

Review Article

Regenerative Endodontics -Present Practice to Promising Prospects: A Literature Review

Asiya Sameer Mujawar^{1*}, Varsha Pandit², Madhuri Patil³, Vivek Hegde⁴, Naqiya Khandwawala⁵, Srilatha S⁶, Sumaiyya Shaikh⁷

¹Associate Professor, Department of Conservative Dentistry and Endodontics, MA Rangoonwala College of Dental Sciences and Research Center, PhD Scholar Bharati Vidyapeeth Deemed to Be University, Dental College and Hospital, Pune India

²Associate Professor, Department of Conservative Dentistry and Endodontics, PhD Guide Bharati Vidyapeeth Deemed to Be University, Dental College and Hospital, Pune, India

³Associate Professor, Department of Conservative Dentistry and Endodontics, MA Rangoonwala College of Dental Sciences and Research Center, Pune India

⁴Professor and HOD, Department of Conservative Dentistry and Endodontics, MA Rangoonwala College of Dental Sciences and Research Center, Pune India

⁵Department of Conservative Dentistry and Endodontics Westbay Medicare Doha, Qatar

⁶Professor, Department of Conservative Dentistry and Endodontics, MA Rangoonwala College of Dental Sciences and Research Center, Pune India

⁷Department of Pediatric and Preventive Dentistry, India

Correspondence author: Asiya Sameer Mujawar, MDS, Associate Professor, Department of Conservative Dentistry and Endodontics, MA Rangoonwala College of Dental Sciences and Research Center, PhD Scholar Bharati Vidyapeeth Deemed to Be University, Dental College and Hospital, Pune India;

E-mail: drasiyashaikh786@gmail.com

Citation: Mujawar AS, et al. Regenerative Endodontics -Present Practice to Promising Prospects: A Literature Review. J Dental Health Oral Res. 2024;5(1):1-12.

<https://doi.org/10.46889/JDHOR.2024.5109>

Received Date: 16-02-2024

Accepted Date: 12-03-2024

Published Date: 20-03-2024



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Abstract

Regenerative endodontics is an innovative field within dentistry that aims to restore damaged dental pulp using stem cells, tissue engineering techniques and biocompatible materials. This article provides an overview of the current trends in regenerative endodontics, highlighting recent research findings. Stem cells obtained from different sources like dental pulp, bone marrow and adipose tissue possess the ability to differentiate into cells similar to dental pulp and facilitate the regeneration of tissues. The use of biocompatible substances, such as Mineral Trioxide Aggregate (MTA) biodentine, offers an ideal setting for tissue growth and healing. Dental scaffolds, made from biodegradable materials, support the development of new blood vessels, nerve fibers and dental pulp-like tissues. Growth factors, like PDGF and TGF- β , are incredibly important in stimulating cell growth and specialization. Researchers and clinical trials are currently working on improving regenerative endodontic procedures, with promising results seen in terms of pulp regeneration and root development. By embracing these trends, dental professionals can offer innovative solutions for restoring damaged dental pulp and preserving natural teeth. The present article, is an overview of regenerative endodontics, exploring the current trends that are shaping the future of this field.

Keywords: Regeneration; Endodontics; Growth Factors; Scaffolds; Stem Cells

Introduction

Regenerative endodontics is an emerging field within dentistry that aims to restore the health and vitality of damaged dental pulp. By utilizing the regenerative capacity of stem cells, tissue engineering techniques and biocompatible materials, regenerative endodontics offers a

favorable alternative to traditional root canal treatments. Regenerative endodontics is defined as biologically based procedures designed to physiologically replace damaged tooth structure, including dentin and root structures, as well as the pulp-dentin complex. Clinical Considerations for a Regenerative Procedure, published by the American Association of Endodontists (AAE), states that the regenerative procedure is deemed successful if clinical symptoms and signs are eliminated, apical periodontitis is resolved, the canal walls thicken and/or root maturation continues [1]. The concept of regenerative endodontics is based on tissue engineering, a field that utilizes stem cells, growth factors and scaffolds to support the regeneration of dental pulp and the tissues

surrounding it. A study conducted by Huang, et al., highlights the potential of stem cells in regenerating damaged dental pulp [2]. The researchers demonstrated that stem cells derived from various sources, including dental pulp, bone marrow and adipose tissue, can differentiate into dental pulp-like cells, stimulating the growth of healthy tissues.

Biocompatible materials play a crucial role in regenerative endodontics by providing a favorable environment for tissue regeneration. Calcium hydroxide and Mineral Trioxide Aggregate (MTA) are widely used bioactive materials that promote the healing process and support the growth of new tissues. A comprehensive review by Li, et al., discusses the benefits and applications of these materials in regenerative endodontics, emphasizing their biocompatibility and ability to induce tissue repair and regeneration [3].

Dental scaffolds have emerged as a key trend in regenerative endodontics, providing a three-dimensional structure that supports cell growth and guides tissue formation. A study by Zhang, et al., explores the potential of biodegradable scaffolds in regenerating dental pulp [4]. The researchers developed a scaffold comprised of polycaprolactone and hydroxyapatite, demonstrating its ability to support the formation of new blood vessels, nerve fibers and dental pulp-like tissues.

During the regenerative process, growth factors like PDGF and TGF- β play a crucial role in stimulating cell proliferation and differentiation. Their presence is essential for promoting the growth and specialization of cells. A review article by Chen, et al., discusses the role of growth factors in regenerative endodontics, highlighting their ability to enhance tissue regeneration and improve the success rate of endodontic treatments [5].

According to study by Murray, et al., presents the results of a clinical trial investigating the use of stem cells and scaffolds in regenerating immature permanent teeth with pulp necrosis, demonstrating promising outcomes [6].

Methodology and Search Strategy

The relevant literature regarding the regenerative endodontics was searched by electronic databases such as PubMed, Google Scholar and web of science. Articles published in the English language were included in the current review.

Historical Background

Iwaya and associates introduced the term 'revascularization'. Later, revitalization rather than revascularization was advocated as a more appropriate phrase because the tissues regenerated in the canal space included both hard and soft tissues. The American Association of Endodontists adopted the term 'regenerative endodontics' in 2007 which is based on tissue engineering idea. The experimental research of Nygaard-Ostby and Nygaard-Ostby and Hjortdal laid the groundwork for regenerative endodontics. To partially fill the chemo-mechanically debrided canal space of teeth, Nygaard-Ostby and Hjortdal induced bleeding from the periapical tissues [7].

The European Society of Endodontology (ESE) utilized the term "revitalization" in their 2016 position statement. Revascularization, revitalization and regenerative endodontics are terms that are interchangeably and synonymously used in the endodontic literature.

Cell Navigation in Regenerative Endodontics

Regenerating dental pulp tissue in the root canal space necessitates the creation of new vital tissue in an empty, disinfected environment. The three aspects necessary for tissue regeneration are stem cells, growth factors and scaffolds.

Stem Cells

Dental Pulp Stem Cells (DPSCs) and Their Regenerative Potential: Dental Pulp Stem Cells (DPSCs) are considered a promising cell source for regenerative endodontics due to their multipotent nature and accessibility [4]. DPSCs can be isolated from the dental pulp tissue of extracted teeth, providing a readily available and ethically acceptable source of stem cells [8]. These cells possess the ability to differentiate into dental pulp-like cells, including odontoblasts, fibroblasts and endothelial cells, which are crucial for pulp regeneration [8,9]. SCAP, derived from the developing apical papilla, possess similar properties to DPSCs and

exhibit high regenerative capacity. A study by Wang, et al., investigated the regenerative potential of SCAP in treating immature permanent teeth with pulp necrosis [11]. The results demonstrated successful pulp revascularization and continued root development, highlighting the therapeutic potential of SCAP in regenerative endodontic procedures.

DFSCs, isolated from the dental follicle tissue surrounding developing teeth, have also shown the capacity to differentiate into dental pulp-like cells [12,13]. Studies have reported favorable outcomes, including the regeneration of functional dental pulp, continued root development and improved tooth vitality.

Growth Factors

Growth factors are polypeptides or proteins that, when bound, give rise to a broad range of cellular activities such as migration, proliferation, differentiation and maturation [13-15]. Growth factors play a crucial role in regeneration endodontics by promoting the repair and regeneration of dental tissues within the tooth. Here are some of the key growth factors used in this field: Bone Morphogenetic Proteins (BMPs): BMPs are a family of growth factors that are known to induce the formation of bone and dentin [13,16,17]. They are often used in regenerative endodontic procedures to stimulate the differentiation of stem cells into odontoblast-like cells, which are responsible for dentin formation. Transforming Growth Factor Beta (TGF- β): TGF- β is a growth factor that plays a pivotal role in various cellular processes, including tissue regeneration [17]. Vascular Endothelial Growth Factor (VEGF): VEGF is crucial for angiogenesis, the formation of new blood vessels. In regenerative endodontics, it can help ensure proper vascularization within the regenerated dental tissues, providing essential nutrients and oxygen for the developing structures [18]. Fibroblast Growth Factor (FGF): FGFs are involved in tissue repair and regeneration. In the context of regeneration endodontics, FGFs can aid in the growth and differentiation of various cell types, including those responsible for dentin formation [19]. Platelet-Derived Growth Factors (PDGF): PDGFs are naturally occurring growth factors found in platelets. They play a role in wound healing and tissue repair. In regenerative endodontics, PDGFs can be used to enhance the regenerative process by stimulating cell proliferation and tissue formation [20]. Insulin-like Growth Factor (IGF): IGF is essential for the growth and development of various tissues. It can be utilized to promote the differentiation and proliferation of dental pulp stem cells, contributing to the regeneration of dental tissues [20]. Epidermal Growth Factor (EGF): EGF is known for its role in cell growth and proliferation [18-20]. It can be applied in regenerative endodontics to encourage the proliferation of cells involved in the regeneration of dental pulp and dentin. These growth factors, often used in combination with stem cells, provide a supportive environment for tissue regeneration within the tooth. They can be delivered through various methods, such as scaffolds, gels or other carriers, to maximize their effectiveness in promoting the healing and regeneration of dental tissues in regenerative endodontic procedures.

Scaffolds

In regenerative endodontics, a variety of scaffold types are utilized to support tissue regeneration within the root canal [18]. These include polymeric scaffolds, crafted from biocompatible materials like Polylactic Acid (PLA) or Polyglycolic Acid (PGA), offering customizable mechanical properties and degradation rates. Natural biomaterial scaffolds, derived from sources such as collagen or chitosan, closely mimic the native extracellular matrix, fostering cell attachment and differentiation. Ceramic scaffolds, composed of materials like hydroxyapatite or tricalcium phosphate, provide a rigid framework conducive to tissue ingrowth and mineralization [19]. Composite scaffolds combine different materials, enabling tailored mechanical and bioactive properties. Decellularized Extracellular Matrix (ECM) scaffolds, derived from natural tissues, retain native tissue architecture and composition, creating an optimal microenvironment for cell colonization and regeneration [18-20]. Each scaffold type presents distinct advantages, allowing for tailored approaches to tissue engineering in regenerative endodontics.

REP Protocol

According to the AAE Clinical protocol the REP should be done in two appointments with an interval of 3-4 weeks (Fig. 1,2 and Table 1).

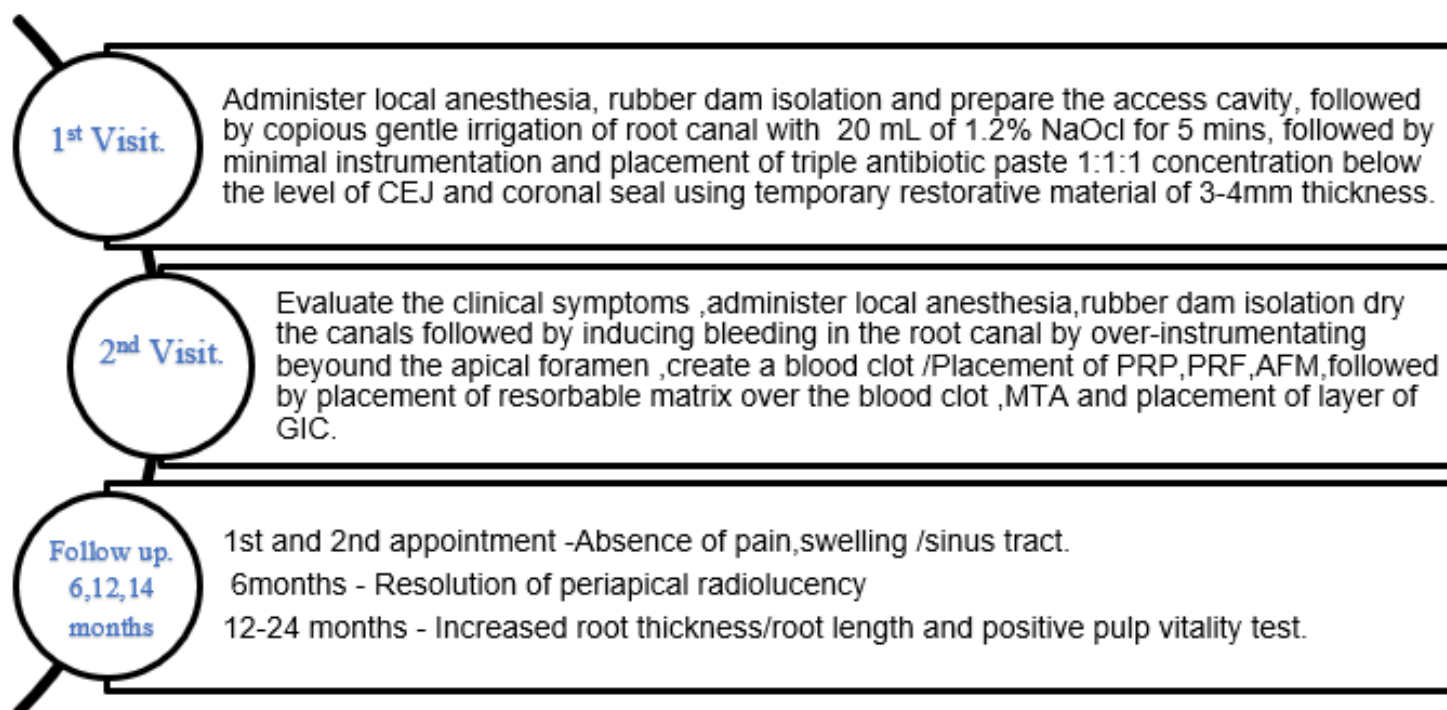


Figure 1: Flow chart of steps in Regenerative endodontic procedure as per AAE 2021.

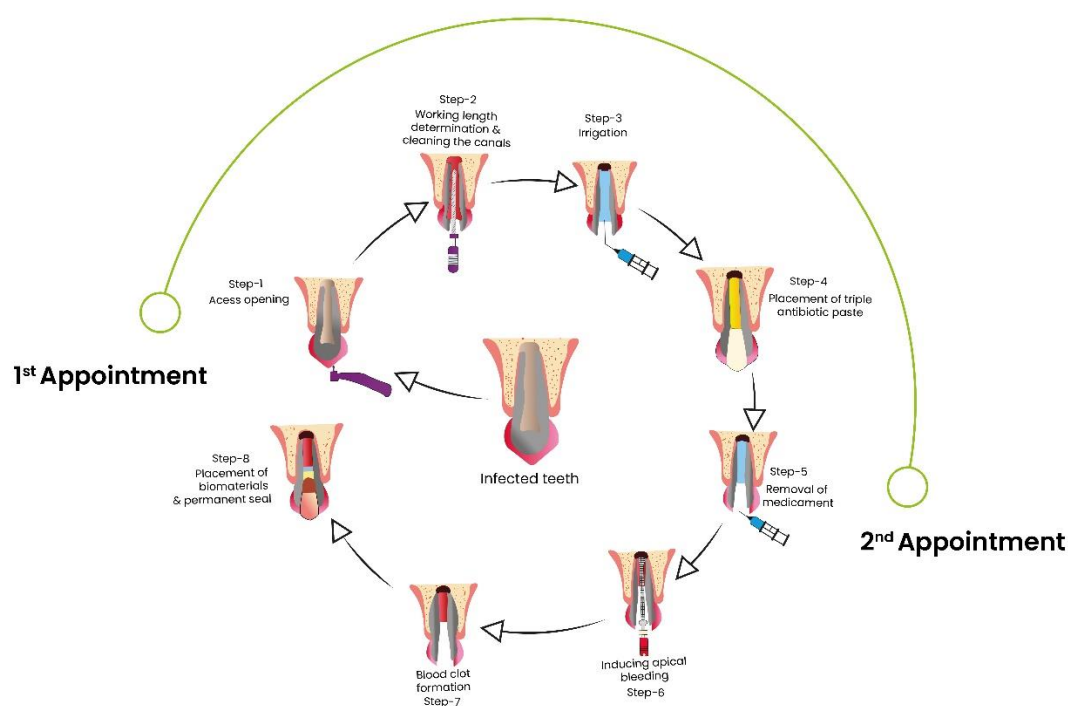


Figure 2: Diagrammatic representation of steps in regenerative endodontic procedure in a mature tooth.

Author and Year of Publication	Study population	Intervention	Comparison	Outcome	Follow-up
Jadhav, et al., [33]	20 patients (6 females, 14 males); Age group (15-28 y); Immature anterior teeth	G1: REP with PRP (n=10) 1 st visit- Irrig: 2.5 % NaOCl; TAP intracanal dressing. 2 nd visit- Induction of bleeding, placement of PRP covered with sterile collagen sponge; access cavity sealed with RMGIC	G2: REP without PRP (n=10) 1 st visit-Irrig: 2.5 % NaOCl; TAP intracanal dressing. 2 nd visit- Induction of bleeding, placement of sterile collagen sponge over BC; access cavity sealed with RMGIC	Clinical- complete resolution of signs and symptoms. R/F- satisfactory periapical healing, apical closure and dentinal wall thickening	12 months
Nagy, et al., [34]	36patients (18 females, 18 males); age group (9-13 y); Immature necrotic permanent maxillary central incisors.	REP group G1: (BC scaffold) (n=12) G2: BC+ FGF (n=12) 1 st visit: Irrig: 2.6% NaOCl; intracanal dressing TAP (metronidazole (500-mg +ciprofloxacin (250-mg + doxycycline 100 mg) (3 weeks) 2 nd visit: Scaffold (150 mg FGF + 300 mL phosphate-buffered saline + 2-mg dried gelatin hydrogel sheet. Restoration (MTA and Adhesive composite resin)	REP: G3: MTA apical plug (control) (n = 12) 1 st visit: Irrig: 2.6% NaOCl; intracanal dressing TAP (metronidazole (500-mg +ciprofloxacin (250-mg + doxycycline 100 mg) (3 weeks) 2 nd visit: Placement of MTA plug (4-5 mm) and access cavity sealed with temporary restoration. 1week later: root canal obturation and restoration Adhesive composite resin)	Radiographic evidence of periapical healing G1 and G2 showed a progressive increase in root length and width and a decrease in apical diameter.	18 months
Narang, et al., [35]	20 patients; Age group (below 20 y); Immature necrotic permanent teeth with or without associated apical periodontitis	REP groups G1: (BC) scaffold G2: (PRP+collagen) scaffold G3: (PRF or PRFM) scaffold 1 visit: Irrig: 2.5 % NaOCl, placement of TAP (4 weeks) 2nd visit: bleeding induced, placement of scaffolds, placement of 3-4 mm of RMGIC followed by composite resin.	G4: MTA apexification Placement of (4-5 mm) apical plug After 1-week obturation followed by placement of adhesive composite resin.	PRF accelerate the growth characteristics in immature necrotic permanent teeth as compared to PRP and BC.	6-18 months

Sharma, et al., [36]	16 patients; age group (10-25 y), Necrotic immature permanent maxillary incisors with or without periapical lesions	REP Groups according to scaffolds G1: PRF G2: Collagen G3: PLGA (Poly-lactic-co-glycolic acid) 1 st visit: Irrig: 2.5 % NaOCl (side vented needle), +TAP (interappointment medicament) for 4 weeks; 2 nd visit: blood clot induced in the root canal, REP using different scaffolds, access cavity sealed with GIC.	G4: BC (blood clot) First visit: Irrig: 2.5 % NaOCl (side vented needle), +TAP (interappointment medicament) for 4 weeks; second visit: REP on frank bleeding tight cotton pellet placed in coronal portion (7-10 min) to induce clot formation), access cavity sealed with GIC.	Clinical outcome All the patients were asymptomatic. R/F: Improved periapical healing, apical closure, root lengthening and dentinal wall thickening	6-12 months
Jiang, et al., [37]	43 patients (children) yielding 46 non-vital immature teeth	REP Groups according to scaffolds G1: REP with Bioguide 1 st visit-Irrig: provided twice- 1.25%NaOCl (20 ml;5min) followed by saline (20ml/canal) +Ca (OH) ₂ intracanal dressing (2 weeks) 2 nd visit- Bleeding induced in the canal and placement of bioguide (middle third of the root)+ placement of MTA (ProRoot) followed by adhesive resin	G2: REP without Bioguide (control) First visit-Irrig: provided twice-i) 1.25%NaOCl (20 ml;5min) followed by saline (20ml/canal) +Ca (OH) ₂ intracanal dressing (2 weeks) 2 nd visit- Bleeding induced in the canal + placement of MTA (ProRoot) followed by adhesive resin	Clinical outcome: Complete resolution of clinical signs and symptoms R/F: thickness of the dentin wall in the middle third of the root was higher with the use of Bioguide collagen than the control group	6 months
Ulusoy AT, et al., [38]	77 patients (33 girls and 44 boys); age group (8-11 y); 88 Necrotic immature permanent incisors	REP Groups according to the scaffolds (n=17) G1: PRP G2: PRF G3: PP G4: BC 1 st visit: Irrig: 1.5%NaOCl (20ml) + intracanal dressing (4 weeks) TAP (20mg)(clindamycin,ciprofloxacin and metronidazole) 2 nd visit: Irrig: 2% CHX,17 % EDTA (2min) placement of scaffold followed by MTA placement and coronal restoration with composite resin	Control group was not used- conventional Endodontic procedures using different apexification techniques do not permit an increase in root dimensions and apical closure.	Clinical outcome: positive response to sensitivity test R/F outcome: increased root length and apical closure seen	6 months

Aly, et al., [39]	26 patients; necrotic immature permanent anterior teeth	REP Groups according to coronal plug G1: Biodentin 1st visit- Irrig:1.5%NaOCl (20 ml/canal,5min) +saline, DAP (Metronidazole 500mg+Ciprofloxacin 500 mg) (time:4 weeks) 2nd visit: bleeding induced formation of blood clot+ Biodentin (3-4 mm) placement over the blood clot, access cavity sealed with composite resin	G2: MTA First visit- Irrig:1.5%NaOCl (20 ml/canal,5 min) +saline, DAP (Metronidazole 500mg+Ciprofloxacin 500 mg) (time:4 weeks) 2nd visit: bleeding induced+ formation of blood clot+ MTA (3-4 mm) placement over the blood clot, access cavity sealed with composite resin	Clinical outcome: successful resolution of swelling, pain on percussion, pain on biting, mobility sinus or fistula. R/F: increase in root length	12 months
El Sheshtawy, et al., [40]	26 patients; necrotic immature permanent anterior teeth	REP groups G1: platelet-rich plasma (PRP, test group) 1st visit: Irrig: 20 mL of 5.25% sodium hypochlorite (NaOCl; TAP (intracanal dressing Minocycline 100mg+ciprofloxacin 250 mg +Metronidaz500 mg) 2nd visit: induction of bleeding in the canal; placement of PRP followed by collagen plug; covered with MTA. 3rd visit- Final restoration using composite resin	G2: Blood clot (BLC, control group) 1st visit: Irrig: 20 ml of 5.25% sodium hypochlorite (NaOCl; TAP (intracanal dressing Minocycline 100mg+ciprofloxacin 250 mg +Metronidaz500 mg) 2nd visit: induction of bleeding in the canal; placement collagen plug; covered with MTA. 3rd visit- Final restoration using composite resin	Standardized and calibrated 2-dimensional radiographic assessment was as effective as CBCT in assessing RET outcomes. Clinical outcome: successful resolution of swelling, pain on percussion, pain on biting, mobility sinus or fistula. R/F: increase in root length	12 months
Arslan, et al., [41]	49 patients; age group (18-30 y), 56 mature teeth with large periapical lesions	REP group 1st visit: Triple antibiotic paste intracanal dressing (Doxycycline+metronidazole+ciprofloxacin), Time (3 weeks) 2nd visit: Irrig: 5 ml 1 % NaOCl+2 ml 5% EDTA for 1 min; bleeding induction for blood clot formation), placement of MTA 3 mm below the CEJ followed by temporary dressing 3rd visit: permanent restoration using resin composite material.	CRCT group- 1st visit: Irrig: (5 ml)1 % NaOCl+ 5 % EDTA; Ca(OH)₂ intracanal dressing(1 week) 2nd visit: Canals filled with gutta-percha cones and epoxy resin-based sealer-cold lateral compaction	. Clinical outcome- 80% of teeth in CRCT and 92.3% teeth in REP group were considered successful 2. Radiographic outcome: Absence and reduction of apical lesions in 85% CRCT compared to 92.4 %of REP group	12 months

Brizuela, et al., [42]	36 patients (25 females, 11 males; age group (16-58 y), mature incisors, canine, premolars with apical lesions	G1: REP group 1 st visit- Ca(OH) ₂ intracranial dressing (time-3 weeks) 2 nd Visit: PRP encapsulated human umbilical cord mesenchymal stem cells in a plasma-derived biomaterial)	G2: CRCT group 1 st visit: Ca(OH) ₂ intracranial dressing (time-3 weeks) 2 nd visit: Obturation with gutta- percha cones Topseal sealer- continuous wave condensation technique)	1 Clinical outcome: Safety- No adverse reactions observed throughout the follow-up period Positive response to thermal test and EPT 2. Radiographic outcome: Successful cases of healing	12 months
El- Kateb, et al., [43]	18 patients (11 females, 7 males; age group (20-34 y), 18 mature necrotic maxillary anteriors with apical lesions (17 maxillary central incisors, 1 lateral incisor)	G1: REP with rotary instrumentation (PTN- X3) (test) 1 st visit: Irrig: 20 ml 1.5%NaOCl, Ca(OH) ₂ intracanal dressing, 2 nd visit: Irrig: final rinse of 17% EDTA, bleeding induction for blood clot formation and placement of Biodentine. Final coronal restoration with RMGIC (base)+ composite resin	G2: REP with rotary instrumentation (PTN- X5) (control) (clinical procedure similar for test and control group)	Clinical outcome: satisfactory (No pain, sensitivity to percussion or swelling) Radiographic outcome: digital radiographic healing of periapical lesions	12 months
Jha, et al., [44]	30 patients (age range, 9-15 y); permanent mature teeth with apical lesions	G1: REP (EDTA SealBio technique) 1 st visit: Irrig: Negative pressure (Endovac) 2.5% NaOCl; TAP intracanal dressing (2 weeks) 2 nd visit: Irrig: 17 %EDTA, induction of bleeding (#15, 20 K file)+ calcium sulfate-based cement), followed by coronal restoration	G2: NSRCT 1 st visit: Irrig: Negative pressure (Endovac) 2.5% NaOCl; TAP intracanal dressing (2 weeks) 2 visit: obturation with gutta-percha cones-cold lateral condensation technique)	Clinical and radiographic outcome- Successful healing	18 months
Liang, et al., [45]	346 patients (age range overall (10-59 y); (mature permanent teeth	REP (calcium hydroxide and EDTA 17%/ bleeding induction for blood clot formation and placement of i-PRF into the root canal to a level of 3mm below CEJ/covered with i-Root BP plus	REP (calcium hydroxide and EDTA 17%/ bleeding induction for blood clot formation to a level of 3mm below CEJ/BC covered by 3mm layer of i-Root BP plus	Successful healing (combined clinical and radiographic findings)	24 months

	diagnosed with pulp necrosis)				
REP- Regenerative Endodontic Procedure; CEJ- cemento-Enamel Junction; TAP- Triple Antibiotic Paste; DAP-Double Antibiotic Paste; PRP- Platelet Rich Plasma; PRF-Platelet Rich Fibrin; PP-Platelet Pellet; BC-Blood Clot; Irrig- Irrigation; bFGF- Fibroblast Growth Factor; NaOCl- Sodium Hypochlorite; EDTA-Ethylene Diamine Tetra Acetic Acid; CHX- Chlorhexidine; MTA-Mineral Tri-Oxide Aggregate; Ca(OH) ₂ - Calcium Hydroxide; CRCT-conventional root canal treatment /NSRCT- Non-Surgical Root Canal Treatment; PTN-Protaper Next; RMGIC- Resin Modified Glass-Ionomer Cement					

Table 1: Summary of studies included in the present literature review (Immature and Mature teeth).

Future Directions

Cell Sheets (Fig. 2)

It represents an innovative approach in the field of regenerative medicine, offering a three-dimensional structure that mimics native tissue architecture [21]. This technique involves cultivating monolayers of cells along with their extracellular matrix, providing a scaffold-free platform for tissue engineering [21]. What sets cell sheets apart is their ability to preserve cell-to-cell communication and maintain the integrity of cellular interactions. This promotes a more natural microenvironment upon transplantation, potentially enhancing the engraftment and functionality of the cells [21]. The versatility of cell sheets extends across various tissues and organs, making them a promising tool for addressing critical injuries, degenerative diseases and congenital anomalies. While the field is rapidly advancing, challenges such as scalability and standardization need to be addressed for widespread clinical application [21,22]. Despite these challenges, cell sheets hold great promise for revolutionizing regenerative medicine by harnessing the collective power of cells in a manner that closely resembles the intricate dynamics of native tissues (Fig. 3).

1. **Cell Spheroids:** In addition to having well-formed cell networks, these dense 3D cell aggregates have been used to create peri-vascularized microtissue spheroids of DPSCs [23]. These spheroids have shown the ability to generate dental pulp-like tissue with blood vessels in immunodeficient mice. Another regenerative approach involves creating organoids, which are 3D tissue constructs that mimic the complex microanatomy and function of the corresponding tissue *in-vivo* [23,24]. This is achieved by using induced Pluripotent Stem Cells (iPSCs), Embryonic Stem Cells (ESCs) or adult stem cells [23,24]
2. **3D Bioprinting:** It has emerged as a ground breaking technology with transformative implications in the field of endodontics [25]. This innovative approach involves the precise layer-by-layer deposition of biomaterials, cells and bioactive factors to construct intricate three-dimensional structures. In the context of endodontics, 3D bioprinting holds immense promise for fabricating customized scaffolds and constructs that mimic the complex architecture of dental tissues [25,26]. This technology enables the creation of bioengineered root canal fillings, pulp scaffolds and other structures, offering a tailored and patient-specific approach to treatment. The precision afforded by 3D bioprinting allows for the incorporation of multiple cell types and growth factors, fostering an environment conducive to tissue regeneration [25-27]. As the field advances, the integration of 3D bioprinting in endodontics not only has the potential to revolutionize the conventional approaches to root canal therapy but also represents a significant stride towards more personalized and regenerative dental treatments
3. **Layered scaffolds:** They have emerged as integral components in the realm of regenerative endodontics, providing a sophisticated framework to guide the repair and restoration of dental tissues [28]. These scaffolds are designed with precision, allowing for a structured layer-by-layer deposition of biomaterials that closely mimic the intricate architecture of native tissues [28]. In regenerative endodontics, these layered scaffolds play a pivotal role in creating a conducive environment for stem cells, growth factors and other bioactive agents. By providing mechanical support and spatial cues, these scaffolds aid in the regeneration of dental pulp and periapical tissues within the root canal system [29]. Their customizable nature enables the incorporation of various materials to enhance biocompatibility and they serve as a platform for controlled release of therapeutic agents. As research progresses, layered scaffolds in regenerative endodontics stand poised to revolutionize traditional treatment modalities, offering a tailored and regenerative approach to restore the vitality and function of dental tissues [28,29]
4. **Gene Therapy:** It has emerged as a cutting-edge avenue in regenerative endodontics, introducing a transformative approach to harness the potential of genetic interventions for tissue repair [30]. In this innovative paradigm, therapeutic genes are

strategically delivered to the target tissues within the root canal system, aiming to stimulate and guide the regeneration of dental structures [30]. Gene therapy holds the promise of modulating cellular behavior, promoting the differentiation of stem cells into specialized dental cell types and enhancing the synthesis of extracellular matrix components crucial for tissue regeneration [30,31]. This approach not only addresses the source of dental pathology but also fosters a regenerative environment. The targeted delivery of therapeutic genes offers a precise and controlled means to influence cellular activities, paving the way for more effective and personalized regenerative treatments in endodontics [31]. As research in gene therapy progresses, its integration into regenerative endodontic protocols holds great potential for revolutionizing the field, providing new avenues for restoring damaged dental tissues at the molecular level

5. **Bio-banking:** It has emerged as a valuable asset in the landscape of regenerative endodontics, providing a strategic repository for the preservation and storage of biological materials crucial for research and therapeutic advancements [32]. Within this innovative field, bio-banking plays a pivotal role in the collection and conservation of various biological samples, including dental pulp stem cells, growth factors and other regenerative materials [32]. The establishment of well-curated bio-banks facilitates the availability of standardized and characterized biological resources, ensuring a readily accessible pool for regenerative studies and clinical applications [32]. By preserving these valuable materials, bio-banking not only supports ongoing research endeavors but also enhances the reproducibility and translational potential of regenerative therapies in endodontics. As bio-banking protocols continue to evolve, their integration into regenerative endodontic frameworks contributes significantly to advancing our understanding and application of regenerative strategies, ultimately fostering progress in the quest for effective and personalized dental tissue repair [32].

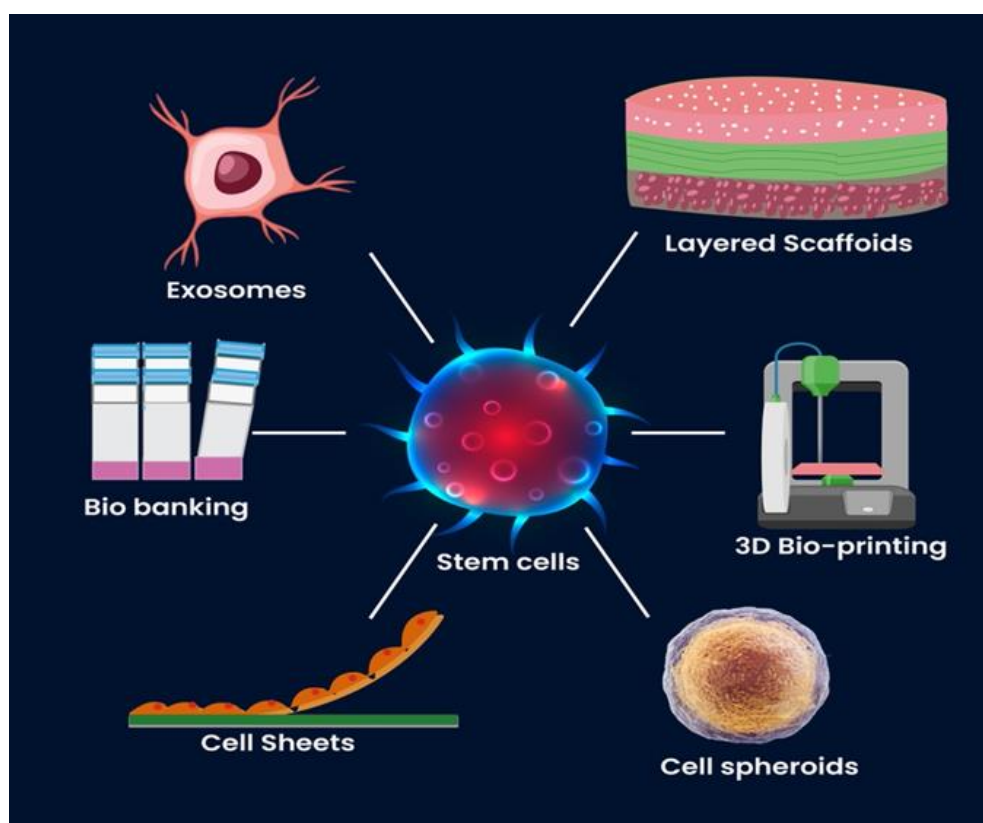


Figure 3: Advances in stem cell-based techniques.

Conclusion

This literature review highlights regenerative endodontics, from its present practices to promising prospects on the horizon. Through a rigorous examination of existing research, it is evident that regenerative techniques such as stem cell therapy and scaffold development have opened new avenues in endodontics we thus, conclude that regenerative endodontics is still an evolving field and has a promising scope with favorable results and improved treatment prognosis for the management of non-vital immature as well as mature teeth with periapical lesions.

Conflict of Interests

The authors have no conflict of interest to declare.

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