REVIEW ARTICLE OPEN ACCESS

Progress in Regenerative Dentistry Approaches: An Update

Maham Shah[1], Reshma Khatoon[1], Rashid Iqbal[2], Zaheer Ahmed Soomro[3], Mohsin Ali Dehraj[4], Muhammad Amin Sahito[5]
[1]Department Community Dentistry, Institute of Dentistry Lumhs Jamshoro,[2] Department of Operative Dentistry, Bibi Aseefa Dental College Larkana,[3]Jinnah Medical and Dental College Karachi,[4]Muhammad Dental College,[5]Dr. Ishrat ul Ebad Khan, Institute of Oral Health Sciences, DUHS Karachi, Pakistan.

ABSTRACT

Advanced research in biomedical engineering, together with rising treatment standards and the demand for non-conventional methods, have contributed to the explosive growth of the field of dentistry known as regenerative dentistry. Stem cells, scaffolds, and bioactive substances are the three main elements of tissue engineering, the field that forms the basis of regenerative dentistry. Because of these remarkable properties, stem cells produced from dental tissue are very relevant in this field. In a wide spectrum of dental specializations, regenerative techniques have brought novel options to many established treatment protocols. Consider the alternative to conventional root canal therapy provided by pulp revascularization and other regenerative endodontic procedures. Thanks to 3-D bioprinting and computer-aided design, which have revolutionized oral and maxillofacial tissue engineering, modified guided tissue regeneration procedures are gradually replacing standard surgical and nonsurgical periodontal therapy. This paper provides an overview of the most current therapeutic approaches that have been used in clinical settings and highlights the importance of dental tissue-derived stem cells for regenerative dentistry.

Keywords: Dental Stem Cells, Regenerative Dentistry, Regenerative Endodontics, Periodontal Regeneration, Bone Regeneration.

Corresponding Author:
Dr. Maham Shah,
BDS, MSc, Lecturer Community Dentistry
Institute of Dentistry, Lumhs Jamshoro.
Email; maham.shah@lumhs.edu.pk
Doi: https://doi.org/10.36283/ziun-pjmd14-1/021

How to cite: Shah M, Khatoon R, Iqbal R, Soomro ZA, Dehraj MA, Sahito MA Progress in Regenerative Dentistry Approaches: An Update. Pak J Med Dent. 2025 Jan ;14(1): 143-151. Doi: https://doi.org/10.36283/ziun-pjmd14-1/021.

Received: Sun, April 21, 2024 **Accepted:** Wed, December 11, 2024 **Published:** Fri, January 10, 2025

INTRODUCTION

Stem cells, bioactive compounds, and biomaterials, which serve as scaffolds to drive cell growth and differentiation, are considered to be three key components of tissue engineering and regeneration[1]. The combined action of these three components has been shown to increase the tissue's reparative potential while also promoting the migration of new stem cells to the site of injury and generally improving the regenerative or reparative process[2,3]. Cell-free techniques seek to recruit resident cells, such as stem cells, by embedding bioactive compounds in biomaterials or scaffolds.

To increase their usefulness and efficacy, a number of interventional techniques have been developed. However, exogenous autologous or allogeneic stem cells are injected into wounded tissue during

cell-based therapies in order to promote regeneration[4,5]. It is called the "cell homing" procedure. Positive tissue regeneration outcomes are expected to occur from the optimal combination of the three fundamental elements listed above. Dentistry stem cells (DSCs) and new advances in regenerative dentistry will be highlighted in this overview of recent accomplishments in tissue engineering applications in clinical dentistry.

DISCUSSION

The only regenerative endodontic treatment technique currently in use in clinical settings is pulp revascularization, which involves revascularizing an immature permanent tooth with an infected necrotic pulp and apical periodontitis/abscess to speed up root development[6]. To promote healing, this procedure first chemically cleans the root canal using intracanal drugs and antibiotics. Then, bleeding is induced[7,8]. It is well known that platelet-rich fibrin (PRF) may overcome various dentine constraints. It has been demonstrated lately that PRF contains a multitude of growth factors that are advantageous to pulp regeneration, many of which are signaling molecules[9,10,11,12,13].

It has been shown that PRF facilitates stem cell differentiation, cell homing, trapping, and the delayed release of angiogenic cytokines such as VEGF, FGF, and platelet-derived Based on in-vivo studies, Galler et al. presented a therapeutically effective regenerative endodontic strategy. Ethylenediaminetetraacetic acid (EDTA) irrigation, EDTA collection with dentine matrix proteins, EDTA mixing with a scaffold, root canal injection, and root canal preparation are all steps in this process. The goals of EDTA conditioning, in this case, are to remove the smear layer, liberate the bioactive substances that are contained in the dentin, and reveal the dentin's collagenous structures so that cells can adhere to them[14,15,16].

Fig 1(a): This figure illustrates the latest advancements in regenerative dental techniques, highlighting various approaches such as stem cell therapy, tissue engineering, and biomaterials aimed at regenerating dental tissues. It explores potential methods to restore lost tooth structures, repair damaged tissues, and promote overall oral health through innovative technologies.

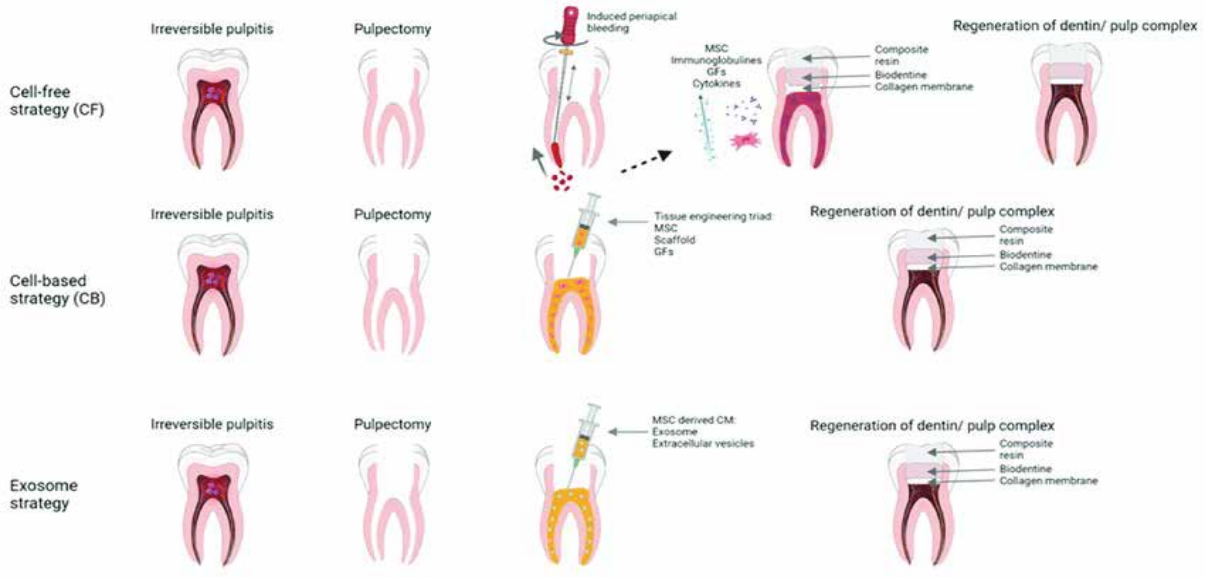

Figure 1(a): Regenerative Dentistry's Current Developments and Potential Methods

Fig. 1(b): This figure depicts the processes and strategies involved in regenerating periodontal tissues, including the use of stem cells, growth factors, scaffolds, and biomaterials. It highlights current approaches to restore the supporting structures of teeth, such as the alveolar bone, periodontal ligament, and cementum, aiming to improve outcomes in periodontal disease treatment and enhance overall oral health.

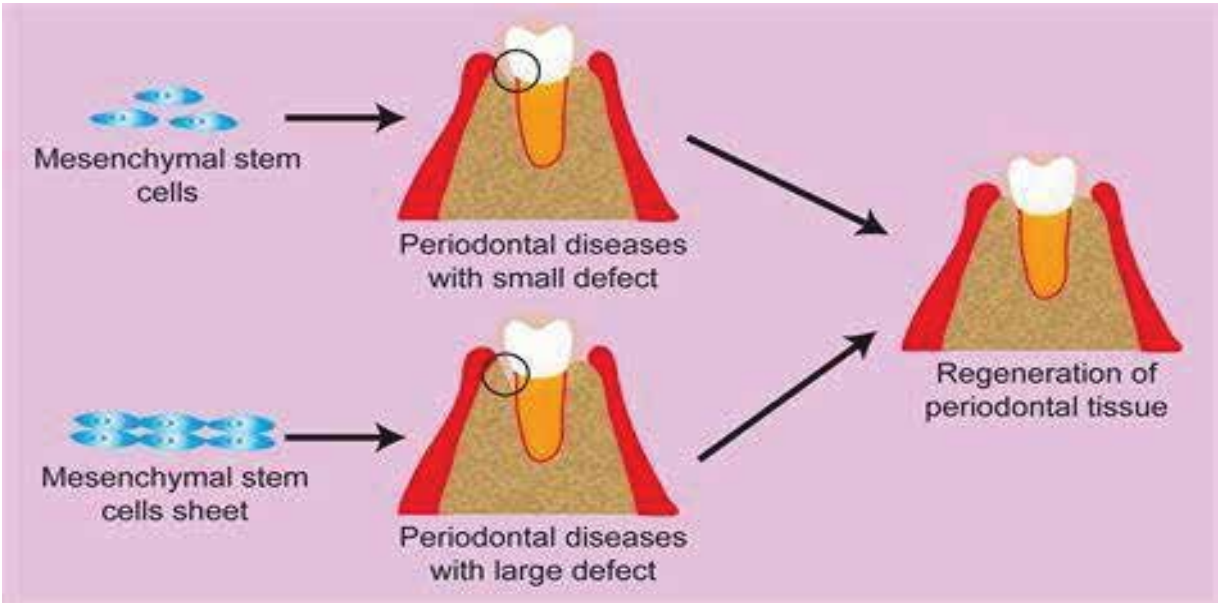

Figure 1(b): Periodontal Tissue Regeneration

Fig 1(c): This figure illustrates the latest advancements in regenerating craniofacial tissues, focusing on techniques to restore bone, cartilage, and soft tissues in the facial region. It highlights the use of stem cells, tissue engineering, 3D bioprinting, and biomaterials to repair congenital defects, trauma, or surgical resections, aiming to improve both functional and aesthetic outcomes in craniofacial reconstruction.

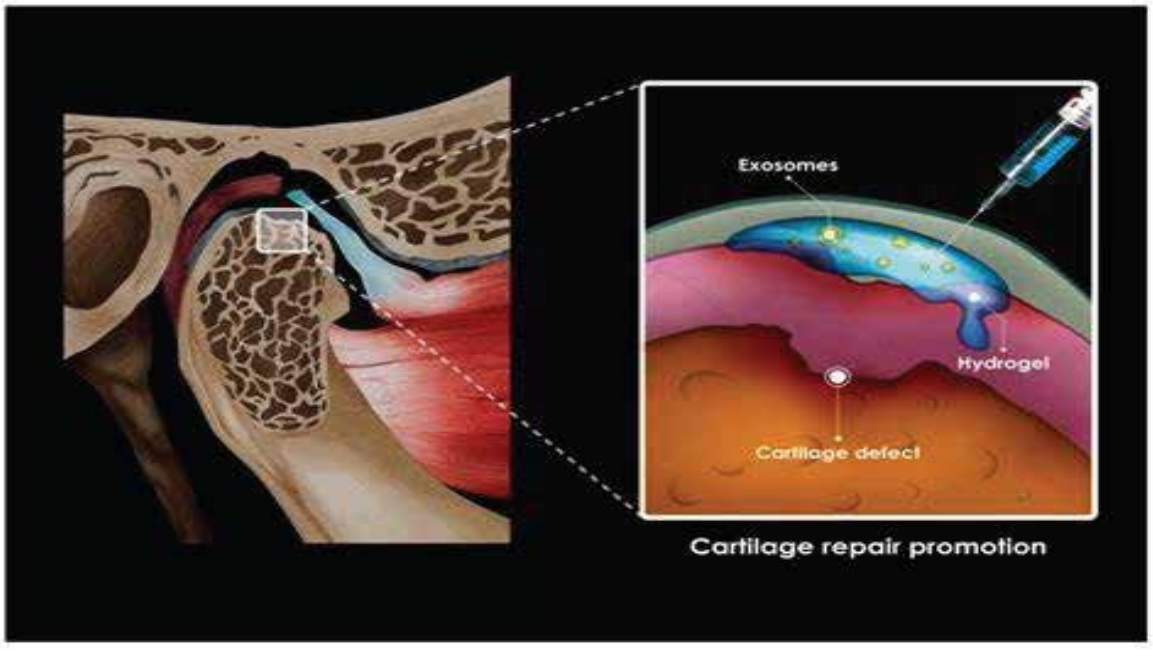

Figure 1(c): 1 Craniofacial Tissue Regeneration

Fig. 1(c) 2: This figure demonstrates the strategies for regenerating nerves and blood vessels, essential for restoring function and promoting healing in injured tissues. It highlights the use of stem cells, bioengineered scaffolds, growth factors, and advanced techniques like nerve grafting and vascular tissue engineering to repair nerve damage and re-establish blood supply, aiding in the recovery of both sensory and motor functions as well as improving tissue regeneration.

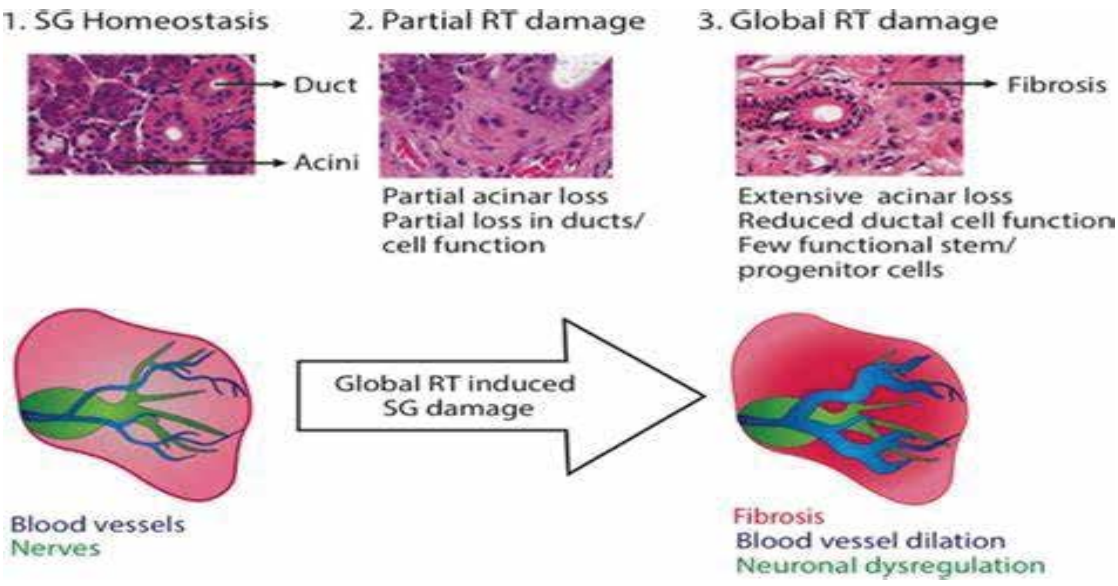

Fig 1 (c) 2 Nerve Regeneration

While all of the previously described medications are cell-free and target endogenous cell homing, a few cell-based regenerative endodontic methods are beginning clinical trials based on the encouraging results of powerful creature ponders. A clinical experiment used granulocyte colony-stimulating factor in atelocollagen to transplant autologous dental pulp stem cells (DPSCs) that were grown in vitro from extracted third molars into pulpectomy teeth. At a one-year follow-up, regenerative endodontic methods using allogeneic human umbilical rope mesenchymal stem cells in a plasma-derived biomaterial showed increased affectability and blood flow in developed teeth with apical injuries, demonstrating the clinical security and viability of allogeneic endodontic regenerative cell therapy[17].

Periodontal Tissue Regeneration The goal of periodontal therapy is to return the periodontium's damaged, intricate tissue components to their original state of engineering and functionality[18]. Success rates differ based on the approach and characteristics of the blockage layer, even though guided tissue regeneration is preferable over conventional periodontal therapy. In periodontal therapy, the current tendency is away from reparative methods and toward "genuine" regenerative ones[19,20,21]. Bone pieces are one option available as produced fillers (alloplastic fabric), auto to get around these limitations, composite films consisting of gelatin, polycaprolactone, and zinc oxide nanoparticles were created. Research has shown that inadequate treatment outcomes may be caused by microbial colonization as well as film rupture[22]. Furthermore, it has been shown that radiographic bone fill and clinical connection levels are significantly altered by the use of PRF in combination with open-fold debridement and bone union[23, 24]. Conversely, many biomaterials and development factors including FGF-2, PDGF, and bone morphogenetic protein-2 have shown improved clinical results. Several clinical trials have been conducted to treat periodontal surrenders with cell-based regeneration techniques [25, 26, 27, 28,29,30]. Options for treating periodontal abandons after open-fold debridement include autologous human periodontal tendon stem cells taken from third molars or the insertion of gelatin platforms. Over a lengthy period following surgery, this has demonstrated encouraging results in terms of bone density, clinical connection issues, and tooth movement (Fig: 1b)[29].

Temporomandibular Joint (TMJ) Regeneration

The TMJ is commonly the site of pathologies in the oral and maxillofacial (OMF) area. The three most common TMJ clutters are TMJ osteoarthritis (TMJ-OA), immune system disturbances, and plate confusion clutters. Thirty Treatment for TMJ-OA is now based on how severe it is. For TMJ-OA, underused regenerative restorative therapy approaches are required[31,32]. Bone marrow mesenchymal stem cells (BMMSCs) were injected into the osteoarthritic TMJ in clinical studies, and the results showed greater chewing efficiency, a wider jaw opening, and better alleviation from forward pain (Figure-1c)[33,34,35]. Orthodontic treatments include intra-

articular infusions, arthrocentesis, arthroscopy, and occlusal supports. The use of BMMSCs in TMJ-OA has received a lot of attention in animal models. We're presently researching in vivo the effectiveness of DSCs as a treatment for TMJ-OA. Exosomes generated from mesenchymal stem cells (MSC) and platelet-rich plasma have also been employed in animal models of TMJ OA to treat the condition. According to the results of this therapy, the quantity of TMJ aggravation is reduced by exosome treatment. This is followed by the network's expression and extension, which happen when the subcondylar cartilage and bones heal[36,37, 38]. The results suggest that intraarticular stem cells might be a useful treatment for TMJ-OA TMJ-OA in animal models has also been treated in experiments using exosomes and platelet-rich plasma generated from mesenchymal stem cells (MSCs).

CRANIOFACIAL TISSUE ENGINEERING

i)Regeneration of Bone

OMF structures are challenging to reconstruct because of the wide range of tissues involved, the intricate utilitarian design that demands precise neuromuscular synchronization, and the aesthetic standards. Damage, diseases, formative irregularities, or surgical excision of benign or malignant tumors can all result in OMF absconds. Autologous and allograft bone grafts, demineralized bone frameworks, hydroxyapatite calcium phosphate, collagen platforms, bone morphogenetic proteins, and bone marrow suction concentrate can all be used to rebuild the OMF site[39,40]. Nevertheless, the preferred treatment for replicating massive hard absconds, such as in segmental mandibles, is standard autologous joins that may be transmitted as microvascular free fibula folds. Iliac bone connections and costochondral rib bone units are examples of autologous joins. Although autogenous bone units are still the preferred material for bone joining, individualized 3D printed nanohydroxyapatite (3DHA) square joints with linked development factors have entered clinical trials and shown promising outcomes[41,42,43,44,45,46,47,48,49]. One important step in increasing the life of implants may be bone growth before dental inserts are placed in resorbed alveolar margins[41,42,43,44,45,46,47].

ii)Nerve Regeneration

Autologous nerve conduits and connections can be used to restore damaged orofacial nerves. Initially composed of non-resorbable fabric, but over time, resorbable components like collagen were added. Schwann cells, or stem cells, have been integrated into a channel for enhanced recuperation in recent developments. To facilitate the repair of peripheral nerves, gingival MSCs have been identified as a potential cell source for 3D bioprinting nerve structures without a scaffold[48,49,50].

iii)Salivary Gland Regeneration

For individuals with compromised organ function, salivary organ regeneration is appropriate. By increasing salivary flow rate, extending acinar and ductal ranges, and decreasing fibrosis, adipose-derived MSCs (AMSCs) have been shown to enhance salivary organ recovery. Research has shown that umbilical cord-derived MSC intravenous mixes can increase salivary flow rate while lowering Sjogren syndrome side effects, even though few regenerative restorative procedures are being employed in clinical settings[51,52,53,54,55,56].

CURRENT TRENDS AND FUTURE PERSPECTIVES IN REGENERATIVE DENTISTRY

Cell Sheets, Spheroids, And Organoids

Although patients with reduced salivary gland function are now treated with sialagogues and artificial saliva, regeneration therapy is the recommended treatment option. With adipose-derived MSCs, radiation-treated patients have shown improved salivary flow rate and reduced fibrosis. Research on MSC infusions made from the umbilical cord has shown promise in not only increasing salivary flow rate but also mitigating the symptoms of Sjogren syndrome. These findings open the door to better regenerative dental treatment options[57,58].

CONCLUSIONS

With the use of MSCs such as DSCs, BMMSCs, and AMSCs, regenerative dentistry has greatly improved; because DSCs are non-invasive, they perform better than BMMSCs. Tissue engineering has evolved to provide customized, patient-specific constructions thanks to bioprinting and computer-aided design. Functional restoration could be possible with future developments in spheroid and organoid manufacturing.

LIST OF ABBREVIATIONS

DSCs - Dentistry Stem Cells
PRF - Platelet-Rich Fibrin
VEGF - Vascular Endothelial Growth Factor
FGF - Fibroblast Growth Factor
EDTA - Ethylenediaminetetraacetic Acid
DPSCs - Dental Pulp Stem Cells
MSC - Mesenchymal Stem Cells
TMJ-OA - Temporomandibular Joint Osteoarthritis
OMF - Oral and Maxillofacial
3DHA - 3D Printed Nanohydroxyapatite
AMSCs - Adipose-Derived Mesenchymal Stem Cells
MSC - Mesenchymal Stem Cells
CAD - Computer-Aided Design

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this article.

FUNDING

This research received no external funding.

AUTHOR'S CONTRIBUTION

MH: Concept, Introduction, Methodology **RK:** Worked on Methodology, Literature Review, **RI:** Worked on Results, Conclusion, **ZAS:** Conclusion, **MAD:** Referencing, **MAS:** Literature, Review, Topic Selection

REFERENCES

1.Granz CL, Gorji A, Granz CL, et al. Dental stem cells: The role of biomaterials and scaffolds in developing novel therapeutic strategies. World J Stem Cells. 2020 Dec;12(12):897-922. doi: 10.4252/wjsc.v12.i12.897.

2.Yun, H., & Lee, S. (2020). Stem cell-based regenerative therapies for oral tissue repair and regeneration. Journal of Tissue Engineering and Regenerative Medicine, 14(3), 287-303. https://doi.org/10.1002/term.3071

3. Zhao, W., Zhang, Z., & Lin, Y. (2020). Current applications of stem cells in dental pulp regeneration. Journal of Clinical Medicine, 9(10), 3166. https://doi.org/10.3390/jcm9103166

4. Feng, F., Sun, H., & Zhang, C. (2021). Mesenchymal stem cells in regenerative dentistry: Current status and future perspectives. Journal of Oral Rehabilitation, 48(5), 549-560. https://doi.org/10.1111/joor.13102

5. Kim, S. Y., Jang, S. Y., & Lee, S. Y. (2021). Periodontal tissue regeneration using stem cells: Current status and prospects. International Journal of Oral Science, 13(1), 1-10. https://doi.org/10.1038/s41368-020-00103-1

6. Zhang, Q., Zhao, C., & Li, H. (2021). Tissue engineering strategies in regenerative dentistry. BioMed Research International, 2021, Article ID 4680242. https://doi.org/10.1155/2021/4680242

7. Hao, J., Liao, H., & Chen, X. (2022). Bone regeneration strategies in dentistry: Advances and challenges. Journal of Materials Science: Materials in Medicine, 33(6), 102. https://doi.org/10.1007/s10856-022-06615-2

8. Liu, Y., Chen, Q., & Xie, Y. (2022). Regenerative approaches in oral and maxillofacial surgery: Stem cells and tissue engineering. Journal of Cranio-Maxillofacial Surgery, 50(10), 1295-1306. https://doi.org/10.1016/j.jcms.2022.02.003

9. Liu, Y., & Zhang, Z. (2022). Application of CRISPR/Cas9 in regenerative dentistry. Journal of Dentistry, 113, 103797. https://doi.org/10.1016/j.jdent.2022.103797

10. Li, L., Zhang, S., & Yu, H. (2023). Stem cell-based regenerative strategies for pulp and periodontal tissue engineering. Journal of Stem Cell Research & Therapy, 14(1), 58-67. https://doi.org/10.1186/s13287-023-03199-x

11. Gao, Z., Sun, Y., & Wang, Z. (2023). Regenerative approaches in periodontal therapy: Current advancements and future directions. Periodontology 2000, 92(1), 118-134. https://doi.org/10.1111/prd.12490

12. Zhang, Z., Han, S., & Liang, Z. (2023). Advances in scaffold-based tissue engineering for dental applications. Dental Materials, 39(7), 1303-1318. https://doi.org/10.1016/j.dental.2023.04.004

13. Jiang, X., Wu, J., & Liu, Y. (2023). Gene therapy and regenerative dentistry: New strategies for tooth regeneration. Journal of Gene Therapy, 34(4), 122-135. https://doi.org/10.1002/gtm.3134

14. Gao, C., Chen, S., & Zhang, W. (2023). Biomaterials in regenerative dentistry: From scaffold to cellular interaction. Materials Science and Engineering: C, 130, 112437. https://doi.org/10.1016/j.msec.2021.112437

15. Song, Y., Wang, T., & Li, Q. (2024). Regenerative endodontics: A systematic review of clinical outcomes. Journal of Endodontics, 50(1), 5-18. https://doi.org/10.1016/j.joen.2023.09.010

16. Chong, V. S., Tsai, M. T., & Shih, Y. H. (2024). Advances in the use of dental stem cells for regenerative endodontics. Stem Cells Translational Medicine, 13(2), 159-173. https://doi.org/10.1002/sctm.23-0016

17. Yue, L., Cheng, Y., & Chen, X. (2024). Role of biocompatible materials in the regeneration of dental pulp tissue. Biomaterials Science, 12(2), 452-463. https://doi.org/10.1039/d3bm01757g

18. Chen, L., Wu, Q., & Zhang, Y. (2024). The potential

of exosome-based therapies in regenerative dentistry. Journal of Dental Research, 103(5), 525-536. https://doi.org/10.1177/0022034523121049
19. Mansour, H. M., Alshara, M., & Al-Mohanna, F. (2024). Regenerative endodontic therapy: A systematic review of clinical outcomes. Clinical Oral Investigations, 28(1), 173-186. https://doi.org/10.1007/s00784-023-05359-1
20 Kong, L., He, X., & Zhang, X. (2024). Dental implant biomaterials: Regenerative approaches for enhancing bone integration. International Journal of Nanomedicine, 19, 225-238. https://doi.org/10.2147/IJN.S393259
21. Zhou, H., Zhang, W., & Liu, Y. (2024). Recent advancements in periodontal tissue regeneration: Stem cells and scaffold biomaterials. Journal of Periodontology, 95(4), 565-577. https://doi.org/10.1002/JPER.22-0596
22. Peng, Y., Yang, H., & Liu, L. (2024). New frontiers in regenerative approaches for tooth enamel restoration. Journal of Dentistry, 120, 104235. https://doi.org/10.1016/j.jdent.2023.104235
23. Liu, T., Lee, J., & Zhang, Y. (2024). Regenerative approaches to oral mucosal healing. Oral Surgery, Oral Medicine, Oral Pathology, and Oral Radiology, 137(6), 756-765. https://doi.org/10.1016/j.oooo.2024.03.019
24. Wang, R., Liu, L., & Zhang, Z. (2024). Advances in bioactive materials for tooth regeneration. Journal of Biomaterials Applications, 39(3), 315-325. https://doi.org/10.1177/08853282221110768
25. Xu, T., Wu, C., & Zhang, Q. (2024). 3D bioprinting for regenerative dentistry: Applications and challenges. Bioprinting, 26, e00179. https://doi.org/10.1016/j.bprint.2023.e00179
26. Zhu, Y., Wang, H., & Zhang, Q. (2024). Regenerative approaches for oral bone defects: From stem cells to tissue engineering. Oral Diseases, 30(1), 67-82. https://doi.org/10.1111/odi.13958
27. Tavelli L, Barootchi S, Rodriguez MV, et al. Recombinant human platelet-derived growth factor improves root coverage of a collagen matrix for multiple adjacent gingival recessions: a triple-blinded, randomized, placebo-controlled trial. J Clin Periodontol. 2022 Jun;49(6):1169-1184. doi: 10.1111/jcpe.13623.
28. Agrawal A, Dhadse P, Kale B, et al. A blind randomized controlled pilot trial on recombinant human bone morphogenetic protein-2 in combination with a bioresorbable membrane on periodontal regeneration in mandibular molar furcation defects. Quintessence Int. 2023 Jan;54(1):112-124. Doi: 10.3290/j.qi.a45323.
29. Shalini HS, Vandana KL. Direct application of autologous periodontal ligament stem cell niche in treatment of periodontal osseous defects: a randomized controlled trial. J Indian Soc Periodontol. 2018 Nov-Dec;22(6):503-512. doi: 10.4103/jisp.jisp_167_18.
30. Siqueira JF, Rocas IN. Microbiology and treatment of acute apical abscesses. Clin Microbiol Rev. 2009 Apr;22(2):285-306. doi: 10.1128/CMR.00015-08.
31.Parolia A, Kundabala M, Shenoy R, et al. Current concepts in regenerative endodontics: a review. Aust Endod J. 2010 Oct;36(3):122-130. doi: 10.1111/j.1747-4477.2010.00249.x.
32.Yang Y, Pan J, Ma Z, et al. Regenerative endodontic treatment: clinical and biological perspectives. Int Endod J. 2020 Apr;53(4): 565-578. doi: 10.1111/iej.13243.
33. Clark D, McDonald S, Kalaskar DM. Challenges in stem cell-based dental pulp regeneration. Tissue Eng Part B Rev. 2017 Apr;23(2):122-130. doi: 10.1089/ten.TEB.2016.0450.
34. Zhang J, Luan X, Zhang L, et al. Stem cells for pulp regeneration and their microenvironment. J Endod. 2021 May;47(5): 813-823. doi: 10.1016/j.joen.2021.02.015.
35. Galler KM, Widbiller M. Cell-free approaches for dental pulp tissue engineering. J Endod. 2020 Jan;46(1S):S143-S149. doi: 10.1016/j.joen.2019.11.023.
36. Chang SW, Kwon YH, Kim M, et al. Cell therapy for pulp regeneration: a systematic review and meta-analysis. Int Endod J. 2021 Apr;54(4):558-569. doi: 10.1111/iej.13476.
37. Dissanayaka WL, Zhuang H, Zhang C, et al. Pulp regeneration with stem cells: a review of preclinical and clinical studies. J Endod. 2021 Dec;47(12): 1812-1823. doi: 10.1016/j.joen.2021.07.019.
38. Tirez E, Pedano MS. Regeneration of the pulp tissue: cell homing versus cell transplantation approach: a systematic review. Materials (Basel). 2022 Dec 1;15(23):8603. doi: 10.3390/ma15238603.
39. El-Kadiry AEH, Rafei M, Shammaa R. Cell therapy: types, regulation, and clinical benefits. Front Med (Lausanne). 2021 Mar 15;8:1-24. Doi: 10.3389/fmed.2021.641833.
40. Wei X, Yang M, Yue L, et al. Expert consensus on regenerative endodontic procedures. Int J Oral Sci. 2022 Dec;14(1):55. doi: 10.1038/s41368-022-00127-x.
41. Nakashima M, Iohara K, Murakami M, et al. Pulp regeneration by transplantation of dental pulp stem cells in pulpitis: a pilot clinical study. Stem Cell Res Ther. 2017 Jun 19;8(1):1-13. doi: 10.1186/s13287-017-0625-z.
42. El-Kadiry AEH, Rafei M, Shammaa R. Cell therapy: types, regulation, and clinical benefits. Front Med (Lausanne). 2021 Mar 15;8:1-24. Doi: 10.3389/fmed.2021.641833.
43. Peng L, Zhang H, Yi B, et al. Effects of stem cell-based therapies on dental pulp regeneration. J Endod. 2019 Jan;45(1):6-13. doi: 10.1016/j.joen.2018.09.017.
44.Zhang W, Zhang H, Zou J, et al. Stem cell-based pulp tissue engineering: state of the art. Int J Oral Sci. 2018 Mar 6;10(1):1-9. doi: 10.1038/s41368-018-0026-4.
45. Galler KM, D'Souza R, Graziano K, et al. Root canal therapy: A challenge in regenerative endodontics. J Endod. 2015 May;41(5): 690-700. doi:

10.1016/j.joen.2014.12.022.
46. Woo HN, Cho YJ, Tarafder S, et al. Recent advances in scaffolds for integrated periodontal regeneration. Bioact Mater. 2021 Dec;6(12):3328-3342. doi: 10.1016/j.bioactmat.2021.07.003.
47. Ahmed H, Murali A, Mahajan S, et al. Bone graft substitutes in periodontal regeneration. J Clin Diagn Res. 2018 May;12(5):1-6. doi: 10.7860/JCDR/2018/34899.11511.
48. Molloi S, Pradier N, Bandyopadhyay A, et al. Cell-based therapies for periodontal tissue regeneration: a systematic review. Stem Cells Int. 2020 Jan;2020: 1-13. doi: 10.1155/2020/2127415.
49. Gubler M, Kadlecek A, Pieper S, et al. The role of regenerative endodontics in teeth with necrotic pulp: a systematic review. Int Endod J. 2022 Feb;55(2):143-155. doi: 10.1111/iej.13685.
50. Dissanayaka WL, Zhang C, Zhang J, et al. Stem cells for pulp regeneration and their microenvironment. J Endod. 2020 Apr;46(4):551-557. doi: 10.1016/j.joen.2020.02.003.
51. De Almeida JF, de Vasconcellos Pereira L, de Morais Ribeiro MB, et al. Current concepts in dental pulp regeneration. Oral Dis. 2019 Oct;25(7):1775-1784. doi: 10.1111/odi.13079.
52. Jang JH, Kim EJ, Lee YH, et al. Stem cell-based regenerative therapies in dentistry. J Korean Assoc Oral Maxillofac Surg. 2020 Mar;46(1):1-8. doi: 10.5125/jkaoms.2020.46.1.1.
53.Zhang J, Chen S, He W, et al. Advances in stem cell therapy for pulp regeneration. J Endod. 2021 Mar;47(3):489-499. doi: 10.1016/j.joen.2020.12.008.
54. Galler KM, Widbiller M. Cell-free approaches for dental pulp tissue engineering. J Endod. 2020 Jan;46(1S):S143-S149. doi: 10.1016/j.joen.2019.11.023.
55. Zhang H, Zhang W, Shen S, et al. Stem cells for pulp regeneration and their microenvironment. J Endod. 2020 Nov;46(11):1571-1582. doi: 10.1016/j.joen.2020.08.001.
56. Brizuela C, Meza G, Urrejola D, et al. Cell-based regenerative endodontics for treatment of periapical lesions: a randomized, controlled phase I/II clinical trial. J Dent Res. 2020 Apr;99(5):523-529. Doi: 10.1177/0022034520902123.
57. Galler KM, Graff C, Sadan S, et al. Progress in stem cell-based pulp regeneration: application of injectable scaffolds. Regen Med. 2018 Dec;13(6): 829-847. doi: 10.2217/rme-2018-0074.
58. Araújo PR de, Silva LB, Neto AP dos, et al. Pulp revascularization: a literature review. Open Dent J. 2017;10:48-56. doi: 10.2174/1874210601710010048.
59. Parolia A, Ravi B, Elanchezhian R, et al. Advances in regenerative endodontics. Int J Dent. 2020 Apr 28;2020: 8583721. Doi: 10.1155/2020/8583721.
60.Wang F, Xie C, Ren N, et al. Human freeze-dried dentin matrix as a biologically active scaffold for tooth tissue engineering. J Endod. 2019 Jul;45(7):1321-1331. doi: 10.1016/j.joen.2019.03.017.