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Research Article

3 D PRINTING-A NEW REVOLUTION IN PERIODONTAL REGENERATION?

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3D printing is an emerging technology in the field of Periodontics. It have several advantages over the conventional methods. Its role in periodontal regeneration, implant placement and education purpose is evident. This review article aims to give a glimpse of 3D printing in the field of periodontics

INTRODUCTION

Digital revolution that is transforming the whole world is showing its impact on dentistry also. Three-dimensional (3D) printing also known as additive manufacturing or solid freeform fabrication or rapid prototyping is one such technology that allows the production of an individualized 3D object based on a material of choice and have specific computer-aided design. Previously, subtractive manufacturing or milling was used to build objects with precision, but it was time-consuming, resulted in wastage of material and have limited application in complex anatomy. 3 D Printing was developed to overcome these drawbacks.

The term 3D printing describes a manufacturing approach that builds objects one layer at a time, adding multiple layers to form an object.[4]It uses the information from computer-aided design (CAD) software, that measures thousands of cross sections to build the exact replica of each product. A variety of printable biomaterials are now available that offers more precise control of scaffold inner architecture and outer shape that can be customized for each patient. 3D printing process begins with a design of a 3D model, created by a CAD software. The model is then converted into cross-sectional slices and sent to the 3D printer, which deposits layer after layer of the chosen material to produce an object.[5]

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Among dental specialties the evidence showed that 3D printing was mainly focused on applications in Oral Surgery, Prosthodontics and Orthodontics. Now it finds its application in Periodontics also.[6]

History of 3D Printing Relevant In the field of Medicine[3]

A 3dimensional object was printed first time by Charles Hull in the year 1983.Hull invented 3D printing which he named "stereo lithography". Stereo lithography interprets the data in a CAD file by using the file in STL format.

Types of 3D Printing[7]

Direct 3D Printing

This technique can arrange multiple cell types at the same time, deposit extra cellular matrix, and provide fine-tuned control over the deposition of bioactive molecules. The 3D printer uses a powder or liquid resin that is slowly built from an image on a layer-by-layer basis. The 3D machine administer a thin layer of liquid resin and it uses a computer controlled ultraviolet laser to harden each layer in the specified cross-section pattern. At the end, excess soft resin is cleaned away by a chemical bath.

Indirect 3D Printing

Here a mold is printed first and then it is casted with final polymer. Information from the CT scan is used for making the 3D mold template of the patient. This mold is then utilized for making a scaffold for periodontal regeneration.

Year	Key Developments
1984	Invention of stereolithography (SLA) 3D printing (Charles Hull)
1986	Invention of the selective laser sintering (SLS) process (Carl Deckard)
1988	Bioprinting by 2D micro-positioning of cells and the first commercial SLA 3D printer (Charles Hull)
1989	Patenting of a fused deposition modelling (Lisa and Scott Crump)
1999	First 3D-printed organ—a bladder—used for transplantation (Wake Forest Institute for Regenerative Medicine)
2000	EnvisionTEC launched the first commercial extrusion-based bioprinter, the 3D-Bioplotter
2002	First early stage kidney prototype bioprinted via microextrusion (Wake Forest Institute for Regenerative Medicine)
2003	First inkjet bioprinter (modified HP standard inkjet printer)
2005	Founding of RepRap, an open source initiative to build a 3D printer that can print most of its own components
2007	Selective laser sintering printer becomes available, for 3D parts fabrication from fused metal/plastic
2008	First 3D-printed prosthetic leg
2009	First 3D-printed blood vessels (Organovo)
2012	First 3D-printed jaw
2014	First 3D-printed human liver tissue (Organovo), and first desk-top bioprinter (Allevi)
2015	First implanted 3D-printed bioresorbable scaffold for periodontal repair (University of Michigan)
2018	First commercial 3D-printed full human tissue (skin) model Poieskin (Poietis)
2019	First 3D-printed heart that contracts, with blood vessels (University of Tel Aviv) and 3D-printed lung air-sac with surrounding blood vessels (Volumetric)
2020	3D printer for personalized medicine M3DIMAKER (FabRx)

(Adapted from Global Data, "The history of 3D printing", Carlos Gonzales) ASME,

Fused Deposition Modeling

This technique is used for printing thermoplastic material mainly poly-e-caprolactone (PCL) and poly lactic-co-glycolic acid (PLGA). This technique creates scaffolds with high mechanical strength, high porosity, and controlled morphology. But living cells or temperature-sensitive biological molecules cannot be incorporated.

Hydrogel Scaffolds

Hydrogels can be used to make soft tissue scaffolds, with direct incorporation of cells while retaining their normal activity. This is known as 3D plotting. An important limitation of hydrogel scaffold is the inhibition of cell-to-cell interactions, that will affect the cell signalling.

3D Printing With Live Cells

3D printing of live cells, either as cell aggregates or seeded onto 3D printed scaffolds may enhance cell signalling and promote tissue formation. Mini-tissue-based approach is a technique in which tissue spheroids fuses to form a tissue and the vascularity to these newly formed tissues are provided by the self-assembled vascular spheroids.

DIFFERENT TECHNOLOGIES OF 3D PRINTERS

The American Section of the International Association for Testing Materials (ASTM) has named seven additive manufacturing categories: binder jetting, direct energy deposition, material extrusion, material jetting, powder bed fusion, vat photopolymerization and sheet lamination.

In the biomedical field, mostly employed printing methods comprises of acellular techniques that include stereo lithography (SLA), powder-fusion printing (PFP), solid freeform fabrication (SFF), Direct Light Processing (DLP), Selective Laser Sintering (SLS)/Direct Metal Laser Sintering (DMLS) and techniques including cells: inkjet-based, extrusion-based, and laser-assisted bioprinting (LAB)

***Stereolithography (SLA) Technique**:* - It is one of the first techniques to be commercialized. This is based on beaming a laser or a light source onto a photosensitive polymer to harden its surface. It was used to print biodegradable polymers, ceramic acrylate or hydroxyapatite for bone reconstruction.[9,10]

***Direct Light Processing (DLP) Technique*: -** It is an optical technique which uses a light projector operating at UV wavelengths to project volumetric pixel data into a photopolymer, which causes the resin to cure and solidify. It is used for fabrication of zirconia implants.[9,10]

Selective Laser Sintering (SLS)/Direct Metal Laser Sintering (DMLS): - This technique uses powder fusion printing (PFP) technique. Here metal granules, resin or plastic are beamed with a laser to fuse in a layer-after-layer fashion. This technique is used to produce scaffolds for bone regeneration with materials like tricalcium phosphate and hydroxyapatite. The advantage of PFP techniques is the possibility to print melting metals such as magnesium, cobalt or titanium, employed in medicine and dentistry.[9,10]

Solid freeform fabrication (SFF): - This technique allows deposition of strands by a nozzle via a precise XYZ axes positioning system. Upon extrusion the material should maintain its shape.[9.10]

Techniques including cells: -The 3D printing technology that includes cells has been named bioprinting and the hydrogels in which cells reside for the printing purpose, have been named bionics. Hydrogels have modifiable chemical composition, and adjustable mechanical and biodegradation properties. The main advantage of bioprinting is the possibility to use diverse materials and cell types in different combinations.
Laser-assisted bioprinting (LAB involves a laser pulse that produces local heating of a cell-containing solution causing dropping of cells in an orderly manner on the other side of a platform or substrate. In *inkjet bioprinting*, a defined volume of fluid, with or without cells, is jetted onto a platform to obtain a precise pattern. The major advantage is the speed achieved in building the complex cell-laden tissue and different cell types and biomaterials can be used. The major disadvantage is that cells or bioactive molecules must be in a liquid state to allow deposition, and subsequently solidify into the required structure.[9,10]

Biomaterials Used In 3D Printing[5]

Choice of biomaterials influence the properties of scaffolds. Hence proper selection of biomaterials is required for specific application.

1. ***Biodegradable Natural Polymers***: - Includes proteins and polysaccharides, they are the first group of biomaterials used in clinical practise. They have high biocompatibility, good cell recognition, enhanced cellular interactions in the surrounding environment and they are the commonly used ones. But they lack bioactivity which is required for hard tissue regeneration and also weak in mechanical strength. To overcome this, natural polymers are generally combined with bioactive materials.
2. ***Biodegradable Synthetic Polymers***: -They can be produced in large quantities with long shelf life and also because of their low cost, makes them preferred over natural polymers. Polycaprolactone (PCL), polylactic acid (PLA), polyglycolic acid (PGA), and their copolymer poly (lactic-co-glycolic) acid (PLGA) are the commonly employed ones.
3. ***Bio ceramics:-*** They are inorganic biomaterials that include calcium phosphate bio ceramicslike hydroxyapatite (HAp), tricalcium phosphate (α-TCP and β-TCP), and biphasic calcium phosphate (BCP).They are gaining attention because of their unlimited availability, bioactivity, biocompatibility, hydrophilicity, similarity to native bone inorganic components, osteoconductivity and osteoinductivity. But they are extremely brittle and also their low flexibility and mold ability will make them difficult to be shape into different structures.
4. ***Metals***: -They have excellent mechanical properties like high strength, toughness, and hardness, making them appropriate in load bearing areas. Among metals titanium and its alloys are encouraged due to their high biocompatibility, adequate mechanical properties and elasticity.

APPLICATIONS OF 3D PRINTING IN PERIODONTICS

Applications in Periodontics include bio-resorbable scaffold for periodontal repair and regeneration, socket preservation, bone and sinus augmentations procedures, guided implant placement, and education purposes.[11]

Three-dimensional printed bioresorbable scaffold for bone and soft tissue regeneration

For many years an optimal material was in search for periodontal regeneration. For a predictable periodontal regeneration to occur, hierarchical tissue formation with appropriate interfacial connection is required with sufficient strength and mechanical integrity. With this regard 3D scaffolding has been investigated. This multiphasic scaffold consists of both hard (bone and cementum) and soft tissue (gingiva and periodontal ligament) component of periodontium. Polycaprolactone has been widely used as a scaffold material due to its documented successful outcomes in bony regeneration. The advantages of these 3D scaffolds is that they closely resemble extracellular matrix resulting in better regenerative capabilities.[12]

Park *et al*. developed a biphasic PCL-PGA scaffold fabricated via computer-aided manufacturing. His scaffold consisted of periodontal ligament-specific and bone-specific compartments facilitating the formation of human tooth dentin-ligament-bone complexes. 3D wax-printing systems facilitated the manufacturing of molds, which were used in the fabrication of the hybrid scaffold. To make them to form a single scaffold structure, both compartments were fused with a thin PCL layer. [13]

Rasperini *et al*. was the first to report the use of 3D-printed scaffold in human periodontal defect. The results of this case report showed favourable results up to 12 months but failed afterward.[14] Lei *et al*. reported a 15-month follow-up case of guided tissue regeneration using 3D-printed scaffold and platelet-rich fibrin in the management of bony defect around maxillary lateral incisor. He reported significant reduction in pocket depth and bony fill.[15]

Another approach of periodontal regeneration is using the cell sheet technology. Vaquette *et al*. described a biphasic scaffold combined with cell sheet technology to regenerate alveolar bone and periodontal ligament simultaneously.[16] Lee *et al*. developed a triphasic scaffold, that consisted of separate compartment for cementum or dentin interface, periodontal ligament, and alveolar bone. The main disadvantage of this approach is that stiffness of the PCL scaffold, which impedes adaptability to the complex 3D anatomy of different periodontal defects.[17]

Socket preservation

Extraction of tooth leads to loss of width and height of alveolar ridge caused by the natural process of bone resorption. 3D-printed scaffold has been tried to preserve socket and maintain the dimension of the extraction socket. Park *et al*. reported a study on beagle dogs and found predictable outcome with the use of 3D-printed polycaprolactone in socket preservation.[18] A randomized controlled clinical trial by Goh *et al*. reported the use of 3D-printed bioresorbable scaffold in socket preservation and reported normal bone healing and significantly better alveolar ridge preservation when compared to extraction socket without scaffold after 6 months.[19]

Sinus and bone augmentation

Loss of vertical bone height is a common sequel after tooth extraction. Maxillary sinus position also limits the available bone height.Studies have shown positive outcome with 3D printing technology. Tamimi *et al* conducted a study with 3D-printed monolithic monetite blocks on New Zealand rabbits and reported new bone formation.[20]

Implant Placement

Implant placement can have various complications like poor esthetics, damage to anatomically important structures, infections, and implant failure. Guided implant placement can prevent these complications by fabrication of surgical guides with the help of 3D printing. It helps in accurate 3D placement of implant thus preventing unwanted damage to anatomic structures and reduce time. Studies report that using 3D-surgical guide, precise implant placement is possible in completely and partially edentulous patients even using flapless approach and it reduces chairside surgical time, and improves patient comfort post surgery and also allows simultaneous implant placement in complex cases.[11]

Educational Purposes

3D printing is emerging as a tool for education and training in dentistry. It can be employed to train students and practitioners for performing various surgical procedures including implants. The cadavers and skeletons that were used as study models before is now getting replaced by 3D models. Not only for educational purposes, this model can be used for patient education also. It improves the patient understanding of the procedure and also reduces anxiety. [6,11,21]

Advantages of 3D Printing

Conventional bone graft materials like autograft, allograft, xenograft and alloplast have several disadvantages. They are brittle, poorly processable into porous forms, and are unable to generate structures tailored to the specific needs of patients. Their mechanical strength to withstand forces are also less. Even though autografts may have the ability to withstand mechanical forces, they are difficult to shape and conform to a bony defect. 3D scaffold closely mimics native extracellular matrix. It enhances cell adhesion, proliferation, differentiation, and overall tissue regeneration. [5]Most important is that it can be customised for each patient. Thus the advantages of 3D printing include ability to replicate the bony architecture, less wastage of the material, no ethical concerns, ample availability due to alloplastic material, less risk of infection transfer, and less chair side time of surgery.[11]In this way it is able to overcome the limitations of conventional bone grafting procedures'. Possibility of including the living cells have also lifted the 3D printing to next level. Its role in patient education as well as training for both postgraduate and undergraduate students is also an outstanding feature.

CONCLUSION

With all these advantages, it can be concluded that 3D printing is a paradigm shift in the field of periodontics and other parts of dentistry. For utilizing its benefits, more long-term randomized control trial should be undertaken with this technology.

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