Additive Manufacturing: A 3-Dimensional Approach in Periodontics

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Authors' contributions

This work was carried out in collaboration among all authors. Author A. Bhatnagar designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors A. Bhardwaj and SV managed the analyses of the study. Author SV managed the literature searches. All authors read and approved the final manuscript.

Mini-review Article

ABSTRACT

Additive manufacturing technology or 3-dimensional printing has been used since ages in various fields including medical. Their addition to dentistry is recent and has tried to revolutionize the field. It is being used in various fields of dentistry like endodontics, prosthodontics, orthodontics, oral and maxillofacial surgery and recently in periodontics and Implantology. With introduction of recent "layer-by-layer" additive technology, their use in periodontal field has changed its treatment planning. It is use in preparation of customized scaffold with or without stem cell therapy, ridge augmentation, sinus lift and guided implant surgery, implant fixtures, education models, drug technology and many more. This review has tried to explain the various applications of the additive manufacturing in the field of periodontics with recent evidences. This paper highlights the role of 3-dimensional printing which can change the future of periodontal management.

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ABBREVIATIONS

AM	: Additive Manufacturing
3-D	: Three Dimensional
3DP	: Three Dimensional Printing
CAD-CAM	: Computer Aided Design-Computer Aided Manufacturing
STL	: Stereolithography
SLS	: Selective Laser Sintering
FDM	: Fluid Deposition Modeling
PCL	: Polycaprolactone
PLAG	: Poly lactic-co-glycolic Acid
PGA	: Polyglycolic Acid
PDLLA	: Poly-D, L-Lactic Acid
HA/p	: Hydroxyapatite
TCP	: Tricalcium Phosphate
PLA	: Polylactic Acid
PDL	: Periodontal Ligament
hPDL	: Human Periodontal Ligament Cells
CBCT	: Cone Beam Computer Tomography
GPa	: Giga Pascle
rhBMP	: Recombinant Bone Morphogenetic Protein

1. INTRODUCTION

Product manufacturing techniques has helped humans to build things through techniques like turning, milling, drilling and grilling also classified under Traditional machining systems or Subtractive Manufacturing since many years. This technique has its own limitations which merely includes wastage of up to 90% during fabrication of components.[1] The present manufacturing systems has changed the production quality in industries as well as in medical and dental world with introduction of computers and robots. Compared to traditional machining, the newer 3-Dimensional (3D) printing is a process of creating objects directly by means of addition hence also referred as Additive Manufacturing.

Additive Manufacturing (AM) is a process of joining materials to make objects from three dimensional model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies. As a new tool in the entrepreneurial toolbox, additive manufacturing system uses computer- aided design (CAD) models and 3D scanning systems for reproduction [2].

Hideo Kodama of Nayoga Municipal Industrial Research Institute has printed the first solid object from a digital design. However, the credit for the first 3D printer goes to Charles Hull, as he designed it in 1984. Charles Hull was a pioneer of the solid imaging process known as stereolithography and stereolithographic (SLA) file format and is the most widely used format in 3D printing. In 1990, the plastic extrusion technology was invented by Stratasys and named it as fused deposition modeling (FDM) [3].

Nowadays, additive manufacturing has a wide range of applications in various fields of human activities: research, engineering, medical industry, military, construction, architecture, dental industry, education and many others.[3] This technology has become an integral part in dental applications, whether as a tool for teaching or as device in treating patients. The use of 3D technology is now incorporated in almost all fields of dentistry that includes periodontics, implantology, prosthetics, endodontics, oral and maxillofacial surgery and orthoganathic surgery. In dental applications, 3D printing is being used for fabrication of customised scaffolds for tissue growth and reconstruction of lost tissues structures, construction of study models, prosthetic components and pontics, implant stents and guides. Although their use in dental field is limited due to cost of machine, limited raw materials, limited availability and application of biomaterials, allergic reaction to these materials and in some techniques it is time consuming as the product is formed through layer by layer deposition.[4] The Additive Manufacturing technology has gained its momentum in human mankind as it is used in production of customized product, ease in sharing of data and thereafter its application and as a valuable educational tool. AM that has gained rapid popularity in dentistry includes methods like Selective Laser Sintering (SLS), stereolithographic, Fused Deposition Modeling (FDM), Inkjet printer/ Binder Jetting and latest is Bio-printing (Table 1). FDM printer is commonly used in dentistry as it is readily available, easy to use and install, acceptable quality of print and is cost effective in this case [5].

Materials that are used in 3D printing vary as per object to be printed. Acrylonirile Butadiene Styrene (ABS) and Polylactic Acid (PLA) are the most common materials used in printing. The recent 3D bio-printer uses cell based ink or micro-tissue based ink system in order to generate artificial tissue in *in-vitro* models for regenerative medicine.[5] Other materials that are used for periodontal use are: Hydrogels (Methacrylate gelatin, Polycaprolactone),

ceramics (Hydroxyapatite, beta-tricalcium Phosphate), Composites (Poly-ceramics plus cell ink) and Metals (Titanium and alloys) [6] (Table 2).

3D printing is becoming an important part of periodontal therapy. Various authors has applied 3D printing technology for treating alveolar bone defects, for guided implant placement, as drug delivery system and more recently an optimal volume of human bone and skin grafts has been generated in-vitro and their application in human mankind will revolutionize treatment outcome. There is a potential rise in adopting this advancement to replace existing periodontal treatment modalities.[5] Keeping this into consideration, the aim of this review is to draw attention towards the various aspects of additive manufacturing in the field of periodontics along with its future implications. Medline and Google search using key words were used for the literature search that is compiled below.

2. GENERAL PRINCIPLES OF 3D PRINTING

The additive manufacturing technology basically works on three general principles that are Modelling, Printing and Finishing. 3D printable models are created using CAD design or a scanner. The collected data on shape and size of the object is transferred into computer for analysis and finally designing the product. This process from collection of data till formulation of computer design is termed as Modelling. During printing stage the modelling format is converted to G-code file format[3] or Surface Tessellation Language (STL) file[7] that sections the object into thin layers. Other programmes that are commonly used are Slic3r, KISSlicer, and Cura.[3] The G-code/STL instructions are followed by the printer to laydown successive layers of material in order to build a 3D model. Additive manufacturing system reduces the time of manufacturing from days to few hours depending upon type of printer being used. Final step in 3D Printing is finishing the printed product. Once printed, the model produced will be oversized or is some cases surface roughness[6,8] may be present. Hence removal of extra material is required to produce an accurate fit for further usage [8].

Additive manufacturing has various advantages. It is time saving, can accurately scan details and produce good reproduction of model, prints complex geometrical shape and structures, reduces total material loss, can produce single objects in small quantities with fast delivery and most importantly, it provides "custom-made" products. However like any other new technology additive manufacturing also has some disadvantages and limitations. Its high investment cost, inbuilt weakness of product as it is built by successive deposition of layer, requires finishing step which is time consuming, material dependency as limited biocompatible material is useful in 3D printing and sterilization property of resin material still needs to be explored [8].

3. CINICAL APPLICATIONS

3.1 3D Scaffolds for Periodontal Complex Regeneration

Different techniques have been employed for the fabrication of 3D scaffold using few conventional methods like gas foaming, phase suspension, fibre mesh and casting. The main limitation of the above mentioned techniques are unequal pore size, internal channel formation and pore volume. Therefore these techniques can't produce scaffold for customized use. This limitation was answered with the development of "additive manufacturing" that creates scaffolds with precision and reproducible architecture. Use of 3D scaffold has been investigated for different periodontal applications. Image-based 3D printed (3DP) scaffold that follows CAD models have shown promising results *in-vitro* [8].

Experimental studies on animals showed the use of Polycaprolactone(PCL)/Hydroxyapatite(HA) scaffold in rat models to induce regeneration by cell homing technology. In another rat model using Melchers concept of compartmentalization, PCL printed scaffold was enclosed at alveolar bone and periodontal ligament (PDL) interface with fibrin glue. Histological result showed regeneration of cementum- like tissue, alveolar bone and PDL fiber growing obliquely. In recent years CT imaging based 3D printed bee wax scaffold have been used to improve migration of cells. The combination of 3D scaffold and cell sheet technology also called biphasic framework proved to have provided additional benefit for delivering multiple periodontal cells at stir for regeneration. Biphasic technology allows healing with biomechanical support that was lagging from previous cell sheet technology. PCL scaffold modified with beta-Tri-Calcium Phosphate (TCP) and calcium phosphate were used in animals for regeneration showed improved cell interaction and vascularization [9].

Table 1. Types of additive manufacturing techniques used in periodontics and implantology

Type of 3D printer [5]	Inventor/patent	Material used [34]	Periodontal application [34]
Stereolithography (SLA)	Chuck Hull Alain Le Mehaute [6]	Photopolymer resin Stainless steel	Bone, dental models, dental implant guides and splints [29] Implant
Fused Deposition Modeling (FDM)	S. Scott Crump [6]	Plastics, Biomedical Polymers: Acrylonitrile butadiene styrene, Polylactic Acid [7]	Production of basic concept models, [7] Medical instruments and devices, rapid prototyping exoskeleton
Selective Laser Sintering (SLS)	Carl Deckard [6]	Powder-based materials. Common metals and polymers used are stainless steel, titanium, aluminium, cobalt chrome, steel	Implants [25]
Inkjet Powder Printing/ 3D-powder printing system	-	Stainless steel, Polymers: Acrylonitrile butadiene styrene, Ceramics: glass, beta tri-calcium phosphate [36]	Bone block synthesis [36]
Bioprinter (a modification of Inkjet Printing)	Thomas Boland [35]	Cell-loaded gels and inks based on collagen, photopolymer resins, agarose, alginate, hyaluronan, chitosan [5]	Cell-laden scaffolds for hard and soft tissue printing, stem cell therapeutics [5]

Basic 3D printing technologies used in the field of dentistry. Each as has specific dental application using specific material

Table 2. Materials used in additive manufacturing for periodontal and implant use

Materials [8]		Basic properties	Material types and its property
Biodegradable Polymer	Natural	Highly biocompatible, cell reorganization, enhanced cell interactions, water loving materials.	a) Collagen: Enhanced osteoblast adhesion/ migration b) Chitosan: Antibacterial- antifungal, Enhances blood clot formation, analgesic c) Alginate: Mimics natural bone extracellular matrix, encapsulates living cells
	Synthetic	Low cost, readily available, can be produced in larger amount, longer shelf-life period, low creep and Young's Modulus compared to metals	a) Polycaprolactone (PCL): scaffolding fabrication made easy, slow rate of degradation, mechanical stability can be achieved. b) Polylactic Acid (PLA), Poly lactic-co-glycolic Acid (PLGA): water repelling nature, scaffolding material c) Polyglycolic Acid (PGA): water loving nature
Bioceramics	Calcium Phosphate	Intimate adaptation to complex bone deformities/ defects, bioactive, biocompatible, abundant availability, osteoconductive and sometimes osteoinductive, water loving nature	a) Hydroxyapatite (HAp): influences adhesion and proliferation of osteoblast cells, slow degradation. b) Beta-tricalcium Phosphate (Beta-TCP): stronger bonding with calcium and phosphate of bone, faster degradation, controlled bioactivity, promotes in-growth of bone.
Metals	Alloys or	Support in place of lost bone structure,	a) Titanium and its alloys: Biocompatible, high mechanical property, better

Materials [8]	Basic properties	Material types and its property
pure forms	higher strength among all materials, toughness and roughness (promotes cells adhesion), as load bearing structures (Implants and frameworks)	scaffold for augmentation procedures (good hydrophilicity) b) Magnesium and its alloys: Osteo-conductive, increased cell attachment, increased osteogenic marker expression.

The following table gives an idea of some useful dental 3D printing material and classified it into biopolymers, bioceramic and metals. Properties and dental application is mentioned above

Multiphasic design incorporated with various biomaterials like PCL, HA etc. have been investigated in combination with cells and proteins (rhBMP). Forming a scaffold with controlled pore size (100-600 microns) using AM have proved to be beneficial.[10] 3D printed hybrid scaffolds including biphasic scaffold design with multiple compartments and perpendicularly oriented microchannels designed by Park et al [10-11] to facilitate PDL fibers organization was done in-vivo. Very recently, first human case report was published on the treatment modality for treating large periodontal osseous defect using 3D printed bioresorbable polymeric scaffold impregnated with signalling growth factor. The author had used SLS 3D printer to fabricate scaffold with polycaprolactone (PCL) biomaterial mixed with 4% Hydroxyapatite (HA) in combination with rhPDGF-BB. The treatment modality provides optimal mechanical and resorptive properties with some stability of soft tissue and PDL complex formation for up to 1 year [12].

Very recently new biomaterials have been introduced. Studies using bio-printing technology to print periodontal cells with hydrogel [13] have proven to be quite useful as scaffold free approach for delivering periodontal stem cells to targeted area of interest [14]. Other natural polymers like chitosan that as antimicrobial property as well have been employed as bio-scaffold material. Gelatin has displayed biological properties to attract and adhere with intrinsic cell on its scaffold material [8,15-16].

Scaffolds for periodontal complex regeneration therefore must be investigated further before its commercial application. Properties such as degradation rate, spatial arrangement of cells in scaffold, vascularization of scaffold materials must be considered. In short 3D scaffolding should be based on "functional tissue formation" [8] for regeneration of multiple periodontal structures.

3.2 3D Drug Printing

In the arena of pharmaceutics, 3D printing has various advantages over conventional drugs. With the technology there is a greater control of accuracy and precision to deposit active ingredients, high production value, reduced waste, ability to design complex drug structures and fabrication of dosage based drugs with numerous combinations. It has provided a new dimensional approach in the drug industry that has ability to produce customized medicines, which marks the new begging of "Personalized Medicine" (PM). In 2015 FDA approves its first 3D tablet designed for the treatment of epilepsy, Spritam® [17].

The 3D print includes precise control over size of droplets, dosage, reproducibility, and controlled drug release for specific individual. Purpose of PM is to increase the efficacy and decrease the adverse effects. PM drugs can benefit patients who have pharmacogenetic polymorphism or those who need narrow spectrum index [18].

Using AM technology (inkjet printer and electrospinning) a formulation was prepared to incorporate lidocaine hydrochloride (LH) with piroxicam (PRX) for oromucosal administration that was investigated *in-vitro*. The drug printed incorporated 2−3 milligrams and had shown a noticeable degradation rate over months with immediate release of 85% amount in 8 minutes. Therefore this combination of AM technology allowed a new preparation for a dual drug system for the control and management of pain [19].

PM concept therefore can be a boon in periodontics as well as in dentistry where complex and specific targeted drugs can produce drastic change in treatment outcome whether it is recurrent periodontal infections, aggressive periodontitis or sever space infection.

3.3 3D Drug Delivery System

Another pharmaceutical application of 3D printing is in development of drug delivery system. It can print a biocompatible, patient specific morphological micro and macroscopic pore arrangement can incorporate drugs and proteins. The unexplored field of lipid based drug delivery system can enhance drug absorption, bioavailability of lipophilic drugs and high membrane permeability. Lipid has low temperature melting point and therefore is used in 3D print based thermo-labile compounds. These compounds can be processed into local drug delivery system.

An *in-vitro* experiment was done to formulate amorphous self-emulsifying drug delivery system using inkjet technology to incorporate celecoxib [20]. The result showed good dissolution behaviour. Another experimental study used bee wax as carrier to produce fenofibrate-loaded solid dosages system using inkjet 3D technology [21] in order to release the a desired drug. These results suggest a potential use of 3D based lipid

derived drug delivery system that can be applicable in local drug delivery for periodontal disease treatment.

Studies have indicated that small volume drug delivery chambers provide a more physiological environment in periodontal pockets. This was backed by an in-vitro computer simulated and experimental model. In this model a 3D-printed flow-through chambers of volume 0.04 milli-liters with PerioChip®, a sustained release drug was used to measure dissolution flow rate and enzymatic clearance of the drug. It suggested that the dissolution rate of the drug under high flow conditions was slower compared to the bulk solution, making the new 3D printed biodegradable device more appropriate for its use in clinical application [22]. Vomdran et al. printed a biodegradable bioceramic scaffold made from calcium phosphate using multijet 3D printer having spatial resolution of 300 microns impregnated by active drug (Vancomycin) and proteins (Heparin, Recombinant Bone Morphogenic Protein- 2). This modification of bone graft as drug delivery system resulted in a zero-order kinetics with release rate of 0.68%-0.96%/hour allowing a discrete deposition of pharmaceutical agents [23].

3.4 3D Printing in Dental Education

In the past decades, cadavers and skeletons were used as study models in field of medicine and dentistry. These are almost replaced by synthetic mannequins and 3D models. A need for more realistic tooth models for education has often been expressed by dental students. On the 3D biomodels, different surgical procedures can be demonstrated and practiced so as to manage the decision, pre surgical planning and selection of surgical techniques [7,24].

In 2019, Liya and Vandana introduced a 3D Printed design in the field of periodontics called 3D VANPERIO model meant for the purpose of patient education and motivation, student activities and demonstration of basic clinical aspects along with periodontal osseous defects. The model was a combination of traditional and modern approach and proved to be useful in academic and clinical field among patients and oral health professionals [7].

3.5 3D in Dental Implants

Dental implants are now commonly used as alternative to missing tooth replacement. There are few problems with the conventional implant placement and implant fixtures. The implants are made from either pure titanium (also called cpTi) or alloy of titanium aluminium and valladium (Ti-6Al-4V). These metal are quite rigid and their Young's elastic modulus is a mismatch with its surrounding bone (young's modulus of implant is 112-115 GPa and cortical none is 10-26 GPa). In order to obtain a long term stability and integration of implants with surrounding bone, primary stability and surface topography of implants is essential. With newer implants, increased surface roughness has shown better biological response. What is lagging from conventional implants is a high porous surface and a dense core. A porous structure can improve the biological response with formation of open interconnected system which can promote bone ingrowth into the metal framework providing strong mechanical phase connection between implant and bone. To obtain titanium scaffold around implants it is essential to find a technique that forms the fixture within one step and eliminate the need of powder plasma spray or titanium fibre sintering [25].

In the past few years 3D AM technique has been used in medical field to fabricate such porous Titanium implants. High laser beam fuses the powdered metal particles layer by layer with selective precision to fabricate porous outer scaffold and denser inner core. In- vitro studies on such implants showed clot stabilization and growth of osteoblast and mesenchyme stem cells [26]. Tunchel et al. in 2016 performed a prospective study with 3 years follow-up on patients who received 3D manufactured single titanium implants (company used: Tixos®, Leader Implants, Milan, Italy). The implants were made from titanium alloy powder of size 25-45 microns which was fused together layer by layer using 1054 nanometer 200 Watt Ytterbium fiber laser and was further chemically treated. The pore surfaces then created were of 66.8 microns (μm), 77.55 μm, and 358.3 μm with surface roughness of 5-50 microns. Implants were placed in the single tooth space and recall follow-up programme was done every 6 month after functional loading till next three years. The sites were analyzed using radiographic technique along with stability and clinical parameters like pain, sensitivity, suppuration and mobility. The result showed that out of 110 3DP implants only 6 underwent complications and a crown-implant success rate calculated was as high as 94.5% with mean crestal bone loss of 0.89 mm recorded over 3 years. It was concluded that 3DP titanium

dental implants seem to represent a successful clinical option for the rehabilitation of single-tooth gaps in both jaws [25].

Another area where AM technology use 3D printer in placement of implants is by using a 3DP surgical guide. During implant placement, a surgical guide's accuracy is checked by the deviation and angulation of implant placed. Studies have found that a deviation of 1° of a 10mm fixture can deviate implant up to 0.34mm and that of 5° can deviate up to 1.7 mm. Therefore implant angulation should not be deviated more than 3° to safely place it without damaging adjacent structures [27-28]. Flugge et al. produced an implant drilling surgical guides using tools like 3D radiograph technology, laser surface scanning, computer-aided design and manufacturing. After intraoral digital impression and radiography the data were studied and analyzed to perform virtual implant placement. During the time of implant surgery a CAD-based 3DP surgical guide based on the virtual surgery was used. The result offered additional drilling guidance for implant placement which was accurate and free from hassle [29].

The main advantages in using 3D technology for implant placement are: 1) there is no need for additional scan after surgery, 2) virtual planning can be helpful in deciding the direction of implant placemen, 3) there is no loss of accuracy during drilling when the guide is utilized [29].

3.6 3D in Augmentation of Alveolar Ridge

The innovation of 3D scanning technology like CBCT, anatomic variations or defects can be well documented before surgical re-entry. This helps in devising strategies to treat or correct the alveolar deficiencies or preservation of an extraction socket. Combination of 3D imaging and additive manufacturing to develop a 3D replica of bone architecture has proven to be a useful diagnostic tool and this enables surgeons to feel the concerned area before surgical treatment planning [30].

3D printed allogenic bone graft blocks can be used to augment bone defects. With recent advancements, it is possible to print patient specific bone tissue, which can act as biomimetic scaffold for bone cell growth and differentiation [30]. Alveolar ridge reconstructions including vertical augmentations are challenging procedures in dental implantology and can be summarized as complex bone augmentations. These techniques require a mechanical stabilization of the augmented area due to the lack of natural support by the bony wall of the alveolar ridge. Biomaterials with interconnecting porous system, analogous to natural cancellous bone have been used in augmentation. Mechanical stability and elastic properties of appropriate materials must allow drilling and screwing for fixation at the site of augmentation which depends on individuals skills and is difficult to manage. 3D techniques allow the individual adjustment of a biomaterial shell before surgery. Draenert et al. applied AM techniques to create customized model of ridge defect that could be confectioned into a standard biopolymer membrane made of Poly-D, L-lactic acid (PDLLA). They found that PDLLA like biomaterials can be adapted to the situation by bending directly at the bony defect site (chair site adaptation) [31].

Major challenges exist in rehabilitating patients with atrophic edentulous crest using implant-supported fixed dentures is the requirement of some bone regeneration/ augmentation with minimum intervention. Ciocca et al. in their experimental approach designed a prosthetically guided bone augmentation model for a definitive fixed rehabilitation. A 0.3 mm thick titanium mesh was customized using CAD-CAM for bone augmentation and 3DP by SLS with powdered Ti6AlV4 alloy. The result showed bone augmentation with minimal intervention to meet the functional needs for definitive fixed rehabilitation process [32].

Currently there is capability to add osteoinductive factors like Bone Morphogenic Proteins to stimulate osteogenesis; thereby enhancing osseointegration. However, research lags long term documented follow-up studies to evaluate their healing process and osseointegration. The advantage of such graft is that, they are patient specific and lack cross contamination and donor site morbidity issue [32].

A 3D printed scaffold (HA (30%), β-TCP (60%), and α-TCP (10%)) showed favourable outcomes with formation of new bone ~~in~~ biomaterial for sinus augmentation in an *in-vivo* study. The combined 3D printed scaffold decreased the risk of tissue inflammation and also enhanced osteogenesis [8].

Studies have shown that use of additive manufacturing for bone augmentation or

Table 3. Recent studies related to additive manufacturing in the field of periodontics

Reference and type of study	Technology	Procedure	Conclusion
Anil Liya and Vandana KL, 2019, *in-vitro* education model. [7]	Fusion Deposition Modeling (FDM)	Fabrication of Vanperio model into 3D using Polylactic acid (PLA) to teach periodontology.	Was useful in academic and clinical field to create awareness among patients and comprehensive understanding for the students.
Palo Mirja et al. 2017, *in-vitro* [9]	Inkjet Printing	Personalized drug Lidocaine hydrochloride and Piroxicam in 3DP printed drug delivery device.	Immediate to slow release of drug. Gelatin scaffolds shown to be suitable substrates for inkjet printing of oromucosal formulations.
Rasperini G et al. 2015, *in-vivo* (human case report) [19]	Selective Laser Sintering (SLS)	Scaffold prepared from polycaprolactone(PCL) and 4% hydroxyapatite impregnated with recombinant human platelet-derived growth factor BB.	Site intact at 12 month follow-up. Suggests that a 3D-printed image-based scaffold is a potential periodontal reconstruction.
Tunchel Samy et al. 2016, *in-vivo* (clinical study) [25]	Yb (ytterbium) fiber laser system	Sintered titanium alloy powder printed into dental implants placed in 82 patients with single missing tooth region. Follow-up for 3 years after prosthetic restoration.	3-D Printed titanium dental implants seem to represent a successful clinical option for the rehabilitation of single-tooth gaps in both jaws.
Mangano Carlo et al. 2015, *in-vivo* (animal model) [26]	Direct rapid prototyping technique dispensing-plotting	Ceramic scaffold from hydroxyapatite and TCP powder was fabricated and direct sinus augmentation done in sheep models.	Scaffold showed good osteoconductive properties. Helped in reconstruction of complete alveolar ridge.
Flugge Tabea Viktoria et al. 2013, *in-vivo* (human case report) [29]	Stereolithography (STL)	Implant drilling guide printed using STL printer and a transparent polymer (DIN EN ISO 10993-1: 2009) after CBCT scan. Straumann implants placed using the guide and radiographs were observed.	CBCT, CAD-CAM and STL produces implant drilling guides with 1 clinical consultation for final implant placement.
Draenert G.F et al. 2017, *in-vivo*, (human study) [31]	Stereolithography (STL)	PLA scaffold fabricated for vertical and horizontal ridge components. Autogenous bone	Resorbable biopolymers, (lactides) can be adapted to the situation by bending directly at the bony defect site.

Reference and type of study	Technology	Procedure	Conclusion
		chips placed below scaffold	
Wei Ren et al. 2019, *in-vitro and in-vivo* (animal model) [37]	Stereolithography (STL)	Dissolution of biodegradable sustained release device: periochip into 3DP dissolution chamber	Slow rate of dissolution of biodegradable sustained release device in designed chamber. Rate of dissolution changes due to enzymatic reaction.
Costa PF et al. 2014, *in-vivo* (animal study) [38]	Fluid Deposition Modeling (FDM) And Electrospun	Production of biphasic scaffold (PCL and beta Tricalcium Phosphate (TCP)) was impregnated with osteoblast and periodontal ligament (PDL) cells placed in rats subcutaneously.	Displayed suitable properties for periodontal regeneration, high levels of vascularization and tissue orientation in both the bone and periodontal compartment.
Park Chan Ho, 2019, *in-vivo* [39]	3-Dimensional (3-D)Wax Printer	Wax mould with 25% PCL printed and processed chemically to remove wax later. Human PDL (hPDL) cultured with scaffold prototype.	Prototype scaffolding system showed geometric adaptation to the digitized image dataset, hPDL orientations on microgroove-patterned surface.
Pilipchuk Sophia P. et al. 2016, *in-vivo (*animal model-murine) [40]	3D Printed Wax-Based Molds	Wax model used to cast PCL micro-pattern scaffold and random pattern scaffolds, impregnated with hPDL, fibroblasts labeled with bone morphogenetic protein-7 genes.	Aligned cells for oral tissue repair having potential for improving the regenerative response of other bone–ligament complexes with micro-pattern model.
Pae Hyung-Chul et al. 2018, *in-vivo* (animal rabbit model) [41]	3-D Bioprinting System	Scaffold printed: 1) PCL, 2) PCL + 10% weight Beta TCP, 3) PCL + 10% weight Beta TCP+ type-1 collagen membrane.	PCL and beta-TCP are biocompatible and favorable material used in Guided Bone Regeneration.

Table explains the recent studies in each of the periodontal application with its final outcome

preservation has predictable outcomes. What matters the most is the selection of right material for 3D printing.

Table 3 gives a brief about few of the recent studies in 3D printing related to the field of periodontics and implantology.

4. FUTURE ASPECTS

The application of additive manufacturing models itself is quite advance, but its integration with the mainstream periodontics is under process. The future possibilities for its application in the field can be customized scaffold based regeneration, bio-printed lost tissue planted in the defect and 3D printed tailor-made implants whose design, shape and size can be designed from scratch. In recent years the concept of personalized medicine has gained interest in medical field. Using 3D print technology, specific drugs have been manufactured. Their incorporation in periodontics can help in producing patient specific medicines, particularly for children and disabled individuals. These drugs produced will be dose dependent, specific, safer and effective in reducing antimicrobial drug resistance.

Manipulating the materials themselves is an area of research and innovation that will widen the possibilities and thus improve the mechanical responses of the printed models and provide better teaching tool for surgical training [33].

Incorporation of the above mentioned technology in near future will drastically change the face of periodontal treatment.

5. CONCLUSION

The 3D printing in dental field is changing the oral health care and need. The main criteria for its emerging usefulness in the field is because of its spreading awareness, less time required for direct case treatment and its potential area for research towards treatment planning which will revolutionize dentistry.

This technology has been extensively evolved since first 3D printer was developed in 1983, but the cost of initial investment including materials, maintenance and skilled operator is too high. The newer models are although affordable and has gained popularity in the dental market, it is still a long way before it can be fully accepted and its' full potential be realized.

CONSENT AND ETHICAL APPROVAL

As per university standard guideline, participant consent and ethical approval have been collected and preserved by the authors.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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