3D Printing in Periodontics: A Review

Abstract:
The restoration of the lost periodontium, including its soft and hard components, is the main goal of regenerative periodontal therapy. Three-dimensional (3D) printing technology permits the fabrication of an individualized 3D object based on a material of choice, a specific computer-aided design and accurate manufacturing. 3D printing finds use in a variety of industries, such as aerospace, defence, art & design, medicine and dentistry.3D printing is one of the most talked-about technological advancements in dentistry, and they have greatly simplified the planning and execution of dental procedures. The application of 3D printing in the regeneration of lost periodontal tissues represents a novel approach that facilitates optimal cell interactions and promotes the successful regeneration of biological tissues. 3D printing has been modified to print biocompatible materials and living cells to minimize any potential compromise on cell viability

Key-words: 3D Printing, 3D Printers, Bioinks, Scaffold, Periodontal regeneration.

Introduction:

Periodontitis is a condition that gradually damages the periodontium, resulting in severe attachment and bone loss. Untreated periodontitis can lead to compromised functional integration of the periodontium and finally tooth loss.

Periodontal therapy aims to repair and stabilize the affected periodontium. Various therapeutic approaches have been proposed and utilized over decades to restore damaged periodontal tissue complexes. These procedures use techniques including bone grafting, guided tissue membranes, growth hormones and stem cells.[1]

In the realm of periodontal regenerative therapy, an innovative technology known as additive manufacturing or 3D printing, has surfaced. It entails building an object using multiple layers.[2]

3D printing technology have numerous uses in art, design, aerospace, defence, and medical/dental disciplines. In periodontal regenerative therapy, 3D printing has great potential for regenerating and integrating damaged periodontal tissue.

This review paper discusses the foundations of 3D printing and its importance in periodontal regeneration.

Definition of 3D Printing:

A manufacturing process known as "3D printing" creates objects by layer by layer addition to create the finished product. This technique is frequently referred to as rapid prototyping or additive manufacturing.[3]

Access this article online

Quick Response Code

Website:
www.ujds.in

DOI:
https://doi.org/10.21276/ujds.2025.11.1.19

[1]SHARMISTHA VIJAY, [2]PAVITRA JAYAKUMAR, [3]DEBOPRIYA CHATTERJEE, [4]ANJALI KAPOOR, [5]JYOTI DAD
[1-5]Department of Periodontics, RUHS College of Dental Sciences, Shastri Nagar, Opposite to Space Cinema, Jaipur

Address for Correspondence: Dr. Pavitra Jayakumar
Department of Periodontics, RUHS College of Dental Sciences, Shastri Nagar, Opposite to Space Cinema, Jaipur
PIN 302016
Email : pavitrajayakumar24@gmail.com

Received : 30 Dec., 2024, **Published :** 31 March, 2025

How to cite this article: Vijay, D. S., Jayakumar , D. P., Chatterjee, D. D., Kapoor , D. A., & Dad, D. J. (2025). 3D Printing in Periodontics - A Review . UNIVERSITY JOURNAL OF DENTAL SCIENCES, 11(1).

History of 3D Printing:

The first iteration of 3D printing technology was unveiled in 1986 by Charles W. Hull and Raymond S. Freed. As a result, DTM Corporation was founded in 1987 with the intention of bringing selective laser sintering (SLS) technology to the market.[4]

In the 1990s, materials like nanocomposites, mixed polymers, and powdered metal were employed to produce dental implants and custom prosthesis utilizing 3D technology.

In 2010, Orga novo-the Bioprinting Company printed the first blood vessel and today the revolution continues on.

Types of 3D Printers:

Three main categories can be used to classify 3D printers:

a) Inkjet printing

b) Extrusion printing

c) Laser light-assisted printing.

Ink Jet Printing :

In inkjet printing, a controlled flow of biological fluid, typically polymer, is allowed to pass through an orifice on the printer head using acoustic, thermal, or electromagnetic forces.[5]

The first inkjet printer used for bioprinting was a modified version of the commercially available two-dimensional (2D) ink-based printers with a biological material and an electronically controlled elevator.

Extrution Printing:

Extrusion printing, a pressure-driven technology, utilizes an extruder that operates through either pneumatic or mechanical pressure to continuously deposit the biomaterial.[5]

Fused deposition modeling (FDM) and direct ink writing (DIW) are both extrusion-based printings.

The fused deposition modeling (FDM) technique employs a mechanical extruder which is widely used in the fabrication of multiphasic scaffolds for periodontal regeneration.[5,6]

The pneumatic and mechanical (piston or screw) dispensing systems are used to extrude biological materials in DIW.[6,7] The DIW system was used to test the printability of this bioink encapsulated with odontoblast-like cells.[8]

Light Assisted Printing:

Light-assisted 3D printing is mainly based on light polymerization of the biomaterial.[9,10]

It is further sub divided into various types, including laser-based printers, stereo lithography techniques, and direct light processing (DLP).

Laser-based printers have different variations, including laser direct writing (LDW)[11], laser-induced forward transfer (LIFT) and Matrix-assisted pulsed laser evaporation (MAPLE)[12].

The late 1980s saw the development of stereo lithography (SLA), which is recognized as the original rapid prototyping method. For example, filling a SLA structure to function as a negative mould.[13]

DLP based Printers:

Because of its speed, high precision, and integrity of fabrication, the DLP-based printer which was invented by Lu et al. and subsequently refined by Zhang et al. is considered one of the most promising 3D printing techniques in fast prototyping technology. It was built on the foundation of SLA.[10]

Electrospinning:

Electro spinning is another technique which uses an electric force to draw a charged polymer in order to form a fiber. By applying a high voltage, an electric field is created between the tip of the needle and the collector plate.[14]

Drugs and growth factors can be added to the fibers to endow specific therapeutic properties.[15,16]

Types of 3D Printing:

Direct 3D printing-It is possible to manufacture objects directly with the use of direct 3D printing. Moreover, it allows for the creation of 3D scaffolds using cells and extracellular matrix.[3]

Indirect 3D printing- Indirect 3D printing involves a two-step process where a wax mould is initially printed and later used to cast with the final polymer. For instance, a 3D wax mould can be prepared to fabricate a fiber-guided scaffold for preserving the alveolar ridge in the extraction sockets .[17]

3D printing with live cells -This method allows for the 3D printing of living cells. Cell aggregates can be incorporated into the 3D-printed scaffolds. Additionally, these scaffolds have the potential to promote cell signalling and tissue formation.[18]

Materials Used In 3D Printers:

Biomaterials for the creation of new tissues can be broadly classified as organic (which is primarily used for soft tissue regeneration) and inorganic (which is primarily utilized for bone regeneration).[19,20]

Only a few materials have been employed in the creation of teeth and the supporting tissue, but several materials, including polymers, ceramics, and composites, have been applied in 3D-printed scaffolds in regenerative medicine.[21]

Natural Polymers:

These are the materials that were used first because they are easy to use and process, and they have a low cost.

Synthetic Polymers

Synthetic polymers are most commonly used for 3D printing in biomedical applications.[22] The most used materials are aliphatic polyethers, polycaprolactone (PCL), polylactic acid, polyglycolic acid and their co-polymer poly lactic-co-glycolic (PLGA). For example, PCL and its modified composites (PCL blended with either natural or synthetic polymers and ceramic materials) are the most common polymers used in printed dental biostructures.

Bioceramics:

Because of its infinite supply, superior biocompatibility, hydrophilic characteristics, and bioactivity, bioceramics are the preferred material for bone repair. They are osteoconductive and may even be osteoinductive, bearing a striking resemblance to the inorganic elements of bone tissue. Because hydroxyapatite (HA) has the same metabolic structure as bone tissue, which promotes osteoblast adhesion and proliferation, HA is the most well-documented phosphocalcic bioceramic.[23,24]

Bio Inks:

"Bioprinting" is the term for the cell-based 3D printing technique, and "bioinks" are the hydrogels that contain the cells needed for printing.

The key characteristics of a bioink should include its biocompatibility, non-toxicity, printable nature, resilience to mechanical strain, shape memory, and capacity to both nourish and stimulate cell metabolism.[25]

General Principles Of 3D Printing:

In short, it operates on three tenets[26]

Modelling: The final version of an object replica is created by transferring the gathered data about an object into computer software for analysis. Thus, modelling refers to the process of gathering data up to the point of computer design expression.

Printing: The modelling format is transformed into a Surface Tessellation Language (STL) file or G-code file, which replicates an object in thin layers. The printer then lays down consecutive layers of material to create a 3D reproduction.

Finishing: The model that is generated after printing will either be large or in certain situations may have surface roughness. Consequently, in order to achieve a precise fitting, the excess material must be eliminated layer by layer.

3D Printing In Periodontal Regeneration:

In a case study done by Rasperini G. et al they used a 3D printed bio resorbable scaffold in treatment of a periodontal defect and this was the first application of a personalized 3D printed scaffold in the field of periodontics.[27] But to our catastrophe, this case was a failure at the end of 13th month, which led to surgical removal of the scaffold. This was because the researchers used only PCL which caused wound dehiscence due to slow tissue degradation rate and led to unsuccessful tissue regeneration due to its inferior cell affinity.[28] Therefore, the scientists came to a conclusion that they should use bioinks with faster resorption rate or the PCL should be incorporated with long standing devices like the titanium screws.[29] But this is strongly believed that this study has paved the way for further research in field of oral regenerative medicine for improved personalized 3D bioprinted structures.

3D Scaffold Design In Periodontal Regeneration:

Scaffold:

The fundamental idea of periodontal tissue engineering is to create a "Tissue Engineered Construct" (TEC) by combining living cells and/or physiologically active chemicals with a scaffold. When this scaffold receives enough blood flow, tissue regeneration will be promoted.

The ideal scaffolds should be biocompatible and biodegradable, promote cell growth and maturation and have a porous 3D structure that makes it easier for cells to connect, migrate, proliferate and differentiate.[30]

Scaffold Designs:

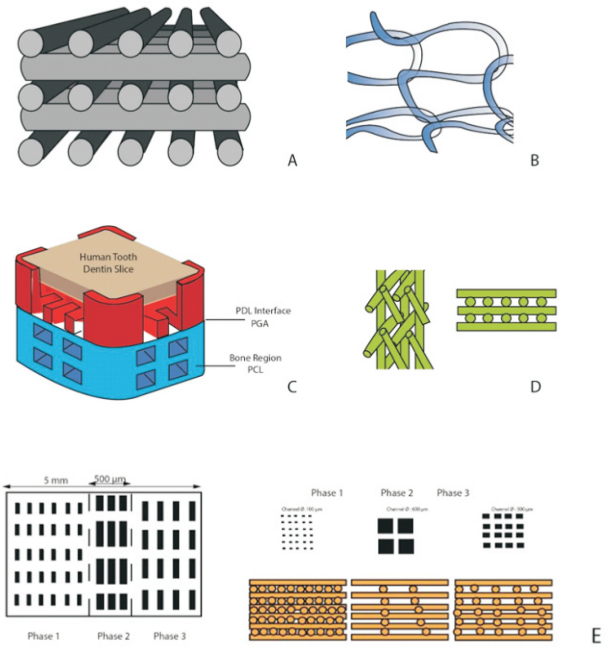
(A) Porous block of laminated strands of biphasic ceramic (-tricalcium phosphate (TCP) + hydroxyapatite (HA)[31];

(B) Monophasic scaffold of poly-L-lactic acid mesh associated with Bone Marrow-derived Mesenchymal Stem Cells with platelet-rich plasma (PRP)[32];

(C) Biphasic scaffold with two compartments: a bone compartment (poly - ε -caprolactone PCL) and a ligament compartment (acid polyglycolique PGA)[33];

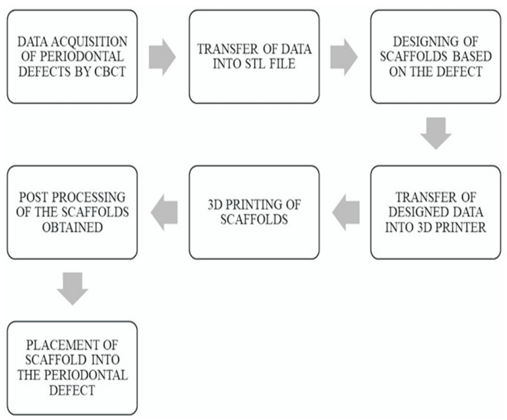
(D) Biphasic scaffold with a bone compartment and a ligament compartment under electron microscopy[34];

(E) Three phase scaffold with distinct phases corresponding to the morphology of the periodontal complex: cement, periodontal ligament and alveolar bone[35].



Steps Involved in 3D Printing of Scaffolds:

This is the Schematic illustration of 3D printing of scaffolds in periodontal regeneration.



Application of 3D Printing in Periodontics:

3D printing in periodontology includes bio-resorbable scaffold for periodontal repair and regeneration, socket preservation, bone and sinus augmentation procedures, guided implant placement, peri-implant maintenance and implant education.[36]

Education of Patient and Dental Students in Periodontal Regenerative Procedures:

Utilising 3D-printed models (such as VANPERIO), patients can be effectively educated about the intricacies of the treatment plan. These 3D models enable patients to grasp the complex treatment procedures involved in achieving successful regeneration of periodontal tissues.[36]

Gingivectomy Surgical Guide:

Using a surgical guide for gingivectomy and smile design is a typical usage of 3D printing in periodontics. Intraoral scanning and computer-aided design (CAD) tools enable the creation and printing of a surgical guide customized for each patient during an aesthetic gingivectomy.[37]

Socket Preservation:

3D-printed scaffolds have shown potential in socket preservation of the alveolar ridge following tooth extraction. A study conducted by Goh et al,[39] evaluated the efficacy of a prefabricated 3D PCL scaffold, printed using FDM in socket preservation and showed integrity of the alveolar ridge over a period of 6 months.[38]

Fenestration Defects:

The use of 3D-printed scaffolds extends to the treatment of fenestration defects as well. Park and Coworkers evaluated the effectiveness of the 3D-printed amorphous and fiber-guided PCL scaffolds in the regeneration of surgically created fenestration defects on the buccal side of the mandible in rats and concluded that fiber-guided 3D-printed scaffolds promoted the successful regeneration of lost periodontal tissues.[39]

Peri Osseous Defects:

Peri-osseous deformities can also be managed with the use of 3D-printed scaffolds. These scaffolds aid in the creation of tailored structures whose size, shape and architecture exactly match those of the peri-osseous deficiencies. The impact of a 3D-printed PCL scaffold made via SLS on the treatment of peri-osseous defects was investigated by Rasperini et al. (2015).[40]

Sinus Augmentation:

The utilisation of 3D-printed scaffolds in sinus augmentation techniques has demonstrated as a potential workable replacement for bone implants. With this method, full bone regeneration was achieved along with a significant osteoconductive impact. Even though, there is now just animal research to support the use of 3D-printed alloplastic block grafts for ridge augmentation, this idea has great potential.[41]

Customized Containment Shells:

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.[42]

3D Printed Bioresorbable Scaffold For Guided Bone And Tissue Regeneration:

The most recent development in tissue engineering is the creation of 3D printed scaffolds. These multiphasic scaffolds are mechanically competent for both the periodontium's hard (cementum and bone) and soft (gingiva and PDL) components. These scaffolds' primary purpose is to encourage the growth of bone, PDL, cementum, and the restoration of their connections.[36]

3D Printing In Implant Placement:

Guided implant placement with fabrication of surgical guides by 3D printing can provide a positive outcome which will also help in accurate 3D placement of implant henceforth preventing any unwanted damage to anatomic structures and can reduce time.Ciocca et al (2015)presented a case report demonstrating a step-by-step procedure for digital alveolar ridge reconstruction to facilitate prosthetically-driven implant placement.[43]

3D Printing For Alveolar Bone Reduction:

A novel concept was developed in 2002 and published for the first time in 2006, which combined the use of 3D printed stereolithographic models with pre-operative virtual planning steps to improve the accuracy of both guided implant osteotomies and bone reduction mandibular edentulous ostectomy in order to achieve the desired amount of bone reduction.[44]

3D Printing For Oral Soft Tissue Regeneration:

By addressing the heterogeneity in the soft tissue shape, inner architecture, thickness, volume, mechanics and function associated with the position in the oral cavity, 3D printing may shouuyoung to be an ideal method for producing scaffolds for soft tissue augmentation. Crucially, the application of the "digital workflow" made possible by 3D printing, would enable the creation of patient-tailored grafts.[45]

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 of the material
- Requires individual training
- Finishing of final product is time consuming and requires skill
- An inherent weakness is literally built into the design.
- Depending on the material, it may still need additional treatment to reach full strength.[46]

Future Prespective:

Even though the previously mentioned applications are equitably futuristic and some have only been tested on animals, some like image-based customized fiber scaffold preparation, can be incorporated into mainstream regenerative periodontology once 3D printing technology becomes more efficient, user-friendly and quick.

There are currently initiatives underway to use 4D printing in the dentistry industry. With the use of 4D printing technology, materials that are 3D printed can respond to environmental stimuli like pressure, heat, light or humidity to change their physical characteristics over time and even after the printing process is finished.[47]

Limitations:

- High cost of 3D printers;
- Need to optimize printing process for biocompatibility;
- Possesses low resolution
- Need to develop appropriate biomaterials;
- Inadequate mechanical properties of the scaffolds;
- Difficulties in preserving cell viability within the printed scaffolds.

Conclusion:

Nowadays, regeneration periodontology is looking forward to the anticipated technological advancement of 3D printing in dentistry. The cost of the equipment and materials, the upkeep and operation of the machineries and the requirement for a trained operator have made 3D printing technology less accessible and less readily available. This technology has the potential to significantly alter the future of not only periodontology but also other dental specialties.

Reference:

1. Lakkaraju, R., Guntakandla, V.R., Gooty, J.R., Palaparthy, R., Vundela, R.K., & Bommireddy, V.S. (2017). "Three-Dimensional Printing" – A New Vista for Periodontal Regeneration: A Review. *International Journal of Medical Reviews, 4*, 81-85. https://doi.org/10.29252/ijmr-040305
2. Ma, Y., Xie, L., Yang, B., & Tian, W. (2019). Three-dimensional printing biotechnology for the regeneration of the tooth and tooth-supporting tissues. *Biotechnology and bioengineering*, *116*(2), 452–468. https://doi.org/10.1002/bit.26882
3. Carter, S. D., Costa, P. F., Vaquette, C., Ivanovski, S., Hutmacher, D. W., & Malda, J. (2017). Additive Biomanufacturing: An Advanced Approach for Periodontal Tissue Regeneration. *Annals of biomedical engineering*, *45*(1), 12–22. https://doi.org/10.1007/s10439-016-1687-2
4. Oberoi, G., Nitsch, S., Edelmayer, M., Janjić, K., Müller, A. S., & Agis, H. (2018). 3D Printing-Encompassing the Facets of Dentistry. *Frontiers in bioengineering and biotechnology*,,172.https://doi.org/10.3389/fbioe.2018.00172
5. Asa'ad, F., Pagni, G., Pilipchuk, S. P., Giannì, A. B., Giannobile, W. V., & Rasperini, G. (2016). 3D-Printed Scaffolds and Biomaterials: Review of Alveolar Bone Augmentation and Periodontal Regeneration Applications. *International journal of dentistry*, *2016*, 1239842. https://doi.org/10.1155/2016/1239842
6. Visser, J., Peters, B., Burger, T. J., Boomstra, J., Dhert, W. J., Melchels, F. P., et al (2013). Biofabrication of multi-material anatomically shaped tissue constructs. *Biofabrication*, *5*(3), 035007. https://doi.org/10.1088/1758-5082/5/3/035007
7. Chang, R., Nam, J., & Sun, W. (2008). Effects of dispensing pressure and nozzle diameter on cell survival from solid freeform fabrication-based direct cell writing. *Tissue engineering. Part A*, *14*(1), 41–48. https://doi.org/10.1089/ten.a.2007.0004
8. Athirasala, A., Tahayeri, A., Thrivikraman, G., França, C. M., Monteiro, N., Tran, V., et al (2018). A dentin-derived hydrogel bioink for 3D bioprinting of cell laden scaffolds for regenerative dentistry. *Biofabrication*, *10*(2), 024101. https://doi.org/10.1088/1758-5090/aa9b4e
9. Michael, S., Sorg, H., Peck, C. T., Koch, L., Deiwick, A., Chichkov, B., et al (2013). Tissue engineered skin substitutes created by laser-assisted bioprinting form skin-like structures in the dorsal skin fold chamber in mice. *PloS one*, *8*(3), e57741. https://doi.org/10.1371/journal.pone.0057741
10. Soman, P., Chung, P. H., Zhang, A. P., & Chen, S. (2013). Digital microfabrication of user-defined 3D microstructures in cell-laden hydrogels. *Biotechnology and bioengineering*, *110*(11), 3038–3047. https://doi.org/10.1002/bit.24957
11. Liao, Y., Song, J., Li, E., Luo, Y., Shen, Y., Chen, D., et al (2012). *Rapid prototyping of three-dimensional microfluidic mixers in glass by femtosecond laser direct writing. Lab on a Chip, 12(4), 746.* https://doi.org/10.1039/c2lc21015k
12. Doraiswamy, A., Narayan, R. J., Lippert, T., Urech, L., Wokaun, A., Nagel, M et al (2006). *Excimer laser forward transfer of mammalian cells using a novel triazene absorbing layer. Applied Surface Science, 252(13), 4743–4747.* https://doi.org/10.1016/j.apsusc.2005.07.166
13. Chia, H. N., & Wu, B. M. (2015). Recent advances in 3D printing of biomaterials. *Journal of biological engineering*, *9*, 4. https://doi.org/10.1186/s13036-015-0001-4
14. Xue, J., Wu, T., Dai, Y., & Xia, Y. (2019). Electrospinning and Electrospun Nanofibers: Methods, Materials, and Applications. *Chemical reviews*, *119*(8), 5298–5415. https://doi.org/10.1021/acs.chemrev.8b00593
15. Bottino, M. C., Kamocki, K., Yassen, G. H., Platt, J. A., Vail, M. M., Ehrlich, Y., et al (2013). Bioactive nanofibrous scaffolds for regenerative endodontics. *Journal of dental research*, *92*(11), 963–969. https://doi.org/10.1177/0022034513505770
16. Bottino, M. C., Arthur, R. A., Waeiss, R. A., Kamocki, K., Gregson, K. S., & Gregory, R. L. (2014). Biodegradable nanofibrous drug delivery systems: effects of metronidazole and ciprofloxacin on periodontopathogens and commensal oral bacteria. *Clinical oral investigations*, *18*(9), 2151–2158. https://doi.org/10.1007/s00784-014-1201-x
17. Park, C. H., Kim, K. H., Rios, H. F., Lee, Y. M., Giannobile, W. V., & Seol, Y. J. (2014). Spatiotemporally controlled microchannels of periodontal mimic scaffolds. *Journal of dental research*, *93*(12), 1304–1312. https://doi.org/10.1177/0022034514550716

18. Kačarević, Ž. P., Rider, P. M., Alkildani, S., Retnasingh, S., Smeets, R., Jung, O., et al (2018). An Introduction to 3D Bioprinting: Possibilities, Challenges and Future Aspects. *Materials (Basel, Switzerland)*, *11*(11), 2199. https://doi.org/10.3390/ma11112199
19. Fahmy, M. D., Jazayeri, H. E., Razavi, M., Masri, R., & Tayebi, L. (2016). Three-Dimensional Bioprinting Materials with Potential Application in Preprosthetic Surgery. *Journal of prosthodontics : official journal of the American College of Prosthodontists*, *25*(4), 310–318. https://doi.org/10.1111/jopr.12431
20. Ceccarelli, G., Presta, R., Benedetti, L., Cusella De Angelis, M. G., Lupi, S. M., & Rodriguez Y Baena, R. (2017). Emerging Perspectives in Scaffold for Tissue Engineering in Oral Surgery. *Stem cells international*, *2017*, 4585401. https://doi.org/10.1155/2017/4585401
21. Obregon, F., Vaquette, C., Ivanovski, S., Hutmacher, D. W., & Bertassoni, L. E. (2015). Three-Dimensional Bioprinting for Regenerative Dentistry and Craniofacial Tissue Engineering. *Journal of dental research*, *94*(9 Suppl), 143S–52S. https://doi.org/10.1177/0022034515588885
22. Woodruff, M. A., & Hutmacher, D. W. (2010). *The return of a forgotten polymer—Polycaprolactone in the 21st century. Progress in Polymer Science, 35(10), 1217–1256.* https://doi.org/10.1016/j.progpolymsci.2010.04.0
23. Wubneh, A., Tsekoura, E. K., Ayranci, C., & Uludağ, H. (2018). Current state of fabrication technologies and materials for bone tissue engineering. *Acta biomaterialia*, *80*, 1–30. https://doi.org/10.1016/j.actbio.2018.09.031
24. Chocholata, P., Kulda, V., & Babuska, V. (2019). Fabrication of Scaffolds for Bone-Tissue Regeneration. *Materials (Basel, Switzerland)*, *12*(4), 568. https://doi.org/10.3390/ma12040568
25. Gopinathan, J., & Noh, I. (2018). Recent trends in bioinks for 3D printing. *Biomaterials research*, *22*, 11. https://doi.org/10.1186/s40824-018-0122-1
26. Kaur N, Grover D, Kaur G, Future dental device- 3-dimensional printing approach in dentistry. ***IP Int J Maxillofac Imaging*** 2021;7(2):37-47. https://doi.org/10.18231/j.ijmi.2021.009
27. Won, J. Y., Park, C. Y., Bae, J. H., Ahn, G., Kim, C., Lim, D. H., et al (2016). Evaluation of 3D printed PCL/PLGA/β-TCP versus collagen membranes for guided bone regeneration in a beagle implant model. *Biomedical materials (Bristol, England)*, *11*(5), 055013. https://doi.org/10.1088/1748-6041/11/5/055013
28. Ausenda, F., Rasperini, G., Acunzo, R., Gorbunkova, A., & Pagni, G. (2019). New Perspectives in the Use of Biomaterials for Periodontal Regeneration. *Materials (Basel, Switzerland)*, *12*(13), 2197. https://doi.org/10.3390/ma12132197
29. Carrel, J. P., Wiskott, A., Moussa, M., Rieder, P., Scherrer, S., & Durual, S. (2016). A 3D printed TCP/HA structure as a new osteoconductive scaffold for vertical bone augmentation. *Clinical oral implants research*, *27*(1), 55–62. https://doi.org/10.1111/clr.12503
30. Dawood, A., Marti Marti, B., Sauret-Jackson, V., & Darwood, A. (2015). 3D printing in dentistry. *British dental journal*, *219*(11), 521–529. https://doi.org/10.1038/sj.bdj.2015.914
31. Carrel, J. P., Wiskott, A., Moussa, M., Rieder, P., Scherrer, S., & Durual, S. (2016). A 3D printed TCP/HA structure as a new osteoconductive scaffold for vertical bone augmentation. *Clinical oral implants research*, *27*(1), 55–62. https://doi.org/10.1111/clr.12503
32. Baba, S., Hashimoto, Y., Inoue, T., Kimura, D., Sumikura, S., Sonoda, Y., (2011). Evaluation of a 3-D, woven-fabric, composite Scaffold using experimental canine models of bone defects in mandibles. *J Oral Tissue Engin, 2011;8(3)*:212-221, https://doi.org/10.11223/jarde.8.212,
33. Park, C. H., Rios, H. F., Jin, Q., Bland, M. E., Flanagan, C. L., Hollister, S. J., et al (2010).Biomimetic hybrid scaffolds for engineering human tooth-ligament interfaces. *Biomaterials*, *31*(23),5945–5952, https://doi.org/10.1016/j.biomaterials.2010.04.027

34. Vaquette, C., Fan, W., Xiao, Y., Hamlet, S., Hutmacher, D. W., & Ivanovski, S. (2012). A biphasic scaffold design combined with cell sheet technology for simultaneous regeneration of alveolar bone/periodontal ligament complex. *Biomaterials*, *33*(22), 5560–5573. https://doi.org/10.1016/j.biomaterials.2012.04.038
35. Lee, C. H., Hajibandeh, J., Suzuki, T., Fan, A., Shang, P., & Mao, J. J. (2014). Three-dimensional printed multiphase scaffolds for regeneration of periodontium complex. *Tissue engineering. Part A*, *20*(78), 1342–1351. https://doi.org/10.1089/ten.TEA.2013.0386
36. Gul, M., Arif, A., & Ghafoor, R. (2019). Role of three-dimensional printing in periodontal regeneration and repair: Literature review. *Journal of Indian Society of Periodontology*, *23*(6), 504–510. https://doi.org/10.4103/jisp.jisp_46_19
37. Oberoi, G., Nitsch, S., Edelmayer, M., Janjić, K., Müller, A. S., & Agis, H. (2018). 3D Printing-Encompassing the Facets of Dentistry. *Frontiers in bioengineering and biotechnology*, *6*, 172. https://doi.org/10.3389/fbioe.2018.00172
38. Goh, B. T., Teh, L. Y., Tan, D. B., Zhang, Z., & Teoh, S. H. (2015). Novel 3D polycaprolactone scaffold for ridge preservation--a pilot randomised controlled clinical trial. *Clinical oral implants research*, *26*(3), 271–277. https://doi.org/10.1111/clr.12486
39. Park, C. H., Kim, K. H., Rios, H. F., Lee, Y. M., Giannobile, W. V., & Seol, Y. J. (2014).Spatiotemporally controlled microchannels of periodontal mimic scaffolds. *Journal of dental research*, *93*(12), 1304–1312. https://doi.org/10.1177/0022034514550716
40. Rasperini, G., Pilipchuk, S. P., Flanagan, C. L., Park, C. H., Pagni, G., Hollister, S. J., et al (2015). 3D-printed Bioresorbable Scaffold for Periodontal Repair. *Journal of dental research*, *94*(9 Suppl), 153S–7S. https://doi.org/10.1177/0022034515588303
41. Mangano, C., Barboni, B., Valbonetti, L., Berardinelli, P., Martelli, A., Muttini, A., et al (2015). In Vivo Behavior of a Custom-Made 3D Synthetic Bone Substitute in Sinus Augmentation Procedures in Sheep. *The Journal of oral implantology*, *41*(3), 240–250. https://doi.org/10.1563/AAID-JOI-D-13-00053
42. Ciocca, L., Ragazzini, S., Fantini, M., Corinaldesi, G., & Scotti, R. (2015). Work flow for the prosthetic rehabilitation of atrophic patients with a minimal-intervention CAD/CAM approach. *The Journal of prosthetic dentistry*, *114*(1), 22–26. https://doi.org/10.1016/j.prosdent.2014.11.014
43. D'haese, J., Ackhurst, J., Wismeijer, D., De Bruyn, H., & Tahmaseb, A. (2017). Current state of the art of computer-guided implant surgery. *Periodontology 2000*, *73*(1), 121–133. https://doi.org/10.1111/prd.12175
44. Mijiritsky, E., Ben Zaken, H., Shacham, M., Cinar, I. C., Tore, C., Nagy, K., et al (2021). Variety of Surgical Guides and Protocols for Bone Reduction Prior to Implant Placement: A Narrative Review. *International journal of environmental research and public health*, *18*(5), 2341. https://doi.org/10.3390/ijerph18052341
45. Murphy, S. V., & Atala, A. (2014). 3D bioprinting of tissues and organs. *Nature biotechnology*, *32*(8), 773–785. https://doi.org/10.1038/nbt.2958
46. Hazra, Yashodhora & Rao, Arathi & Bhat, Suprabha. (2022). 3-D Printing: Its Applications in Pediatric Dental Practice: A Review of Literature. *Indian Journal of Contemporary Dentistry*. 10. https;//doi.org/10.37506/ijocd.v10i2.18421.
47. Salah, M., Tayebi, L., Moharamzadeh, K., & Naini, F. B. (2020). Three-dimensional bio-printing and bone tissue engineering: technical innovations and potential applications in maxillofacial reconstructive surgery. *Maxillofacial plastic and reconstructive surgery*, *42*(1), 18. https://doi.org/10.1186/s40902-020-00263-6