

Advances In Dental Tissue Engineering and Clinical Regeneration

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Abstract

Regenerative dentistry is a new discipline in the field of dentistry that seeks to repair and restore the structure and function of damaged dental and craniofacial tissues using the use of stem cells, biomaterials, scaffolds and bioactive molecules. Regenerative strategies are based on biological tissue repair and regeneration, unlike traditional restorative strategies. Dental tissue engineering has seen great promise from the use of various stem cell populations such as dental pulp stem cells (DPSCs), stem cells from human exfoliated deciduous teeth (SHED), periodontal ligament stem cells (PDLSCs), and stem cells from the apical papilla (SCAP) and adipose-derived stem cells (ADSCs). These cells have been used to successfully regenerate various tissues in regenerative endodontics, periodontal regeneration, alveolar bone reconstruction, and craniofacial tissue repair. Recent improvement in biomaterials and scaffold technologies has also improved the viability of the stem cells, their differentiation and tissue development. With the advent of emerging technologies like artificial intelligence and the dental stem cell biobanking, the potential for individualized regenerative therapies is becoming more and more vast. While promising, standardization, long-term safety and clinical translation challenges remain. Future studies are needed to make regenerative dental therapies routine in the clinic.

Keywords: Regenerative Dentistry, Stem Cells, Dental Pulp Stem Cells, Tissue Engineering, Biomaterials, Scaffolds.

1. Introduction

Regenerative Dentistry is a new science that deals with the use of stem cells, biomaterials, growth factors, and tissue engineering to restore and regenerate damaged oral and craniofacial tissues. Regenerative dentistry differs from traditional restorative dentistry, which focuses on using synthetic materials to replace or restore missing tissues, by attempting to restore the tissues' structure, function, and vitality. With the rise of oral diseases all over the world, innovative therapeutic strategies have emerged as a need¹. The World Health Organization (WHO) estimates that Oral diseases impact around 3.5 billion people worldwide, and are a major public health issue. Although the traditional dental procedures can restore function and aesthetic, there is a lack of tissue regeneration in most of the cases. Stem cell biology has advanced in recent years, thus creating new strategies for dental pulp, dentin, periodontal ligament, alveolar bone and craniofacial tissue regeneration. Stem cells show amazing proliferation and differentiation properties, promising candidates for the regenerative dental applications. As a result, regenerative dentistry is revolutionizing the practice of modern dentistry and presenting new opportunities for individualized and biologically informed dental interventions.

2. Fundamentals of Regenerative Dentistry

Regenerative dentistry is a rapidly growing area of dentistry that follows the principles of tissue engineering and regenerative medicine, which are designed to restore the structure, function and vitality of compromised dental and craniofacial tissues. Regenerative methods aim to regenerate tissues using a combination of stem cells, scaffolds, and growth factors, which are called the Tissue Engineering Triad². This combination is the core of the current modern therapies of regenerative medicine and greatly improved the treatment of dental diseases and tissue defects.

2.1 Stem Cells

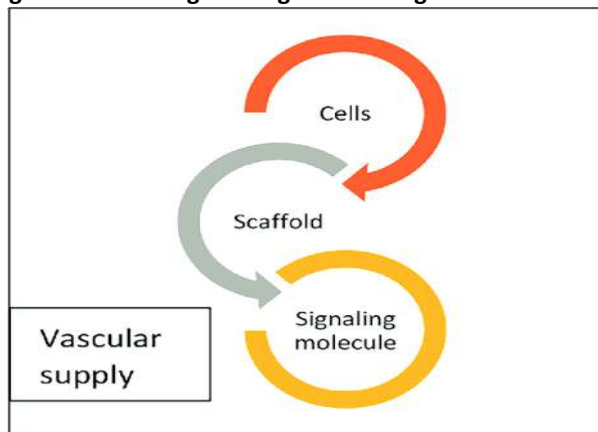
Self-renewal and multilineage differentiation abilities of stem cells make them the key player in regenerative dentistry. These cells have the ability to multiply and develop into specialized cells like odontoblasts, osteoblasts,

cementoblasts, and fibroblasts, which play a role in the regeneration of the dental pulp, dentin, periodontal ligament, and alveolar bone³. A number of dental stem cells (dental pulp stem cells (DPSCs), stem cells from human exfoliated deciduous teeth (SHED), and periodontal ligament stem cells (PDLSCs)) have shown remarkable potential for regeneration, both in preclinical and clinical settings⁴.

2.2 Scaffolds and Growth Factors

The scaffolds are providing a 3D microenvironment which facilitates cell adhesion, proliferation and the formation of tissues. This function is often used with multiple natural materials, including collagen and chitosan, as well as synthetic biomaterials, such as hydroxyapatite and polylactic acid⁵. Growth factors, such as VEGFs, BMPs, TGF- β , and PDGFs, “promote angiogenesis, control cell activities, and promote tissue regeneration. Together, these components create an optimal environment for successful dental tissue engineering and regenerative outcomes⁶.

Figure 1 Tissue Engineering Triad in Regenerative Dentistry



The concepts of stem cells, scaffolds and bioactive molecules in regenerative dentistry are interwoven, as shown in figure 1. Both stem cells and cells derived from them participate in establishing tissue formation through proliferation and differentiation – the biological part. Scaffolds serve to give structure and act as an extracellular matrix for cell adhesion and structure. The bioactive molecules such as growth factors act as regulators of cellular signaling, angiogenesis, cell differentiation and matrix formation. These components together provide conditions of interaction that promote functional dental and craniofacial tissue formation.

Many parameters affect the impact of the tissue engineering triad such as type and source of stem cells, scaffold architecture, scaffold degradation, vascularization, and control release of bioactive molecules. These factors must be coordinated appropriately because the needs for structural and biologic requirements are different for dental tissues. In a particular, adequate vascularization and neural integration is an essential requirement for regeneration of the dental pulp, while, coordinated formation of the cementum, periodontal ligament and alveolar bone is needed for the periodontal regeneration. Thus, strategies to regenerate tissue must be tailored to the type of tissue or defect to be repaired.

3. Types and Sources of Stem Cells Used in Dentistry

The self-renewal ability, multilineage differentiation potential, and role in tissue repair have made stem cells obtained from dental tissues and non-dental tissues as fundamental components in regenerative dentistry. Many stem cell populations have been explored in their ability to regenerate dental pulp, dentin, periodontal tissues, alveolar bone, and craniofacial structures. It has been shown that these cells have different proliferation potential and regenerative abilities, suitable for clinical use⁷.

3.1 Dental Pulp Stem Cells (DPSCs)

The most well-studied dental stem cells are dental pulp stem cells (DPSCs), first discovered by³¹. The efficiency of forming colonies ranges from 22 to 70%, and the population doubling time was estimated to be about 24–36 hours,

suggesting a high proliferative capacity of DPSCs. The studies have demonstrated that DPSCs can produce mineralized nodules under osteogenic conditions and can produce dentin-pulp-like complexes. DPSCs have been shown to be ideal candidates for regenerative endodontics⁹ due to their capacity to form dentin and regenerate pulp tissue.

3.2 Stem Cells from Human Exfoliated Deciduous Teeth (SHED)

Human exfoliated deciduous teeth (SHED) stem cells have been shown to have a 30–50% higher proliferation rate when compared with DPSCs and superior clonogenic potential¹⁰. SHED has the ability to differentiate to odontogenic, osteogenic, adipogenic and neural cell lineage. SHED-derived tissues have been reported to have increased bone regeneration and vascularization properties, which make them useful for pediatric regenerative medicine and craniofacial tissue engineering¹¹.

3.3 Periodontal Ligament Stem Cells (PDLSCs)

PDLSCs can be easily obtained from the periodontal ligament and regenerate periodontal tissues. Research has shown that PDLSCs have been observed to have over 95% of the mesenchymal stem cells being expressed in isolated populations and can markedly enhance the alveolar bone regeneration and periodontal attachment. Clinical research has shown that stem cell-based therapies (SCTs) can result in bone fill improvements between 40% and 70% in periodontal defects. Clinical studies have shown that stem cell based therapies (SCTs) have been able to yield bone fill improvements from 40% to 70% in periodontal defects.

3.4 Dental Follicle Stem Cells (DFSCs)

The dental follicle stem cells (DFSCs) are isolated from the connective tissues surrounding the developing teeth. These cells are highly osteogenic and also shown to enhance alkaline phosphatase activity by almost 2–3 fold throughout bone development. DFSCs can be differentiated into alveolar bone, periodontal ligament, and cementoblasts, making them a valuable option for the repair of alveolar bone and periodontal structures¹².

3.5 Stem Cells from Apical Papilla (SCAP)

Imaginary permanent teeth contain stem cells at their apex known as stem cells of the apical papilla (SCAP), which have greater proliferative potential than DPSCs. SCAP have been shown in various studies to have an increase in proliferation rates of about 2x and increased mineralization ability¹³. During regenerative endodontics, SCAP play a role in maintaining the continued growth of the root, leading to a 20–30% increase in root length, and in significant thickening of dentinal walls after treatment.

3.6 Adipose-Derived Stem Cells (ADSCs)

There are a number of stem cell sources that are not derived from the teeth, including adipose-derived stem cells (ADSCs), which are abundant and easily obtained. The number of stem cells extracted from 1 g of adipose tissue is about 1×10^5 to 1×10^6 , which is considerably higher than the number of stem cells isolated from bone marrow¹⁴. ADSCs also show good osteogenic and angiogenic properties, and superior characteristics of bone regeneration and vascularization in craniofacial defects have been proven, thus connecting their potential use in oral and maxillofacial tissue engineering.

Table 1. Major Stem Cell Sources and Their Applications in Regenerative Dentistry

Stem Cell Type	Source	Key Characteristics	Major Applications
DPSCs	Dental pulp	22–70% colony formation, high proliferation	Dentin-pulp regeneration
SHED	Deciduous teeth	30–50% higher proliferation than DPSCs	Pediatric tissue regeneration
PDLSCs	Periodontal ligament	>95% MSC marker expression	Periodontal regeneration
DFSCs	Dental follicle	2–3 fold increase in osteogenic activity	Bone and periodontal regeneration

SCAP	Apical papilla	2-fold higher proliferation than DPSCs	Root development and endodontics
ADSCs	Adipose tissue	10 ⁵ –10 ⁶ cells/g tissue yield	Bone and craniofacial regeneration

4. Clinical Applications of Stem Cells in Regenerative Dentistry

4.1 Regenerative Endodontics

Regenerative endodontics is one of the most successful clinical uses of stem cell therapy in dentistry. This is done to achieve the restoration of the dentin-pulp complex by biological means, rather than by means of traditional root canal obturation. Regenerative procedures include disinfection of the root canals, induction of bleeding to provide a natural scaffold, and recruitment of stem cells that naturally regenerate tissue, such as stem cells from the apical papilla (SCAP). Clinical studies have shown to be successful with pulp tissue regeneration, revascularisation of immature necrotic teeth, and further root development. ¹⁵reported that regenerative endodontics techniques resulted in changes in root length of 14–28%, dentinal wall thickness of ca. 20–30%, and significant improvement of pulp vitality and apical closure. The results show that stem cells have promise of restoring normal development and function of the tooth.

4.2 Periodontal Regeneration

Periodontal regeneration is used to regenerate the supporting tissues of teeth, such as cementum, periodontal ligament and alveolar bone, which may be lost due to periodontal disease. Periodontal ligament stem cells (PDLSCs) are cells that have demonstrated exceptional tissue regenerative capacity, with capacity to differentiate towards cementoblasts, osteoblasts and fibroblasts. Both clinical and preclinical research have shown significant improvements in periodontal tissue repair. In their study, ¹⁶reported a clinical attachment gain of 2–4 mm and a 40–70 percent improvement in radiographic bone fill in periodontal defects treated with stem cells. The ability of PDLSCs to regenerate functional periodontal structures underscores the potential for their use in restoring periodontal health and preventing tooth loss.

4.3 Alveolar Bone Regeneration

Stem cell therapy has become a hot topic for alveolar bone defects that have formed due to trauma, periodontal disease and tooth loss. The addition of biocompatible scaffolds to mesenchymal stem cells (MSCs) has been shown to promote improved osteogenic differentiation and bone formation. They are especially beneficial in implant site preparation, and guided bone regeneration. A study by ¹⁷showed that new bone formation has been found to be enhanced by around 30–50% with the incorporation of scaffold-based stem cell therapy versus scaffold therapy alone. Moreover, markers of osteogenesis, including alkaline phosphatase activity and mineral deposition, significantly improved as a result of MSC-scaffold combinations, which further demonstrates their potential for clinical bone regeneration.

4.4 Craniofacial and Maxillofacial Regeneration

The use of stem cell-based regenerative strategies has demonstrated significant promise for the treatment of craniofacial defects, cleft palate deformities and reconstruction of jawbones. MSCs obtained from dental and non-dental sources have the capacity to induce bone formation, vascularization and soft tissue repair in complex craniofacial defects. ¹⁸conducted a systematic review, concluding that over 80% of the included studies in the review showed positive tissue regeneration and healing following MSC-based interventions. It was concluded that stem cell therapy is an effective technique for maxillofacial tissue engineering and reconstructive surgery with significant increases in bone volume and defect closure rates.

4.5 Hard Tissue Regeneration

Regeneration of hard dental tissues, such as enamel, dentin and bone, is still a predominant issue in regenerative dentistry. Regeneration of the entire enamel is a difficult and complex process as it involves the regeneration of ameloblasts after tooth eruption; however, progress in biomaterials and stem cell technologies has led to the development of enamel-like structures and bioactive restorative materials. The stem cells of the dental pulp and

other mesenchymal stem cell populations have been shown to be capable of regenerating dentin and mineralized tissues via odontogenic differentiation. It has been demonstrated that groups treated with stem cells exhibited mineralized tissue formation by up to 50–60% higher than conventional treatments¹⁹. The results highlight the importance of stem cells in hard dental tissue regeneration and the development of biologically oriented restorative procedures.

5. Biomaterials and Scaffold Technologies

Regenerative dentistry requires biomaterials and scaffold technologies, which serve as the structural and biological environment for stem cell survival, proliferation, differentiation and tissue formation. Scaffolds are the structures that are 3D structures similar to the natural extracellular matrix and promote tissue regeneration of damaged dental tissues. The ideal scaffold should have good biocompatibility, biodegradability, mechanical properties, and promote cellular attachment and vascularization. Scaffolds can be classified in general as either natural or synthetic biomaterials, depending on their source²⁰.

Biomaterials derived from natural resources such as collagen, chitosan and gelatin which have been extensively used due to their biological properties and similarity to native tissues. Among the scaffolds that exist in nature, collagen is the most widely researched for cell adhesion, cell migration, and tissue regeneration²¹. Chitosan has antimicrobial activity and has a wound healing effect, whilst gelatin has a role in proliferation and differentiation of the cells. This material creates a good environment for dental stem cells and supports tissue repair processes.

These synthetic biomaterials, like poly (lactic-co-glycolic acid) (PLGA), hydroxyapatite and bioactive glass, also have higher mechanical strength, structural stability and degradation rate. Hydroxyapatite is very similar to the mineral content of bone and dentin and has proven to be an excellent osteoconductive material, while bioactive glass is known to stimulate bonding and mineralisation of bone. PLGA has received a great deal of interest for its predictable degradation profile and scaffold fabrication versatility²².

The biomaterials being developed in recent years for dental tissue engineering have been mainly calcium phosphate and silicate.²³found that calcium phosphate scaffolds showed a great increase in proliferation, osteogenic differentiation, and mineralized matrix production of dental pulp stem cells when compared with traditional materials. In addition, the bioactivity of these scaffolds was found to be improved, and mineralized nodules were formed, which suggests that they can be used for dentin and bone regeneration. The combination of advanced biomaterials with stem cell therapy continues to enhance the regenerative outcomes and will likely be a promising approach for future tissue engineering applications in dentistry²⁴.

Table 2. Biomaterials Used in Regenerative Dentistry

Biomaterial	Advantages	Limitations
Collagen	Excellent biocompatibility and cell adhesion	Low mechanical strength
Hydroxyapatite	Highly osteoconductive	Brittle nature
Bioactive Glass	High bioactivity and bone bonding ability	High cost
Calcium Phosphate	Promotes mineralization and osteogenesis	Slow degradation rate

6. Emerging Technologies in Regenerative Dentistry

New technologies are transforming regenerative dentistry, making stem cell therapy more precise, efficient and predictable. One of these innovations is artificial intelligence (AI) which can analyze vast amounts of biological data, find new scaffolds and predict treatment outcomes⁸. AI algorithms can help identify the right stem cell populations, assess the characteristics of biomaterials, and design individualized regenerative treatment strategies. ⁸highlighted that AI-driven approaches are key for optimizing scaffold architecture, improving cell–material interactions, and advancing into more sophisticated regenerative strategies. In addition, machine learning models can aid in clinical decisions by forecasting the outcomes of tissue regeneration and reduce variability in treatment.

Another exciting development is the biobanking of dental stem cells, which includes the collection, processing, and long-term storage of stem cells extracted from third molars, deciduous teeth, and various other dental tissues²⁴. Biobanking offers a reliable and rich source of quality stem cells for future therapeutic applications and assists in the

development of personalized regenerative dentistry, according to²⁴. Research into these technologies will likely have a significant impact for the next generation of dental tissue engineering and regeneration technologies.

7. Challenges and Limitations

Regenerative dentistry has a number of challenges, despite its great advancement. Biological limitations consist of low cell viability, immunogenic response and possible tumorigenicity. Regeneration is hindered by technical problems like insufficient vascularization and scaffold degradation. Lack of standardized procedures and limited long-term clinical evidence are barriers to clinical translation. Moreover, the cost of isolating, growing and storing stem cells to use in the clinic is high²⁹.

8. Future Perspectives

The future of regenerative dentistry will likely include more personalized treatment options, innovative 3D bioprinting methods, and the use of gene-editing tools like CRISPR. Treatment predictability and safety could be enhanced through innovative, AI-driven regenerative planning, cell-free therapy, and exosome-based regenerative strategies. These innovations can pave the way for the clinical translation of stem cell-based dental therapies to be faster³⁰.

9. Conclusion

Stem cells, biomaterials and tissue engineering approaches are being used together as a new regenerative dentistry field to regenerate damaged dental and craniofacial tissues. DPSCs, SHED, SCAP, and PDLSCs have all shown significant capabilities in endodontics, periodontal and bone regeneration. Further developments of scaffold technology and biomaterials have improved the results in tissue repair and regeneration. Future treatment approaches are likely to be revolutionized by emerging innovations like artificial intelligence and dental stem cell biobanking. But there are issues of standardization, long-term safety and effectiveness. Good clinical studies are needed to define appropriate protocols and to make the use of regenerative dentistry a daily practice.

Acknowledgement

The authors would like to express their sincere gratitude to their respective institutions for their encouragement and academic support. The authors acknowledge the valuable contributions and collaborative efforts of all co-authors in preparing this review article. We also thank the researchers and scientific communities whose published work has contributed to the understanding of advances in dental tissue engineering and clinical regeneration. The authors acknowledge the support and guidance received from their colleagues throughout the preparation of this manuscript.

Funding: NIL

Conflicts of Interest: NIL

Clinical trial number: Not applicable

Data availability: Data is available to be used by the journal for publishing the article

Consent to publish: YES

References

1. Thalakiriyawa DS, Dissanayaka WL. Advances in regenerative dentistry approaches: an update. *International Dental Journal*. 2024 Feb 1;74(1):25-34.
2. Hung M, Sadri M, Katz M, Schwartz C, Mohajeri A. A systematic review of stem cell applications in maxillofacial regeneration. *Dentistry Journal*. 2024 Sep 29;12(10):315.

3. Christie B, Musri N, Djustiana N, Takarini V, Tuygunov N, Zakaria MN, Cahyanto A. Advances and challenges in regenerative dentistry: a systematic review of calcium phosphate and silicate-based materials on human dental pulp stem cells. *Materials Today Bio.* 2023 Dec 1;23:100815.
4. Shah P, Aghazadeh M, Rajasingh S, Dixon D, Jain V, Rajasingh J. Stem cells in regenerative dentistry: Current understanding and future directions. *Journal of Oral Biosciences.* 2024 Jun 1;66(2):288-99.
5. Shekatkar M, Kheur S, Deshpande S, Sanap A, Kharat A, Navalakha S, Gupta A, Kheur M, Bhonde R, Merchant YP. Angiogenic Potential of Various Oral Cavity–Derived Mesenchymal Stem Cells and Cell-Derived Secretome: A Systematic Review and Meta-Analysis. *European Journal of Dentistry.* 2024 Jul;18(03):712-42.
6. Alothman FA, Hakami LS, Alnasser A, AlGhamdi FM, Alamri AA, Almutairii BM, AlGhamdi F, Alamri A. Recent advances in regenerative endodontics: a review of current techniques and future directions. *Cureus.* 2024 Nov 20;16(11).
7. Daneshian Y, Lewallen EA, Badreldin AA, Dietz AB, Stein GS, Cool SM, Ryoo HM, Cho YD, van Wijnen AJ. Fundamentals and translational applications of stem cells and biomaterials in dental, oral and craniofacial regenerative medicine. *Critical Reviews™ in Eukaryotic Gene Expression.* 2024;34(6). Saberian E, Jenča A, Zafari Y, Jenča A, Petrášová A, Zare-Zardini H, Jenčová J. Scaffold application for bone regeneration with stem cells in dentistry: literature review. *Cells.* 2024 Jun 19;13(12):1065.
8. Saberian E, Jenča A, Jenča A, Zare-Zardini H, Araghi M, Petrášová A, Jenčová J. Applications of artificial intelligence in regenerative dentistry: promoting stem cell therapy and the scaffold development. *Frontiers in cell and developmental biology.* 2024 Dec 6;12:1497457.
9. Inchingolo AM, Inchingolo AD, Nardelli P, Latini G, Trilli I, Ferrante L, Malcangi G, Palermo A, Inchingolo F, Dipalma G. Stem cells: present understanding and prospects for regenerative dentistry. *Journal of Functional Biomaterials.* 2024 Oct 15;15(10):308.
10. Soudi A, Yazdanian M, Ranjbar R, Tebyanian H, Yazdanian A, Tahmasebi E, Keshvad A, Seifalian A. Role and application of stem cells in dental regeneration: A comprehensive overview. *EXCLI journal.* 2021 Feb 22;20:454.
11. Samiei M, Alipour M, Khezri K, Saadat YR, Forouhandeh H, Abdolahinia ED, Vahed SZ, Sharifi S, Dizaj SM. Application of collagen and mesenchymal stem cells in regenerative dentistry. *Current Stem Cell Research & Therapy.* 2022 Oct 1;17(7):606-20.
12. Capparè P, Tetè G, Sberna MT, Panina-Bordignon P. The emerging role of stem cells in regenerative dentistry. *Current Gene Therapy.* 2020 Aug 1;20(4):259-68.
13. Bartold M, Ivanovski S. Stem cell applications in periodontal regeneration. *Dental Clinics.* 2022 Jan 1;66(1):53-74.
14. Gaur S, Agnihotri R. Application of adipose tissue stem cells in regenerative dentistry: a systematic review. *Journal of International Society of Preventive and Community Dentistry.* 2021 May 1;11(3):266-71.
15. Tatullo M, Codispoti B, Sied J, Makeeva I, Paduano F, Marrelli M, Spagnuolo G. Stem cells-based and molecular-based approaches in regenerative dentistry: a topical review. *Current Stem Cell Research & Therapy.* 2019 Oct 1;14(7):607-16.
16. Tsutsui TW. Dental pulp stem cells: advances to applications. *Stem cells and cloning: advances and applications.* 2020 Feb 13:33-42.
17. Mozaffari MS, Emami G, Khodadadi H, Baban B. Stem cells and tooth regeneration: prospects for personalized dentistry. *Epma Journal.* 2019 Mar 1;10(1):31-42.
18. Zhai Q, Dong Z, Wang W, Li B, Jin Y. Dental stem cell and dental tissue regeneration. *Frontiers of medicine.* 2019 Apr;13(2):152-9.
19. Umapathy VR, Natarajan PM, Swamikannu B. Regenerative strategies in dentistry: harnessing stem cells, biomaterials and bioactive materials for tissue repair". *Biomolecules.* 2025 Apr 8;15(4):546.
20. Wrzyszc-Kowalczyk A, Dobrzynski M, Grzesiak-Gasek I, Zakrzewski W, Mysiak-Debska M, Nowak P, Zimolag M, Wiglusz RJ. Application of selected biomaterials and stem cells in the regeneration of hard dental tissue in paediatric dentistry—based on the current literature. *Nanomaterials.* 2021 Dec 13;11(12):3374.
21. Costela-Ruiz VJ, Melguizo-Rodríguez L, Bellotti C, Illescas-Montes R, Stanco D, Arciola CR, Lucarelli E. Different sources of mesenchymal stem cells for tissue regeneration: a guide to identifying the most favorable one in orthopedics and dentistry applications. *International Journal of Molecular Sciences.* 2022 Jun 6;23(11):6356.

22. Alhazzazi TY, Alghamdi FT. Clinical applications of dental stem cells in modern regenerative medicine: A systematic review with updates. *Nigerian journal of clinical practice*. 2021 Apr 1;24(4):457-63.
23. Kiarashi M, Bayat H, Shahrtash SA, Etajuri EA, Khah MM, Al-Shaheri NA, Nasiri K, Esfahaniani M, Yasamineh S. Mesenchymal stem cell-based scaffolds in regenerative medicine of dental diseases. *Stem Cell Reviews and Reports*. 2024 Apr;20(3):688-721.
24. Yamada S, Malkmus C, Aasebø E, Mustafa K, Egusa H, Volponi AA. Production and biobanking of dental stem cells for clinical applications in regenerative dentistry: Current practices and future perspectives—A narrative review. *Journal of Dentistry*. 2025 Oct 1;161:105934.
25. Gan L, Liu Y, Cui D, Pan Y, Zheng L, Wan M. Dental tissue-derived human mesenchymal stem cells and their potential in therapeutic application. *Stem cells international*. 2020;2020(1):8864572.
26. Zhang W, Yelick PC. Tooth repair and regeneration: potential of dental stem cells. *Trends in molecular medicine*. 2021 May 1;27(5):501-11.
27. Jamal H, Elhussein M. Integration of regenerative dentistry into the dental undergraduate curriculum. *Frontiers in Dental Medicine*. 2020 Nov 10;1:596189.
28. Hsiao HY, Nien CY, Hong HH, Cheng MH, Yen TH. Application of dental stem cells in three-dimensional tissue regeneration. *World Journal of Stem Cells*. 2021 Nov 26;13(11):1610.
29. Marei MK, El Backly RM. Dental mesenchymal stem cell-based translational regenerative dentistry: from artificial to biological replacement. *Frontiers in Bioengineering and Biotechnology*. 2018 May 2;6:49.
30. Karadede B. Stem Cell Usage in Dentistry: A Promising Future. *Journal of Stem Cell Research*. 2025 Jan 14;6(1).
31. Gronthos S, Mankani M, Brahimi J, Robey PG, Shi S. Postnatal human dental pulp stem cells (DPSCs) in vitro and in vivo. *Proceedings of the National Academy of Sciences of the United States of America*. 2000;97(25):13625–13630. doi:10.1073/pnas.240309797.