correctly describe as additive manufacturing, and is also referred to as RAPID PROTOTYPING. With advances in 3D imaging and modeling technologies such as cone beam computed tomography and intraoral scanning, and CAD CAM technologies in dentistry, it will become of increasing importance. Uses include the production of drill guides for dental implants, the production of dental models for prosthodontics, orthodontics and surgery, the manufacture of dental, craniomaxillofacial and orthopedic implants, and the fabrication of crown copings and framework for implant and partial dentures. This technology eliminates labor intensive artisanal production techniques, allowing dentist to focus his manual skills on more creative aspects of manufacturing process. As applications of 3D printing are emerging almost by the day, we have just begun to see the potential of it. This is something that can bring us forward. I see it as a future of dentistry.

KEYWORDS

3dprint, dental models, modeling technologies

INTRODUCTION

With the discovery of 3D imaging, the world of dentistry completely changed. This technology is more accurate and precise than 2D. 3D imaging lead to the development of three-dimensional (3D) structural analysis of unique complex physical model in the dentistry, which was recognized as disruptive technology called 3D PRINTING. 3D printing is described as manufacturing approach that builds objects one layer at a time, adding multiple layers to form an object. Its applications are emerging almost by the day and continues to penetrate more deeply. The first application was used in dental implants and custom prosthetic devices. Since then its applications have significantly grown.

This article explores about the mechanism; technologies, applications; future of 3D Printing

EVOLUTION:-

1984 marked the beginning when Charles Hull of 3D systems developed the first working 3D Printer. Later in 1986, Charles Hull found 3-D systems and developed the first commercial 3D Printing Mahne and it was called as Stereolithography Apparatus. In 1993, Massachusettes Institute of Technology parented "3D Printing techniques". It is similar to the inkjet technology used in 2D Printers.[1] In 2010- Organovo, Inc., a regenerative medicine company prioritized on bioprinting technology, announced the release of data on the first fully bioprinted blood vessels.[2]

EQUIPMENT:-

1) CT scan:- The patient is scanned and DICOM files should be exported. Recommendation of CT slice thickness is less than a 1-mm CT.
2) Data conversion: DICOM data is imported, then the data is converted to STL files. It
takes about 30 minutes for rendering of CT scan DICOM data into STL data files.
3) Fabrication: Converted 3D files are uploaded into the 3D printer. Rapid prototyping follows using laser-by-laser stereolithographic accumulation. Further the RP model is fabricated on plaster via jetting of the material. The materials consist of plaster (≤90 %), vinyl polymer (≤ 20%), and carbohydrate (≤ 10%). It takes about 4-6 hours for the process of printing and filtration.
4) Filtering : unfiltered sections should be removed.[3]

CHOOSING THE RIGHT MATERIAL FOR YOUR

APPLICATION:-

Technology defines the materials in additive manufacturing technology/ 3D Printing systems. This technology transforms material through external heat, light, lasers and other directed energies. The ability of a material's mechanical composition to react positively to a certain directed energy and interacts with that material which can deliver the desired change and bring accurate results. The advancement in the technologies encourages more positive material reactions, layer by layer, to directed external energies. The mechanism of material change—unique to individual 3D printing technologies and processes—defines the material in terms of state changes, final mechanical properties and design capabilities. The development in materials of 3D printing correspond to development in 3D manufacturing; as the build process improves to encourage more positive reactions from materials, material selections will expand.[4] So it is necessary to choose right biocompatible material for your 3D Printing technology. Various material uses include:-

1. **Clear Biocompatible (Med610):-** used in production of orthodontic appliances and surgical guides
2. **Vero Dento Plus(Med690):-** dark beige material provides excellent strength
3. **Vero Glaze(M620):-** opaque material with adequate color match for veneer try-ins and approved medically for temporary in mouth placements upto 24 hrs.

MECHANISM

It is the process in which multiple layers of material is added one by one under computer control to create three-dimensional object. The main objective of this creative method is that the three dimensional model is sliced into many thin layers and the manufacturing equipment uses this geometric data to build each layer sequentially until final desired product is completed. It all starts with the creation of a virtual design of the object. Scanner may be used to scan buildings, rock formations, human parts etc., to manufacture a 3D model. The 3D model is sliced and then it is ready to feed into the 3D Printer of compatible brand and type. This is done via USB, SD or Wi-Fi. When a file is uploaded in a 3D Printer, the object is ready to be 3D printed. The object is printed layer by layer. The 3D printer reads every slice (2D image) and creates a three dimensional object. Objects of any geometry can be made by this technology. This is what is known as slicing. There are four categories of 3D printers available in the market. Firstly, there are printers that extrude a molten or otherwise semi-liquid material. Secondly, printers that solidify a photo curable resin. Thirdly, the printers which fuse the granules of a powder. And finally, are the printers that stick together cut sheets of paper, plastic or metal.[5]

DIFFERENT 3D PRINTING TECHNOLOGIES:-

STEREOLITHOGRAPHY:-

The term "stereolithography" was introduced in 1086 by Charles W. Hull, who defined it as a method for making solid objects by successively printing thin layers of an ultraviolet curable material one on top of the other.[6] As the UV light strikes the surface of liquid polymer, it solidifies one layer of polymer. Once the first layer, (adhering to the platform) has been completely traced, the elevator is lowered to the depth of the next layer. The solid "green" layer is then recoated with resin to form a new layer of liquid resin, then the laser beam tracing process is repeated, which forms another layer on top of previous layer. This process continues layer by layer until the part fabrication is completed. The layers bond to one another due to self adhesive property of the material which eventually form a complete, 3D object.[7] It is used to manufacture implant surgical guides because of high mechanical strength, obturators, surgical stents, duplicating of prosthesis and burn stents.[8] The main disadvantage of SLA is the scarcity of biocompatible resins with proper SLA processing properties and also include expensive equipment and material cost, wet material handling and post-processing. Additional problems of photointiators and radicals which may be cytotoxic (with long processing times), entrapment of unreacted monomer and residual photoinitiator, and inability to create compositional gradients along horizontal planes. The other disadvantage is the poor mechanical properties of photopolymerized resin that are needed for hard tissue engineering. Lastly, temporary support structures must be incorporated into the CAD model to fabricate unsupported features (e.g. overhangs, cantilevers). Complete removal of support structures may be difficult.[9]

SELECTIVE LASER SINTERING/MELTING:-

Selective laser sintering (SLS) was developed by the University of Texas in 1989. The CO_2 laser beam scans the surface of the powdered polymer particles in a specific 2D pattern to sinter by heating them above the glass transition temperature. During sintering, molecular diffusion along the outermost surface of the particle lead to neck formation between neighboring particles. After one layer is created, the piston containing the part is lowered and a fresh layer of powder material is rolled across the top surface. The subsequent layer is formed and is bound to the previous layer. Unbound, loose powder is removed after the part is completed and is heat treated to achieve full density.[9] The main use of this technique is fabrication of anatomical study models, cutting and drilling guides, dental models and also for engineering/design prototypes,[10] including the key advantage as the ability to directly make metallic implants that promote either bone in-growth and regeneration for load-bearing applications in which high fracture toughness and mechanical strength are needed. Even for non-load bearing applications, polymers can be processed without the use of organic solvent. To achieve compositional gradients in SLS is slightly easier as compared to SLA by spreading different powder between different vertical layers, but in horizontal plane this is very limited.[9] Other advantages are autoclavability of the materials used, ease of full mechanical functionality of the printed objects, lower cost materials if used in large volume.[8] The disadvantages are powders are messy with increased inhalation risk, technology is expensive, and remarkable climatic conditions like requirement of compressed air. Other include are limited materials which fuse, but do not decompose under the laser beam (high temperatures) and the post processing needed to remove trapped powder. Another limitation is conduction and diffusion of laser heat causes undesirable fusion of neighboring powder particles, limiting the resolution of final features. Lastly, smaller pore sizes are limited since the created pores depend on the particle size of the powder used. Powder particles too small cannot be used due to poor spreading from powder clumping.[9]

THREE DIMENSIONAL PRINTING:-

Initially when invented at the Massachusetts Institute of Technology, Three Dimensional Printing (3DP) was done by inkjet printing liquid binder solution onto a powder bed[11-13] which fabricated 3D structures. It starts by depositing a layer of powder at the top of a fabrication chamber. To this end, a measured quantity of powder is first dispensed from a similar supply chamber by moving a piston upward incrementally. A roller then distributes and compresses the powder at the top of the fabrication chamber. The multi-channel jetting head subsequently deposits a liquid adhesive in a two-dimensional pattern onto the layer of the powder, which becomes bonded in the areas where the adhesive is deposited, to form a layer of the object. Once a layer is finished, the piston that supports the powder bed and the part lowers so that the next powder layer can be spread and selectively joined. This layer-by-layer process repeats until the whole part is completed. Following a heat treatment, unbound powder is removed, leaving the fabricated part.[10] A wide range of biological agents such as peptides, proteins (e.g. fibrinogen, collagen), polysaccharides (e.g. hyaluronan, alginate), DNA plasmids, and living cells have been printed with 3DP. This technology also allows a construction of a biphasic scaffold to regeneratehybrid tissue systems such as Temporomandibular joint (TMJ).[9] 3DP's advantages include

speedy fabrication and low materials cost, with additional feature of direct control over both the microarchitecture (i.e. pore size) and macroarchitecture (i.e. overall shape). Limitations on resolution, surface finish, part fragility, available materials and limited available pore size in the final constructs when porogens are incorporated into powders prior to fabrication are its disadvantages.[7,9]

FUSED DEPOSITION MODELING:-

Fused deposition modeling (FDM) is the deposition of molten thermoplastic materials through two heated extrusion heads with a small orifice in a specific laydown pattern.[14] It is a widely used rapid prototyping technology. One nozzle deposits the thermoplastic material and the second deposits temporary material to support cantilevers. In FDM, one of the traditional methods melts thermoplastic polymer into a semi-liquid state and the head extrudes the material onto the build platform.[6] The part is built in a layer-by-layer fashion where the layers are fused together. Since multiple extrusion nozzles could be used in FDM, each with a different material, there is no theoretical restriction on compositional gradients in all three dimensions for FDM.[9]

POWDER BINDER JETTING:-

These apparatus use a modified inkjet head to print using, liquid droplets to infiltrate a layer of powder, layer by layer. Typically a pigmented liquid, which is mostly water, is used to print onto the powder. The powder is mostly plaster of paris. A model is built up in layers as the powder bed drops incrementally, and a new fine layer of powder is swept over the surface. The accuracy is limited and models are fragile making it difficult to sterilize is a major disadvantage .

INKJET PRINTING TECHNOLOGY:-

Inkjet printers are capable of printing at a very high resolution by ejecting extremely small ink drops. Inkjet printing works by propelling individual small droplets of "ink" toward

a substrate. In this context the ink can be anything from an aqueous solution of coloring agents and binders to a ceramic suspension, such as used in some studies to produce zirconia

dental restorations [15,16] or a cell solution to produce tissue constructs.[17] The ink is forced through a small orifice by a variety of means including pressure, heat, and vibration.

One approach consists of building up the object layer by layer from depositing droplets to form a layer of the material and then depositing the next layer. To be used for additive

manufacturing, the liquid droplets must change phase to solid upon deposition on the substrate when printing a pattern. Depending on the deposited material, the phase change could be by drying, heat transfer, U.V. light or chemical reaction.

APPLICATIONS :-

1. 3D Printing is widely used for the production of an anatomical "study models". can serve as a hard copy of the scanned data set and provide both visual and tactile information and documentation for visualization, diagnostic, therapeutic, and education purposes.[7]
2. Drilling and Cutting Guides
3. 3D printing can be used for fabrication of metal structures either directly in metals or metal alloys or indirectly by printing in burn-out resins or waxes for lost wax process.
4. Digital smile through 3D Printing. The Invisalign®, system digitally realigns the patients teeth to make a series of 3D printed models for the manufacture of 'aligners', which progressively reposition the teeth over a period of months/years.[18-19]
5. 3D printing has the ability to produce complex geometries, such as a bone-like morphology, which may not be produced by milling alone– although milling/machining may also be used to refine the printed form– for example, the implant platform. There is also the opportunity to create implants which have complex geometry, although ultimately inserting a dental implant using a screw type form seems like a well proven approach.[20]
6. 3D Printed Titanium Implants could be used in human body. The implants fit very well onto pre-existing defects such as calvarium or maxillary defects.[3]
7. 3D printed prototype models are a particularly effective tool for simulating LeFort I, II, Or III midface osteotomy, which require delicate blind osteotomy.[21]
8. Recent advances in 3D printing technology now enable fibular osteotomy and fixation guides to be provided, which enable the dental implants to be inserted in the ideal position. [22,23]
9. 3D printing has a role in the rapid prototyping of instrumentation, which allows creative individuals to take an idea to fruition in a very short period of time.[20]
10. 3D printed master model may be used for conventional aspects of the fabrication of a restoration, such as adding a veneering material, and we are accustomed to seeing restorations displayed on a model– even if they have been directly fabricated digitally. Patient model data may be digitally archived, and only printed when needed, easing storage requirements.[20]

ORGAN 3D PRINTING :-

To address the need for tissues and organs suitable for transplantation 3D bioprinting is being applied to regenerative medicine**.** Many of the challenges facing the 3D bioprinting field relate to specific technical, material and cellular aspects of the bioprinting process. Although the field is at an early stage, it has already succeeded in creating several tissues at human scale that are approaching the functionality required for transplantation. Technological challenges include the need for increased resolution, speed and compatibility with biologically relevant materials. Materials currently used in the field of regenerative medicine for repair and regeneration are predominantly based on either naturally derived polymers (including alginate, gelatin, collagen, chitosan, fibrin and hyaluronic acid, often isolated from animal or human tissues) or synthetic molecules (polyethylene glycol; PEG[24-27]). 3D tissue constructs are being developed not only for transplantation but also for analysis of chemical, drug discovery, toxicological and biological agents, and basic research. With increase in complexity, as we progress toward printing tissues with increasing complexity, beginning with 2D tissues such as skin, through to hollow tubes such as blood vessels, to hollow non-tubular organs such as the bladder, and finally to solid organs such as the kidney. Professionals will have to address increasingly difficult challenges, including cell and tissue maturation and functionality, material requirements and appropriate vascularization and innervation. Multidisciplinary research will be required to meet these challenges and realize the potential of 3D bioprinting to transform the field of regenerative medicine.

CONCLUSION :-

The applications of 3D Printing are growing each day and this technology has greater penetration in the field of medicine and dentistry. 3D printing is now being used to fashion customized laboratory tools and to model complex molecules and protein interaction in this global world not only in dentistry but also in medicine. 3D printing equips dentists and medical professionals to design, visualize, hold and test their ideas in real space. A significant advantage of 3D printing is the ability to quickly and cost-effectively manufacture low demand parts without the risk of carrying an unsold finished goods inventory. Accuracy, Longetivity, Consistency, Efficiency, Reliability are the five factors that govern the process of 3D Printing enabling the professional to deliver successful treatment to the patient. In dentistry, 3D printing has diverse applicability, from study models to diagnosis to manufacturing the exact replicas of complex geometries from digital data.

Although 3D Printing has become available everywhere, but still the cost of running, materials, maintenance and demand of skilled and knowledged operation is must be carefully evaluated. The wide acceptance of this marvelous technology in the field of dentistry has made it an exceptionally exciting future advancement which clearly eradicates 2D technology and opens the gateway to creativity.

REFERENCES

1. Sonick M, Abrahams J, Faiella RA. A comparison of the accuracy of periapical, panoramic, and computerized tomographic radiographs in locating the mandibular canal jomi on cd-rom (1997 © quintessence pub. Co.) 1994;9:455–60.
2. 3D Printer and 3D Printing News,2015. Available from http://www.3eders.org. [last cited on 2015 Dec 15].
3. Choi JW, Kim N. Clinical application of three-dimensional printing technology in craniofacial plastic surgery. Arch Plast Surg 2015;42:267-77.
4. Statasys direct manufacturing 3d printing materials: choosing the right material. stratasysdirect.com
5. Ramya A, Vanapalli S. 3d printing technologies in various applications. International Journal of Mechanical Engineering and Technology (IJMET) 2016;7:396–409.
6. Van NR. The future of dental devices is digital. Dent Mater. 2012;28:3–12.
7. Liu Q, Leu MC, Schmitt SM. Rapid prototyping in dentistry: technology and application. Int J Adv Manuf Technol 2006;29:317–35.
8. Jain R, Supriya, Bindra S, Gupta K. Recent Trends of 3-D Printing in Dentistry. A review. Annals of Prosthodontics and Restorative Dentistry 2016;2:101-04.
9. Chia HN, Wu BM, Recent advances in 3D printing of biomaterials. Journal of Biological Engineering 2015;9:1-14.
10. Chen J, Zhang Z, Chen X, Zhang C, Zhang G, Xu Z. Design and manufacture of customized dental implants by using reverse engineering and selective laser melting technology. J Prosthet Dent 2014;112:1088-95.
11. Cima M J, Sachs E, Cima LG, Yoo J, Khanuja S, Borland SW et al. Computer derived Microstructures By 3d Printing: Bio-And Structural Materials. Solid Freeform Fabr Symp Proc: Dtic Document 1994. p. 181-90
12. Griffith LG, Wu B, Cima MJ, Powers MJ, Chaignaud B, Vacanti JP. In Vitro Organogenesis Of Liver Tissuea. Ann N Y Acad Sci. 1997;831:382–97.
13. Wu BM, Borland SW, Giordano RA, Cima LG, Sachs EM, Cima MJ. Solid Free-Form Fabrication Of Drug Delivery Devices. J Control Release 1996;40:77–87.
14. Zein I, Hutmacher DW, Tan KC, Teoh SH. Fused deposition modeling of novel scaffold architectures for tissue engineering applications.Biomaterials 2002;23:1169–85.
15. Ebert J, Ozkol E, Zeichner A, Uibel K, Weiss O, Koops U et al. Direct inkjet printing of dental prostheses made of zirconia. J Dent Res 2009;88:673–76.
16. Silva NR, Witek L, Coelho PG, Thompson VP, Rekow ED, Smay J. Additive CAD/CAM process for dental restorations. J Prosthodont 2011;20:93–96.
17. Schuurman W, Khristov V, Pot MW, van Weeren PR, Dhert WJ, Malda J. Bioprinting of hybrid tissue constructs with tailorable mechanical properties. Biofabrication 2011;3(June (2)):021001 [Epub 2011 May 20].
18. Tuncay O. The Invisalign System. New Malden: Quintessence Publishing Co., Ltd, 2006.
19. Invisalign Europe. Invisalign - How does it work? Youtube. 2015. Available online at https://www.youtube.com/watch?v=60bJYGDaqx0&feature=youtu.be (accessed November 2015).
20. Dawood A, Marti Marti B, Sauret-Jackson V, Darwood A. 3D Printing in Dentistry. British Dental Journal 2015;219:521-25.
21. Choi JW, Ra YS, Hong SH, Kim H, Shin HW, Chung IW, et al. Use of distraction osteogenesis to change endocranial morphology in unilateral coronal craniosynostosis patients. Plast Reconstr Surg 126;2010:995-1004.
22. Biron VL, Gross M, Broad R, Seikaly H, Wright ED. Radical Forearm Free Flap With Titanium Mesh Sandwich Reconstruction In Complex Anterior Skull Based Defects. J Craniofac Surg 2012;23:1763-5.
23. Lethaus B, Kessler P , Boeckman R , Poort LJ , Tolba R. Reconstruction Of A Maxillary Defect With A Fibula Graft And Titanium Mesh Using CAD/CAM Techniques. Head Face Med 2010;6:16.
24. Hunt NC, Grover LM. Cell encapsulation using biopolymer gels for regenerative medicine. Biotechnol. Lett. 2010;32:733–42.
25. Sun J, Wang J, Cheng W, Zhang J, Li X, Zhang S et al. Chitosan functionalized ionic liquid as a recyclable biopolymer-supported catalyst for cycloaddition of CO2. Green Chem. 2012;14:654 –60.
26. Spiller KL, Maher SA, Lowman AM. Hydrogels for the repair of articular cartilage defects. Tissue Eng. Part B Re 2011;17:281–299.
27. Li Z, Kawashita M. Current progress in inorganic artificial biomaterials. J. Artif. Organs 2011;14:163–170.