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3D Printing in Periodontics: A Review

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Abstract:-Three Dimensional printing is an emerging technology in the field of dentistry. Threedimensional (3D) printing technologies are advanced manufacturing technologies based on computer-aided design digital models to create personalized 3D objectsautomatically. In periodontology various applications of this technology have been reported in including 3D-printed scaffold for socket preservation, periodontal repair and regeneration, and sinus and bone augmentation, peri-implant maintenance, and implant education.This article reviews briefly about 3D printing and its applications in periodontics and implantology.

Keywords:-*3D PRINTING,3D PRINTED SCAFFOLDS,RIDGE AUGMENTATION,SOCKET PRESERVATION,IMPLANT SURGICAL GUIDES.*

I. INTRODUCTION

Tissue engineering is an emerging field in dentistry that aims to develop biological substitutes of native human tissues or organs for in vitro drug screening to decrease the use of animals and increase the reliability of testing results or for in vivo transplantation to mitigate the organ storage and transplantation need. It requires an understanding of the biological process required for cellular proliferation and differentiation[1]By fusing cells and bioactive substances with a biomaterial framework, tissue engineers hope to mimic the body's capacity to repair injured tissue. Typically, in this approach, a biomaterial scaffold is combined with cells and bioactive components to create an implanted construct that can either replace or restore physiological function. The ideal scenario is for the scaffold to be resorbed as the neo tissue develops, producing a viable tissue replacement after the tissue remodelling is finished.[2]

In general, 3D printing is defined as a manufacturing process that produces an object by adding layers one at a time, resulting in the formation of an object based on a specific digital design used as a blueprint.It is also known as rapid prototyping or manufacturing. 3D printing is an emerging and a promising technology which is implemented and used in wide variety of fields includingaerospace,defence,art,medicine,dentistry etc., which allows the individual to personalise designs and fabrication of material.[3]This strategy typically involves the combination of cells and bioactive factors with a biomaterial scaffold to form an implantable construct that can replace or restore physiological function. Ideally the scaffold will be resorbed as the neotissue is formed resulting in a functional tissue replacement after remodelling of tissue is complete[4]

In periodontology,thecomplex hierarchial organization of periodontal tissues requires multiphasic biomaterial constructs that can recaptulaize the structured integrity of the bone, ligament surface. Additive biomanufacturing technologies have been applied into thefeild of periodontal regeneration to develop hierarchial scaffolds,mimicking the properties and architectural configuration of the periodontium ,which consists of both soft (gingiva & periodontal ligament) and hard (cementum & bone) tissues.3D printing also has wide applications in placememt and treatment planning of implant surgery.This article reviews on the brief about 3d printing and its applications in periodontics and implantogy.

II. PIONEER WORK IN 3D PRINTING

Hideo Kodama of Nayoga Municipal Industrial Research Institute has printed the primary solid object from a digital design. However, father for 3D printer considered to Charles Hull, an American engineer designed it in 1984. He was a pioneer of the solid imaging process referred to as stereolithography and stereolithographic (SLA) file format and is generally used format in 3D printing. In 1990, the plastic extrusion technology was invented by Stratasys and named it as fused deposition modelling (FDM).[5]An additional technology, known as "3-Dimensional Printing Techniques," which is comparable to the inkjet technology used in 2D printers, was patented by Massachusetts Institute of Technology (MIT) in 1993. Three significant products were released in 1996: "Genisys" from Stratasys, "Actua 2100" from 3D Systems, and "Z402" from Z Corporation. Spectrum Z510, a ground-breaking product introduced by Z Corp. in 2005, was the first high definition colour 3D printer on the market[5].

III. GENERAL PRINCIPLES OF 3-DIMENSIONAL PRINTING

It basically works on three principles:

- Modelling: The collected data of an object is transferred into computer software for analysis and it makes the final version of the replica of an object. Therefore, the collection of data till expression of computer design is termed as Modelling.
- Printing: Modelling format is converted to G-code file format or Surface Tessellation Language (STL) file that replica of an object into thin layers by layers. The G-code/STL instructions are followed by the printer to laydown successive layers of material in order to build a 3D replica. This system reduces the time of manufacturing from days to few hours depending upon the software being used.
- Finishing: In this step, there is finishing of the printed model. After the printing, the model produced will be

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oversized or is some cases surface roughness may be present. Therefore, the layer-by-layer extra material has to be removed for an accurate fitting[5]

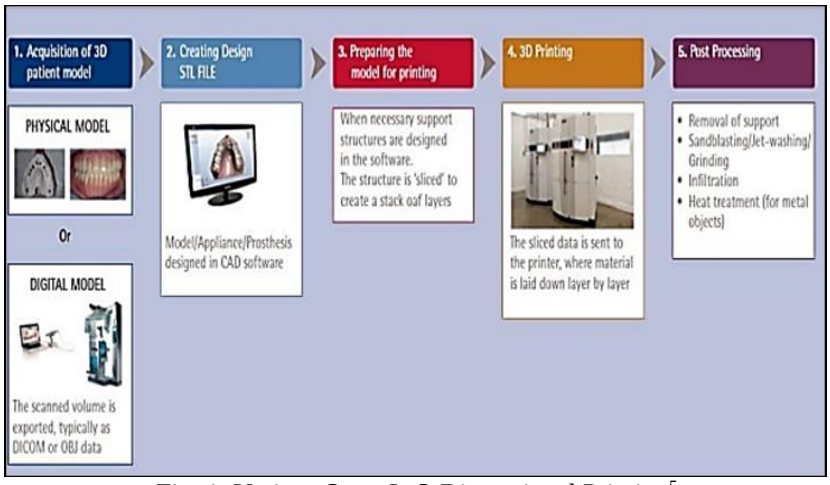

Fig. 1: Various Steps In 3-Dimensional Printing[5]

A. DIRECT 3-DIMENSIONAL PRINTING

Various cells (Living cell peptides), extracellular matrix(proteins, and DNA plasmids) and bioactive moleculedeposition can be done with fine-tuned control with thismethod. The printing of 3D scaffolds with extra cellularmatrix and cells have been done by direct 3D printingtechnology.[6]

B. INDIRECT 3-DIMENSIONAL PRINTING

It involves the printing of a mold (cast) in the form of replicawith the final polymer. The scaffold for gene therapy anda growth factor delivery system are usually formed withthis technique. In this printing, a computed tomography(CT) scan of the patient's defect acts as a template formaking the 3D replica. Park et al. in 2012, 2014 designeda 3D wax replica for periodontal regeneration to produce afibre-guiding scaffold which improves the combination ofPDL fibres into bone and cementum. Alveolar ridgearchitecture can be conserved by placing an indirect 3Dprintedscaffold in post-extraction sockets which results innormal bone healing and better maintenance of the alveolarridge as compared with extraction sockets without scaffolds.[5]

C. VARIOUS TECHNIQUES IN INCLUDE:

STEREOLITHOGRAPHY(SLA)
SELECTIVE LASER SINTERING(SLS)
FUSED DEPOSITING MODELING (FDM)
DIRECT LIGHT PROCESSING(DLP)
BIOPLOTTER PRINTING
INKJET POWER PRINTING

D. MATERIAL USED IN 3-DIMENSIONAL PRINTING

Three types of material are most primarily used in 3-dimensional printing. These are polymers. The use of material depends upon the type of object to be printed. Metals and ceramics are utilized in applications which require the implant to be inert, polymers are utilized in applications in which the substance is needed to degrade for ease and increase the growth of a tissue. Composite implants comprising combination of substances are utilized in applications in which single substance might not serve the desired functionality.

Acrylonirile butadiene styrene (abs) and polylactic acid (pla) are commonly materials used in printing. The latest 3d bio-printer makes primarily use of cellbased ink or micro-tissue-based ink system with a purpose to generate synthetic tissue in in-vitro models or replica for regenerative medicine. Other substances which migh be used for periodontal use are: hydrogels (methacrylate gelatin, polycaprolactone), ceramics (hydroxyapatite, betatricalcium phosphate), composites (poly-ceramics plus cell ink) and metals (titanium and alloys).[5]

E. ADVANTAGES AND DISADVANTAGES OF 3D PRINTING

a) ADVANTAGES OF 3D PRINTING

- Time saving
- Accurate details and scan reproduction that produce high-quality work and reliable results
- It is feasible to print intricate geometric forms and interlocking components that don't need to be assembled.
- Reduction of production-related material loss
- Single items can be produced in small quantities for quick delivery.

b) DISADVANTAGES OF 3D PRINTING

- Cost and availability material
- Requires individual training
- Finishing of final product is time consuming and requires skill
- Likely the largest limitation of 3D printing is the final part quality. Due to the way each successive layer is deposited on top of the last in typical 3D printing methods, an inherent weakness is literally built into the design.
- Depending on the material, it may still need additional treatment to reach full strength.[7]

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Fig. 2: SCAFFOLDS

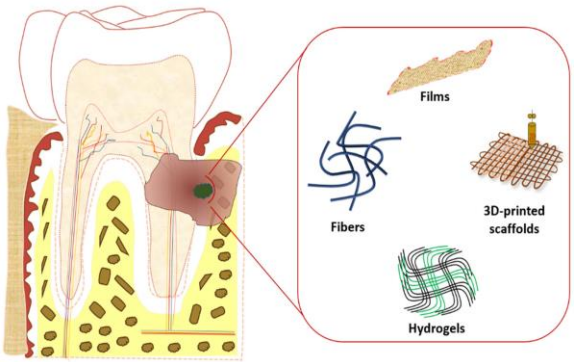
F. APPLICATIONS OF 3D PRINTING IN PERIODONTICS:

a) SCAFFOLDS:

The basic concept of periodontal tissue engineering is to combine a scaffold with living cells and/or biologically active molecules to form a "Tissue Engineered Construct" (TEC). This scaffold, with an adequate blood supply, will promote tissue regeneration. To date, most approaches to periodontal tissue engineering have focused on the use of stem cells to promote a new periodontal attachment. Periodontal ligament stem cells, as well as mesenchymal stem cells, have been used with promising results . Stem cells often need a vector like a scaffold, which will then be implanted in the periodontal defect.These scaffolds can have one or several compartments and be used alone or in combination with bioactive molecules, medicines, and gene therapy and/or cell delivery.

Recent advancement in the field of tissue engineering has led to the development of "3D printed" scaffolds. These multiphasic scaffolds consisting of both hard (bone and cementum) and soft tissues (gingiva and PDL) components of the periodontium, are not only specific for the particular tissue but are also competent mechanically. With the increasing demand for tissue regeneration, these scaffolds have been investigated in different periodontal procedures such as socket preservation, guided tissue and bone regeneration, sinus, and vertical bone augmentation.

Literature search revealed that most of the studies done were preclinical, in vivo, in vitro and case reports describing promising results in the field of periodontal regeneration. Rasperini et al. first time reported the use of 3D-printed scaffold in human periodontal defect (labial soft and hard tissue dehiscence). The results of this case report showed favorable results up to 12 months but failed afterward.[8] Lei et al. also 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[9]



b) MONOPHASIC SCAFFOLDS

The first scaffolds to be designed have only one compartment. They meet the requirements of guided tissue regeneration: wound stabilization, selective cell repopulation, while allowing spatio-temporal control of the periodontal healing process. They can be loaded with cells or growth factors to enhance and promote bone and/or ligament formation.

- SIMPLE MONOPHASIC SCAFFOLDS

The Osteoflux, developed by Carrel et al[10] is a block of laminated strands of biphasic ceramic (α-TCP + HA) printed in 3D by extrusion. It is composed of orthogonal layers of cylindrical filaments. This scaffold was implanted in sheep calvaria and compared to bovine bone (Bio-oss) and β-TCP particles to assess vertical bone regeneration

The use of 3D printed blocks allows both horizontal and vertical augmentation.One of the advantages of 3D blocks is their structure of linear pores controllable in size and permeability over the entire length of the block. Such a structural organization can promote the progression of the mineralization front with its vascular system. Indeed, 3D printing techniques by extrusion allow to the creation of a controlled and reproducible architecture with 60% of total porosity, channels of 250 µm in diameter with an inter pore distance between 150 and 500 µm thus promoting osteoconduction. The authors were thus able to observe a significant increase in bone growth during the first two months; then at 4 months, there was no significant difference between the materials.

Another type of monophasic scaffold was manufactured by extrusion, by Mangano et al[1]. It was composed by 30% HA, 60% β-TCP and 10% α-TCP. It has a characteristic mesh-like structure with rod diameters of 300 ± 30 µm, and pore sizes between the rods of about 370 ± 25 µm. Its macroporosity is 60%. This scaffold was implanted in a sheep sinus. At 45 days, the authors observed good immuno-tolerance of the scaffold, as well as complete tissue integration, and bone remodeling located at the periphery. At 90 days, they observed the formation of a mineralized lamellar bone at the periphery. In the center, a highly vascularized fibrous tissue formed, showing some fibroblasts and a large vascular network comprising capillaries and large vessels with great structural organization. Beyond 90 days, the scaffold continued its gradual resorption. However, it was not entirely replaced by the newly formed bone tissue (formation of fibrous tissue in certain areas).

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- SINGLE-PHASE SCAFFOLD FOR CELL DELIVERY

This technique increases the healing potential by seeding different cell types in the structure. This approach is well documented in the literature. The cells are encapsulated in hydrogels or seeded directly in the scaffolds, which are then implanted in bone defects. Thus, in addition to their role of space maintainer, TECs allow the diffusion of cells in the periodontal defect. While the concept may seem relatively simple, its implementation has led to variable results depending on the biomaterials and the types of cells used.

Baba et al.[12] created by electrospinning a poly-L-lactic acid mesh associated with Bone Marrow-derived Mesenchymal Stem Cells with PRP. In a phase 1 and 2 clinical trial, these scaffolds were implanted in human periodontal defects. They were able to observe a gain in clinical attachment, bone growth and a reduction in pocket depth.

Dan et al.[13]manufactured by electrospinning a CaP-coated PCL scaffold associated with a PCL cell sheet obtained from culture of gum marginal cells, periodontal ligament cells and alveolar bone cells. This scaffold was implanted in rat periodontal defects created surgically.Bone and ligament growth were observed. All three cell types have shown potential for mineralization. In vivo, only alveolar bone cells and periodontal ligament cells were able to obtain periodontal ligament formation after 4 weeks.

- MONOPHASIC SCAFFOLDS FOR THE RELEASE OF GROWTH FACTORS

For the delivery of growth factors, synthetic polymers are used with a delayed degradation profile and improved mechanical properties. The direct incorporation of biological elements into the structure of the scaffold is complicated by the high temperature manufacturing process as well as the use of strong organic solvents resulting in the denaturation of these biological elements. The development of microspheres as vectors has made it possible to overcome these limitations and are now widely used in tissue engineering and in particular in periodontal regeneration.

The studies discussed below have focused on the association of growth factors with 3D printed scaffolds Cho et al.[14] designed a PCL scaffold printed by extrusion, loaded with PLGA microspheres containing BMP-2, BMP-7 and connective tissue growth factor. This scaffold was implanted in vitro on the root surface of human teeth. The incorporation of the microspheres in the TEC radically modifies the release profile of the encapsulated molecules which then reaches a release of 50% after 42 days. Only BMP-7 induces the formation of a cementoid tissue deposit. However, the delayed release of growth factors induces cementogenesis in a later phase which could compromise the insertion of periodontal ligament fibers on the root surface.

Kim et al.[15] designed a scaffold of PCL + HA printed by extrusion, associated with a mixture of SDF1 and BMP-7. It is a scaffold in the form of a rat molar and a rat incisor with interconnecting micro channels of 200 µm in diameter infused in a mixture of SFD1 and BMP7 (100 ng/mL each) associated with a type 1 collagen solution. At 9 weeks, regeneration of the periodontal ligament is observed as well as a new bone formation at the level of the interface with the scaffold in the form of a rat incisor. The use of SDF1 (stromal cell-derived factor 1) and BMP7 made it possible to significantly recruit more endogenous cells, such as mesenchymal and endothelial stem cells, and to increase angiogenesis compared to the control scaffold without growth factor.

Indeed, SDF1 and BMP7 makes it possible to recruit several cell lines. SDF1 has a chemotactic effect on stem cells from bone marrow and endothelial cells, all of which are necessary for angiogenesis. SDF1 binds with chemokine CXCR4, a receptor for these two cell types. BMP7 plays a major role in osteoblastic differentiation, and thus in the mineralization of the alveolar bone. This study once again highlights the value of cell recruitment. This technique would allow easier implementation in clinical practice than cell seeding. In addition, this type of technique has a much lower financial cost.

In the periodontium, the regeneration of the alveolar bone is associated with the regeneration of two other important structures that are the periodontal ligament and the cementum. Thus, in order to have a multi-tissue regeneration, the original concept of the monophasic scaffold has evolved into a polyphasic scaffold. The spatial structure is different in that it has architectural and chemical properties which are closest to the organization of the original tissues[16]. It is therefore necessary to “compartmentalize” in order to produce the spatio–temporal kinetics necessary for the regeneration of the periodontium; alveolar bone on the one hand, and the functional orientation of the periodontal fibers on the other.

c) BIPHASIC SCAFFOLDS

Park et al.[17] designed a scaffold with two compartments: a bone compartment and a ligament compartment. The compartments were not directly 3D printed. Wax molds were made by extrusion, and the materials were then casted into these molds. The bone compartment was seeded with periodontal ligament cells transduced by Ad-CMV-BMP7. The

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structure of the ligament compartment is interesting. It is composed of three superimposed cylinders and is seeded with periodontal ligament cells. This biphasic scaffold was implanted in mice periodontal defects surgically created. This scaffold with controlled architecture allowed a biomimetic multi-tissue compartmentalized formation. Periodontal fibers are formed with an angular orientation to the cementum layer, thus approaching the organization of the native ligament. However, it turns out that the control of cellular directionality in vivo remains unpredictable.

Vaquette et al[18]. designed a scaffold with both a bone compartment and a ligament compartment. The bone compartment is manufactured by FDM in β-TCP/PC and it is seeded with osteoblasts. The periodontal ligament compartment is a cell sheet produced by electrospinning. This scaffold is implanted subcutaneously on a slice of dentin in an athymic mouse. They observe bone neoformation, ligament and cement regeneration (but with non-functional periodontal fibers not oriented perpendicularly). The presence of the cell sheet is essential for the formation of cementum on the dentin surface. However, the partially occlusive nature of the membrane is a limitation because it would impede the integration of the neo-formed periodontal ligament in the bone tissue.

Costa et al.[19] inspired from Vaquette's concept and made several changes to it. The bone compartment of β-TCP/PCL is coated with CaP and seeded with osteoblasts and the pore size is increased. The ligament compartment is modified by the addition of concentric superimposed rings in the cell sheet made by melt electrospinning allowing the membrane to become permeable to cells. This scaffold was also implanted subcutaneously on a slice of dentin in an athymic mouse. These changes resulted in better bone formation, better oblique orientation of the periodontal fibers (but poorly controlled), and increased vascularity. The use of biphasic scaffolds has therefore facilitated alveolar and periodontal ligament regeneration.

d) TRIPHASIC SCAFFOLDS

According to this concept, Lee et al. have developed a three-phase scaffold with a precise architecture and a biochemical gradient. This scaffold is made up of three distinct phases corresponding to the morphology of the periodontal complex: cement, periodontal ligament, and alveolar bone. Each layer has a specific architecture with variable pore sizes (100, 600 and 300 μm).

The cementum, periodontal and bone compartments, respectively, thus creating a hierarchical structure. These parameters are chosen accordingto physiological microbiological characteristics and are also based on their latest studies on the regeneration of soft and hard tissues. In addition to the architectural stratification, a biochemical gradient was added in the various compartments to the incorporation of polyglycolic microspheres charged with growth factors specific to the regeneration of each tissue type.

Amelogenin, connective tissue growth factors and BMP-2 were incorporated into the cement, ligament and bone compartments, respectively. These growth factors could therefore produce a controlled release promoting the recruitment and differentiation of progenitor cells. The production of the scaffold was digitally controlled by Computer Aided Design (CAD). On the other hand, the incorporation of the growth factors was carried out manually by loading the microspheres into the specific compartments using pipettes, thus inducing structural variations depending on the different batches.

Discontinuous cementogenesis was observed, while notable osteogenesis was observed in the bone compartment. Connective tissue was found interposed between these two mineralized formations with an alignment of the fibers and a ligament attachment on the newly formed cementoid tissue. The use of a three-phase scaffold for periodontal regeneration is relatively recent and remains largely unexplored because the clinical implementation of this approach is difficult. The complexity of periodontal regeneration lies in its spatial–temporal coordination and the difficulty of reproducing it. The main challenge lies in the formation and integration of a cementum layer on the root dentin surface.[20]

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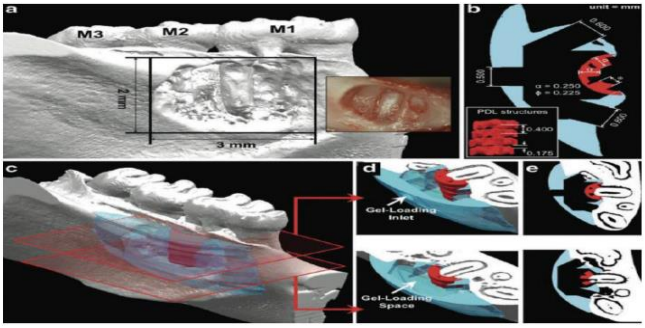

Fig.3:MULTIPHASIC SCAFFOLD AIMED AT MULTIPLE TISSUE REGENERATION (PERIODONTAL LIGAMENT, CEMENTUM, AND ALVEOLAR BONE

e) SINUS AND BONE AUGMENTATION

Alveolar ridge augmentation refers to procedures designed to correct a deformed alveolar ridge, typically in preparation for dental implant placement. Maxillary sinus position also limits the available bone height .Different techniques and materials have been introduced, modified and refined throughout the years; the current modalities of alveolar ridge augmentation include the following categories: guided bone regeneration (GBR), onlay block grafts, distraction osteogenesis, titanium mesh, and ridge split/expansion technique.With the recent advances in planning and manufacturing software and hardware, graft customization using 3D printing techniques

- 3D-PRINTING FOR RIDGE DEFECT SITES

One of the earliest reports of utilization of 3D-printing technology to assist in fabrication of a customized bone block in humans was in 2006. In a clinical case report, Jacotti[21] utilized a 3D-printed maxilla produced from autoclavable nylon polyamide material to allow for preoperative manual milling and adaptation of an allogeneic corticocancellous iliac block graft (Puros block, Zimmer) for horizontal ridge augmentation. The advantages of this technique include improved visualization of the ridge defect, and significant reduction of intraoperative time.

With the conventional technique, most of the time during surgery is spent shaping the bone block and adapting the graft to the recipient site; by having the pre-shaped bone block and fixation screws planned on the sintered model, the surgeon merely needs to transfer the sterile block graft and fixation screws to the patient's recipient site. In this case report, the remaining voids between the block grafts were filled with particulate allograft (Puros cancellous, Zimmer) and covered with an absorbable membrane (BioMend, Zimmer). Healing was evaluated radiographically and clinically at 6 monthreentry surgery and dental implants were placed at that time.

In a more recent clinical case series, Venet et al[22]. utilized similar methodology to shape allogeneic corticocancellous block grafts (TBF, Mions, France) for horizontal ridge augmentation in the anterior maxilla. The pre-shaped bone blocks were delivered to the recipient sites via a minimally invasive subperiosteal tunneling technique, and stabilized with a fixation screw without a barrier membrane; voids were filled with particulate material recovered from the initial block. Healing was evaluated radiographically and clinically at 6 months, at which time implants were placed and allowed to heal for 4 months prior to prosthetic restoration. A total of six patients were treated utilizing a total of 11 bone blocks, and 12 implants were placed, without any complications reported.

- CUSTOMIZED ALLOPLASTIC BLOCK GRAFTS

3D-printing technology for block grafts is currently applicable to alloplastic materials. Critical aspects of biomaterials properties for alveolar ridge augmentation include biocompatibility, absorption rate, ease of handling, and cost. Specifically for alloplastic materials, the macro- and micro-porosity is a determining factor for angiogenesis and cell adhesion, and research is ongoing to identify the optimal architecture.

In an animal study, Tamimi et al.[23] compared 3D-printed monolithic monetite (dicalcium phosphate anhydrous) block grafts to autogenous onlay block grafts for vertical bone augmentation on the calvaria of New Zealand rabbits after 8 weeks of healing. The 3D printed monetite was shown to be osteoconductive, as evidenced by new bone formation on graft sites in contact or close proximity to native bone.

Although no significant differences between materials were observed with regards to vertical bone height gain, the mean bone volume gain was significantly higher for the autogenous group and the mean residual graft volume was significantly higher in the monetite group. These results indicate that 3D-printed monolithic monetite block grafts have the potential to be used as an alternative to autogenous blockgrafts, however, the different healing and resorption patterns need to be taken into consideration.

In a follow-up animal study[24] utilizing similar methodology and comparing two different heights of 3D-printed monolithic monetite block grafts of 4mm and 3mm, the authors concluded that a maximum height of 4mm bone gain is possible on

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the lateral side of the graft where a higher vascular supply is present. The block grafts in general resulted in more new bone formation on the lateral, medial and inferior surfaces and least on central-superior surfaces where it is furthest from native bone. Histomorphometric analysis revealed 40% and 37% mean new bone formation and 50% and 55% mean residual graft for the 3mm and 4mm group respectively.

In order to evaluate the effect of macroporous architecture on new bone formation in 3Dp rintedmonetite blocks, Tamimi et al.tested four different designs utilizing the same animal model. In addition, dental implants were placed to evaluate if osseointegration of titanium implants on monetite is possible. The amount of mean new bone formation within the monetite blocks ranged from 35.7% to 46.9%, while the mean residual graft ranged from 43.1% to 57.7%; mean bone height gain ranged from 3.1mm to 3.7mm; mean bone-to implant contact (BIC) ranged from 20.9% to 37.8%. The results of this study indicate that different macrogeometrydesigns can influence the bone formation pattern, with designs that allow for blood diffusion from high metabolic areas to low metabolic areas providing superior outcomes.

Furthermore, the authors concluded that, although osseointegration is possible, additional research is required to improve BIC.

Another alloplastic material that was recently introduced for 3D-printing is biphasic calcium phosphate (70% β-Tricalcium Phosphate and 30% hydroxyapatite). In an animal study, Mangano et al.58 utilized a sheep maxillary sinus model to evaluate healing of a 3D printed biphasic calcium phosphate block graft at 45 and 90 days. The results indicated that there is complete integration of the scaffold within the sinus cavity, the amount of newly formed bone increases over time, and the periphery of the scaffold shows bone tissue in different amount and maturation compared to the core that mainly consists of connective tissue.

Although currently the evidence available on 3D-printed alloplastic block grafts for ridge augmentation is limited to animal studies, this concept can be very promising. Such a technique for graft manufacturing combines the advantages of an alloplastic material, unlimited availability; no risk for disease transmission; and high patient acceptance, with the advantages of the 3D-printing technology, reduced waste of biomaterial; ability to optimize surface topography and macroporous architecture; reduction of intra-operative time.

- CUSTOMIZED CONTAINMENT SHELLS

Another application of 3D-printing for alveolar ridge augmentation is the manufacturing of a 3D-printed containment shell. The only material that has been used to date for this application is titanium, for the manufacturing of a Ti-mesh, while no true 3D-printed absorbable alloplastic shell materials have been manufactured.

Ciocca et al.[25] presented a case report demonstrating a step-by-step procedure for digital alveolar ridge reconstruction to facilitate prosthetically-driven implant placement. Based on the digital design, a Ti-mesh was 3D-printed to provide the shell needed to contain particulate bone graft; implants were later placed in a fully guided manner into desired positions, and prosthetic frameworks were milled and restored.

More recently, Connors et al.[26] published a case series of a 3D-printed custom titanium ridge augmentation matrix (CTRAM) used for particulate graft material containment in three mandibular posterior sites. The main grafting material used was freeze-dried bone allograft (FDBA, LifeNet Health); in addition, an absorbable membrane (Dynamatrix, Keystone Dental) and platelet-rich plasma (PRP) was used in two sites, while enamel matrix derivative (Emdogain, Straumann) without membrane was used in the third site.

Furthermore, in one case a traditional mesh-like design was used for the CTRAM that is similar to the commercially available Ti-meshes, while on the second case a modified design was employed to facilitate access for graft placement. Surgical reentry was performed at 8 months and 4 dental implants were placed at the appropriate pre-planned position. One out of three sites exhibited an early partial mesh exposure that was successfully managed, and resulted in less than anticipated bone fill that did not, however, negatively affect implant placement; no other complications were noted. This case series demonstrated the potential application of 3D-printing for the fabrication of a custom-fit Ti-mesh, but also for individual design modifications that can improve all aspects of ridge augmentation procedures.

f) SOCKET PRESERVATION

The removal of tooth leads to loss of width and height of alveolar ridge due to the natural process of resorption. It has been reported in a systematic review that after tooth extraction, average reduction in alveolar bone width and height was 3.87 mm and 1.67 mm, respectively. Recent advancement in technology has allowed the use of 3D-printed scaffold to preserve socket and maintain the

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dimension of the extraction socket. Park et al. reported a study on beagle dogs reported a predictable outcome with the use of 3D-printed polycaprolactone in socket preservation.[27]

A pilot randomized controllclinical trial by Goh et al [28]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. Kijartorn et al.[29]also reported in a prospective cohort that 3D-printed hydroxyapatite has potential advantages when used as bone graft material in socket preservation. Clinical studies with long-term follow-up are missing and need consideration.

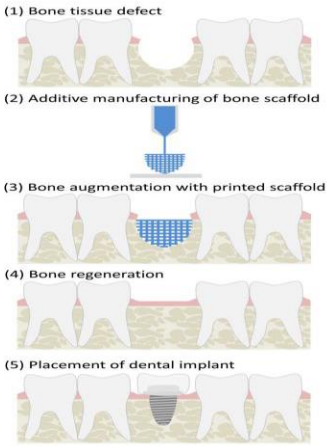

Fig. 4: Alveolar ridge augmentation using an additively manufactured bone tissue scaffold. (1) a bone defect has formed in the alveolar ridge; (2) a bone scaffold is designed and then printed using additive manufacturing technology; (3) the printed bone scaffold is placed in the defect space to support bone regeneration; (4) new bone infiltrates the scaffold, eventually degrading or resorbing the structure; and, (5) a dental implant in positioned in the regenerated bone[30]

g) THREE-DIMENSIONAL PRINTING FOR IMPLANTS PLACEMENT

Implant placement is a routine procedure done by dental professionals to replace missing teeth due to its predictable outcomes. The technical demands of implant placement can result in a number of problems, including poor aesthetics, injury to anatomically significant structures, infections, and implant failure. 31 These issues can be avoided by guided implant placement by creating surgical guides using 3D printing. It facilitates precise 3D implant placement, eliminating unintended harm to anatomical tissues and speeding up the process.

Two protocols of guided implant surgery have been described in literature, static, and dynamic.81 Static guide also called stereo-lithographic guide use the static surgical template and does not allow any changes in planned implant position during surgery, whereas dynamic approach use motion tracking technology and allow changes in implant positioning. The guides are produced using photopolymerization techniques.[32]

A study was conducted on implants, in which a total of 110 3D printed Titanium dental implants were installed in healed alveolar ridges and post extraction socket. The implants were fabricated layer by layer method using powders of titanium alloy (Ti-6Al-4V) by a Yb (YTTERBIUM) fibre laser system. After 3 years 6 implants failed, among 104 surviving implant supported restorations, 6 showed complications and were therefore considered unsuccessful. Mean distance between implant shoulder and first visible bone implant contact was 0.75mm and 0.89mm after 1 and 3 years of installation of implants.

3D printed dental implants seems to represent a successive clinical option for replacement of single tooth gap in both jaws. Digital Light Processing is an efficient method for printing customised zirconia dental implants with sufficient dimensional accuracy. Mechanical properties showed flexure strength close to traditionally produced ceramics. Further research should aim at improving the microstructure of printed object without any cracks or porosities.

Selective laser melting (SLM)-printed customised dental implants demonstrated improved density, strength, and dimensional accuracy.. SLM is an efficient means for printing fully dense customized implants with increased strength and sufficient dimensional accuracy . In cases where conventional implants cannot be used 3D printed customised subperiosteal implants can be used. It also avoids the requirement of an extra oral donor tissue or bone and the use of allografts Common complications in guided implant surgery include guide breakage during surgery, positioning error, and early implant loss due to inadequate primary stability. Studies report that using 3D-surgical guide precise implant placement is possible in partially and completely edentulous patients even using flapless approach, reducing chairside surgical time, and patient comfort postsurgery and also allow simultaneous implant placement in complex cases.

Studies have also reported that care should be taken while using 3D-printed template because angular and linear deviations are possible and have advised use of bone supported surgical guide rather than mucosa or tooth supported along with additional bone pins, sharp drill, physical drill stop, and at least three fixation screws in tripod arrangement to increase the stability of the guide and minimize inaccuracies [27]

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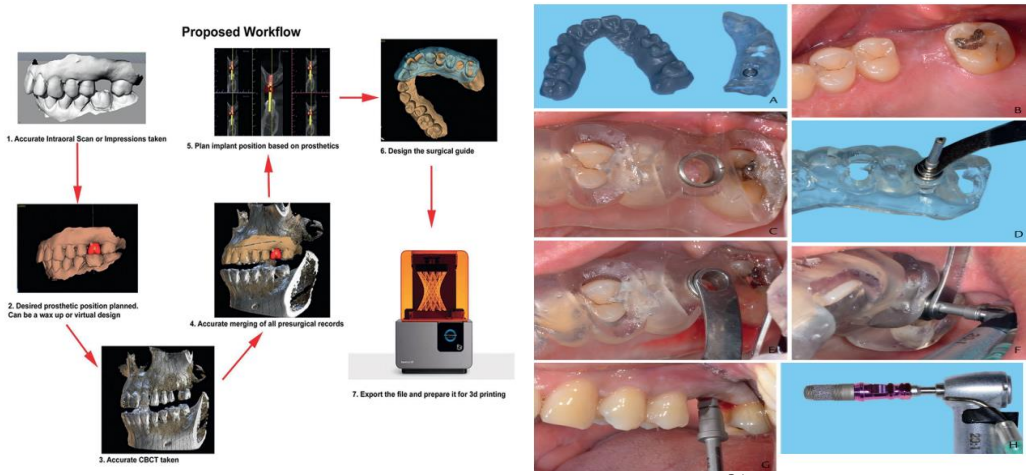

Fig.5: Digital Work Flow Of Surgical Guide[34]

h) D PRINTING FOR ALVEOLAR BONE REDUCTION

To achieve the desired amount of bonereduction a novel concept was developed in 2002 and first published in 2006 illustratedpre-surgical virtual planning steps combined with the use of 3-D printed stereolithographicmodels to improve accuracy of both bone reduction (mandibular edentulous ostectomyfollowed by guided implant osteotomies . Separate sequential 3-D printed templateswere fabricated to facilitate the procedure. I the virtual planningof the implants based on restorative outcomes was the defining step to determine theamount of bone reduction required.

Using the three-dimensional dataset and interactivetreatment planning software the position of the implants were determined first, and thena 3-D printed bone reduction template was fabricated to sit on top of the bone, allowingaccess for bone reduction. After sufficient full thickness mucoperiosteal flap exposedthe thin alveolar ridge, the first surgical template was seated on the exposed mandibularsymphysis with an occlusal window to provide clear visualization and guidance as to theamount of bone reduction required of the knife-edged bony ridge. Due to stability on theresidual bony ridge, there was no need for fixation or anchor pins as shown in Figure 6 A–E.Once the ostectomy was completed and the bone flattened, sequenced bone-borne drillguides were then seated over the newly flattened bone to accurately produce osteotomieswith sequential drilling protocols for dental implant placement, each to carefully expandthe osteotomy based on manufacturer-specific diameters to ensure correct delivery of theimplants as shown in Figure 5F–H.The templates controlled depth, trajectory, and diameter to achieve accurate placementof the implants within the bone [33]

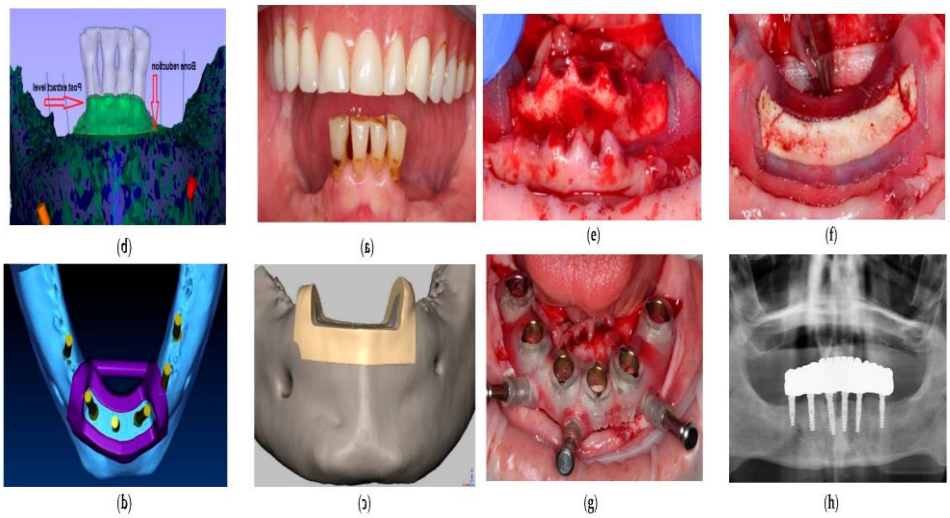

Fig 6: Alveolar Bone Reduction Using 3d Printed Surgical Template

IV. CONCLUSION

3D printing has the capacity to revolutionize dentistry. The different technologies have been applied for a variety of purposes in the field of dentistry 3D printing could prove an ideal approach to produce scaffolds for soft tissue augmentation by addressing the variability in the soft tissue shape, inner architecture, thickness, volume, mechanics, and function associated with the position in the oral cavity. Importantly, 3D printing would allow application of the "digital workflow", resulting in the production of the patient-tailored grafts.

Several decisions would need to be made to establish the 3D printing approach of oral mucosa the most appropriate imaging acquisition, the choice of biomaterial to best correspond to gingiva in its chemical, biological and mechanical properties, inclusion or not of cells (and the source), and finally the choice of the printing technique. Digital imaging of bone, soft tissue, and blood vessels during pre-operative virtual planning for face reconstruction has been accomplished with Haptics system .

With the intraoral scan digital acquisition, the level and the anatomy of tissue insufficiency, as well as the vascular network, can be determined. The desired characteristics of 3D printable biomaterials comprise biocompatibility, high porosity to promote cell population, tissue in-growth and vessel formation, biodegradability according to the rate of new matrix deposition (tissue generation), and mechanical stability. The appropriate macro-architecture characteristics would ensure timely neovascularization, as recently demonstrated for the regeneration of dental pulp.

A smart biomaterial containing all instruction cues could circumvent the need for growth factors or cells. However, in certain pathological cases such as inflammation, infection or necrosis, different anti-inflammatory, and immunomodulatory drugs or antibiotics could be incorporated and released in a timely and concentration-controlled manner. The inclusion of approved autologous blood concentrate preparations, such as PRF or PRP, could facilitate the healing process via the release of natural growth factors. From the dentist's point of view, the "digital workflow" would have to be easy to plan and execute, with the final soft tissue graft that is effortless to handle and suture and provides satisfactory functional as well as esthetical results

In summary, 3D printing is a versatile manufacturing technology offering vast patterning possibilities, precise manufacturing, and abundant choices of biomaterials for a cost-effective patient-tailored end construct. This interdisciplinary approach pursues the integration of technologies from the fields of engineering, digital imaging, materials science, biology, chemistry, and medicine. 3D printing technology has already been largely employed in numerous biomedical applications to make tissues, organs, and medical devices, as well as to provide surgical planning aids and educational models.

Continuous expansion and adaptation of 3D printers' abilities, combined with reduced costs, increased speed, and use of a broader range of printable materials will bring this technology to the forefront of biomedical applications. New challenges, needs, and achievements can be envisioned in the field of bioprinting as more researchers with different backgrounds and research questions employ 3D printers.

In dentistry, particularly for soft tissue regeneration, application of the "digital workflow" to achieve a perfect-fit patient-tailored graft according to the defect, with an adjusted inner architecture and outer shape to maximize tissue mimicry, will result in functional as well as aesthetically pleasing tissue restoration

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