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3-D PRINTING: A WAY AHEAD - REVIEW

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Abstract:

3D printing is a revolutionary concept based on additive process. It offers multifaceted applications for dentistry in general and prosthodontics in particular. A myriad of advantages like reproducibility, accuracy, customisation and ability to create complex parts with ease in less time have provided improved patient treatment options and compliance. This article presents an overview on currently available technologies and their utilisation.

Abbreviations: CAD-computer aided designing, FDM-fused deposition modelling, SLS-selective laser sintering, SLA- standard triangular language, PLA-polylactic acid.

Key words: 3D printing, CAD/CAM, additive manufacturing, bio printing, selective laser sintering, fused deposition modelling.

Introduction

Charles Hull in 1983 printed the first 3D-object using stereolithography.[1] Digital dentistry was pioneered by Francois Duret in 1970, with some initial hiccups it took time to be integrated into current practice.

Last few years have seen strikingly increased application of 3D printing. The desired object/site is scanned using an intraoral (IS) 3D scanner or built using a CAD software. IS consists of a mini camera, integrated software and a computer.

Data is obtained as STF files (standard triangular language)/STL (standard tessalation lan-guage). This information is always broken down and stored as triangles or tessellation. The tessellation is the process of linking the surface with geometric shapes to avoid overlaps and gaps. Stitching the triangular files leads to a process of STL[2]. These STL files store the surface geometry of objects and this information is encoded in ASCII (American Standard Code For Information Interchange) or Binary coding mostly which is used for small sizes[3]. This in-formation is used to print objects in layers through various digital slicing and physically re-produces layers with an automated process[4]. Additive Manufacturing is an additive process referred to as rapid prototyping where a lot of layers are added in contrast to traditional process like subtractive manufacturing[5].

The most widely used additive methods include fused deposition modelling (FDM), Stereo lithography (SLA), Selective laser printing (SLS), Polyjet Printing and Bioprinting[6], Direct metal laser sintering. A variety of materials can be used which include plastics, ceramics, resins and metals

Fused Deposition Modelling:

Developed by Scott Crump 1988, melted material generally thermoplastic polymers such as poly lactic acid (PLA) polycarbonate, polyether ether ketone (PEEK) is extruded through a nozzle to print layer by layer. Print head has multi nozzle and extrudes different types of material at the same time[7]. It is the printer of choice for in-house production of 3D models[8]. It is a flexible method however its use is limited to temporary crown and bridges manufacturing. Limitations include limited colour selection, moderate printing resolution, and complete removal of support material, surface quality and time efficiency.

Selective Laser Printing (SLS) and Stereolithography (SLA):

Both use laser to scan and build object layer by layer but in selective laser sintering powder-based material is used for printing.

SLA uses photo polymerisation - a process by which the UV laser beam causes chain of molecules to link together and form polymers.[9] Products are built with application of UV laser inside a vat of resin.[10]

SLA is used for printing from CT (DICOM data). Advantages include good printing resolution as compared to FDM; support material removal is less too hence less wastage.

SLA is used to print surgical guides, aligners, dental models and crowns, RPD's, fabrication of implant surgical guides.

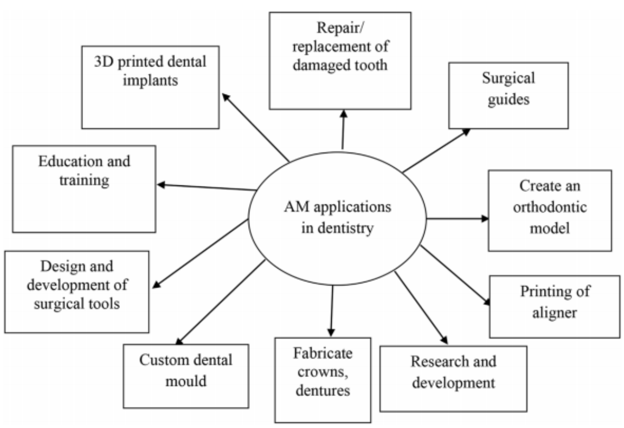

Fig 1: Major additive manufacturing options in Dentistry[10]

SLS prints FDP'S, metal crowns and RPD'S. They can replicate intricate geometries and provide biodegradable scaffold for tissue engineering.

Polyjet Printers:

Printers with highest resolution. 3D model is created one layer at a time by the printer head getting layers of liquid photopolymer acrylic plastic build tray followed by UV light curing[11]. It uses widest choice of printing materials with varieties in density, hardness, flexibility and porosity. Resolution is as fine as 25-80 microns, faster printing and replication of complex geometries.

Disadvantage includes post print model processing such as intensive washing and removal of support material.[12]

Applications include planning patient specific 3D models with complicated geometries, surgical stents and guides, phantoms for orthopaedic and cardiac surgeries, scaffolds for tissue engineering.[13, 14, 15]

Bioprinting:

Uses photo polymerising materials stimulating

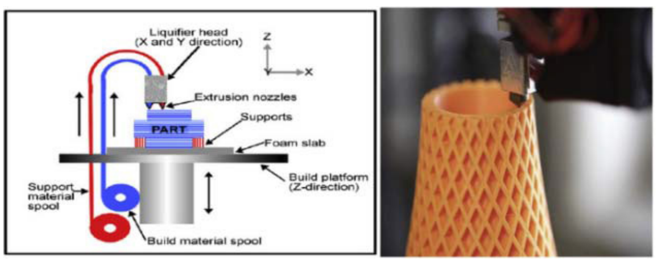

Fig 2: Fused Deposition Modelling[38]

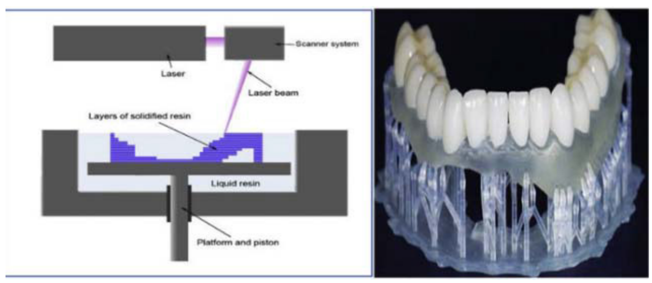

Fig 3: SLA Printing and it's Modes [38]

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natural cells such as chitosan, agar, alginate to print hard and soft tissue scaffolds. Bio printing uses cell ink based bio printers or spheroid or micro tissue based systems have been developed to generate artificial tissues, complex 3D in vitro models.[16,17] With that the additive manufacturing has given a new face to discipline of stem cell therapeutics with the flexibility of printing cells into desired 3D complex, employing it for transplantation and regeneration. 183D printing has found its applications in generating optimal values of human bone and skin grafts in vitro.[19] This has immense potential to replace the current strategies of procuring auto grafts which is associated with donor site morbidity and loss of structure.[20]

Direct Metal Laser Sintering (DMLS):

This technology is used to produce metal parts with high accuracy and better mechanical strength. In this technology metal material is added layer by layer and a laser beam is used to fuse metal at a point.[21,22] This uses titanium, cobalt, aluminium, bronze alloy, steel. Approximate accuracy is 25-35μm.

Laminated Object Manufacturing (LOM):

3D models are fabricated by adding layers of the defined sheet of materials. A laser is used to cut sheet as per the required cross section. Adhesives are used to combine the layers and generated by repeating the steps.[23,24]

Electron Beam Melting (EBM):

Powerful electron beam is used to build product layer by layer by using a metal powder by command of the CAD model with exact geometry. Under a vacuum the raw material is stored and fused by an electron beam.[25, 26] Vacuum eliminates impurities.

Methods

A literature search using search engines such as Google scholar and Pubmed with keywords was done, all articles from 2016 to 2020 printed in English, inclusive of case reports, in vitro studies and systematic reviews were considered.

Discussion

Minev R, Minev E, 2016[27] stated that shrinkage of 3D printed models is an unavoidable problem during the printing process and it affects printing accuracy of most 3D printers. FDM shrinkage occurs due to thermal contraction when melted filaments solidify. In SLA and multijet shrinkage occurs due to polymerisation. *Hambali RH, Cheong KM, Azizan N, 2017*[28] concluded that FDM has bad surface quality due to staircase effect of manufacturing using material extruding through a nozzle. This was improved by approximately 97.2% via immersion in acetone solution for 300 seconds. This chemical treatment is one of the most economical and fast methods to enhance surface

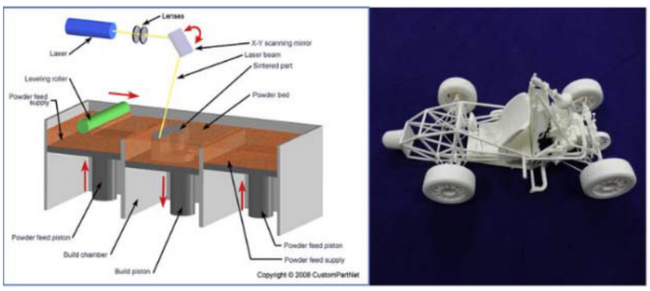

Fig 4: Stereolithographic Printing

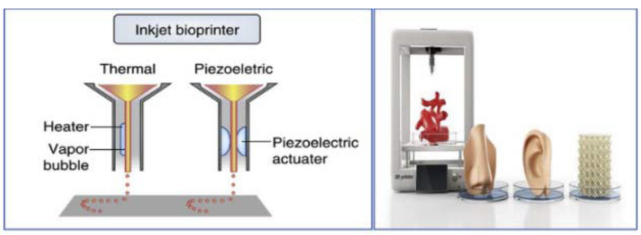

Fig 5: Inkjet Bioprinting and Modes

quality of additive manufacturing parts for future manufacturing industry. *Raymond E Rebong et al 2018*[29] assessed the dimensional accuracy of 3D models with each other and compared with traditional plaster casts. They concluded amongst FDM, SLA, and Polyjet printing, the FDM had fewest dimensional measurement differences as compared to plaster mode.

Daniel Khorsandi et al 2018 [30]

Compared SLA and FDM methods of rapid prototyping. They stated that SLA offers greater efficiency, high level of accuracy. Layer thickness of two different techniques FDM 0.5-0.127mm as compared to SLA 0.05-0. 015mm. Both however make rough patterns that need to be polished to limit bacterial retention. *Ucar et al,* 2018[31] published an in vitro study to show that the ceramics manufactured by stereolithography show comparable mechanical properties to milled ceramics. However, manufacturing process and strength, fracture toughness are areas that require further research. To improve the properties of ceramics so produced, porosity should be eradicated resulting in denser more compact mixture. *Kim et al, 2018*[32] proposed a new digital prosthesis using an FDM printer to make a flask for making a complete denture. This took 7 hours to complete and showed satisfactory results in terms of completeness of complete denture. Using a universal development system software, denture design STL and a denture flask STL were superimposed, and the denture region was set as an empty space. Conventional artificial teeth were inserted into the 3D manufactured flask, resin packing, finishing and polishing was done using conventional method of fabrication of complete denture. Fusong Yuan, Yao Sun, Lei Zhang, 2019[33] implant guide CAD and FDM 3D printing were used to achieve a chair- side high efficiency design for production of implant guides. Visual inspection revealed that the positioning of 30 implant guides was successful and retention was satisfactory. A comparison of 3D data of printed implant guide and CAD guide demonstrated a morphological error of 0.5999 plus minus 0.146. Making FDM and CAD time saving, efficient chair side methods. *Lee D et al, 2020*[34] stated digital light processing 3D printers (DLP) produce shrinkage depending on the material and polymerisation method. Owing to material characteristics the FDM accuracy of full arch dental models is supposed to be higher than that of the DLP however due to surface roughness of the FDM method the crown preparation die for dental prosthesis is not accurate. Therefore, a new hybrid dental model that combines the FDM for full arch and DLP for specific die is proposed.

Table 1: 3D Printers, Materials Used and Applications

3 D Printer	Materials	Potential Applications
FDM	PLA PEEK ABS PC	In house production of basic proof of concept models, low cost prototyping of simple parts
SLA	Photo polymerising ceramic filled resins	Dental models surgical guides splints. Orthodontic aligners castable crowns and bridges
SLS	Powder such as alumide, polyamide, glass particle filled polyamide, rubber like polyurethane etc.	Hospital set up for metal crowns, copings , bridges, metal or resin partial frame work
Polyjet Printing	A variety of photopolymers	Hospital set up manufacturing of cranio maxillary implants, sophisticated anatomical models, drilling and cutting guides, facial prosthesis (eyes, nose, ear)
Bioprinter	Cell loaded gel and bio inks based on collagen, photopolymer resin, agar, alginate, chitosan, hyalurouan etc	Cell laden scaffolds of hard and soft tissue printing (bones - hemimandibulectomy)

Yoshiki Ishida et al, 2020[35] Compared the accuracy of cylindrical patterns fabricated with consumer FDM 3D printers with consumer SLA 3D Printers. After the patency of FDM device expired, several types of small consumer 3D printers were introduced for personal use. The accuracy of these less priced printers was compared with dental FDM 3D and SLA 3D printers. The consumer printers had worse accuracy than dental printers.

An enlargement adjustment of 1-3% along the horizontal axis was necessary to realise the set design. In terms of surface roughness consumer SLA produced smooth patterns. Hence, they concluded that consumer printers have potential to be used in dental applications.

Not only for manufacturing 3D has led to an exemplary shift in training by providing idealistic plastic typodonts to more real-life 3D printed models that are based on data obtained by intraoral scan of patients[36]. Polyjet printing has successfully been used to create models in different levels of hardness, replicating that of healthy enamel, dentin and caries so that the trainee experience proprioception of working on real tooth[37]. 3D manufacturing undoubtedly offers a promising future due to its multiple applications and accurate detail reproduction however at the same time it involves high investment cost. One of its largest limitation is the quality. Due to the way successive layers are deposited on top of each other an inherent weakness is literally build into the design. Finishing of final product is time consuming and requires skill. Depending on the material it may need additional treatment to reach full strength. For example, zirconia blocks used require further sintering to reach high strength. SLA can be done only by using photopolymerising resins. These are messy and can cause inflammation and irritation on inhalation. Also, resins cannot be heat sterilised.

Conclusion

3D printing has the potential of revolutionising dentistry in general and Prosthodontics in particular. Although the initial investment is high and it requires training in usage, it helps to re-duce the time for actual patient care. In today's scenario of emerging infective pandemics minimal exposure to the clinician, technician and patient can be offered. It can allow patient care from any part of the world by exchange of information. It has a great potential in research and treatment modalities. Because the print object is produced according to the image of the patient, the print can be tailored to optimally fit the condition of the patient. The problem that requires further research is the limitation of available material assortment in particular when moving beyond the canonical polymers as well as improvement of printing speed and post processing requires.

Although it is not a replacement for conventional treatment methods but its scope to improve and develop is what the future of dentistry holds.

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