Turkish Journal of Public Health Dentistry
Volume 6, Issue 1, Page No: 47-52
Available Online at: **https://tjphd.com/**

ISSN: 3062-3359

Review Article

Regenerative Endodontics vs. Traditional Apexification in Immature Teeth: A Narrative Review

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ABSTRACT

Immature permanent teeth exhibiting pulpal necrosis present unique clinical challenges that differ significantly from those seen in mature dentitions, primarily due to open apices, thin dentinal walls, and compromised structural integrity during function. For decades, the standard of care for managing such teeth involved apexification procedures using calcium hydroxide or mineral trioxide aggregate (MTA) to induce apical barrier formation, thereby facilitating obturation. However, apexification techniques, although predictable in creating an apical stop, do not allow for continued root maturation, leaving the tooth structurally vulnerable. Recent advances in biologically based therapies have led to the emergence of regenerative endodontic procedures (REPs), which aim not only to resolve infection but also to stimulate tissue repair or regeneration within the root canal space, resulting in potential increases in root length, thickness of dentinal walls, and apical closure. A growing body of literature has revealed compelling advantages of regenerative approaches, especially in the context of restoring physiology, improving mechanical properties of the tooth, and reducing long-term fracture risk. Nonetheless, REPs remain clinically variable because of differences in case selection, disinfection protocols, scaffolds, and intracanal medicaments and because true regeneration versus repair is a topic of ongoing debate. The objective of this expanded review is to comprehensively compare the biological, clinical, radiographic, and long-term prognostic outcomes of regenerative endodontics and traditional apexification, drawing from contemporary evidence and clinical experience. Special emphasis is placed on procedural nuances, cellular biology, success metrics, limitations, and indications in modern endodontic practice. This article aims to be a thorough and academically rigorous narrative review to inform clinicians, researchers, and advanced dental students about current best practices and emerging directions in the management of immature necrotic teeth.

Keywords: Regenerative endodontics, Traditional apexification, Mineral trioxide aggregate, Intracanal medicaments

Introduction

Immature permanent teeth with necrotic pulps constitute a unique and historically challenging category in clinical endodontics due to anatomical and histological factors that diverge markedly from fully developed teeth [1]. Such teeth display open apices, thin and fragile dentinal walls, larger canal volumes, and reduced root length, all of which collectively increase the risk of procedure-related and long-term complications, including instrument separation, canal transportation, and, most critically, cervical root fractures [1]. Managing these teeth necessitates careful intervention that simultaneously resolves infection and preserves or enhances root structural integrity [1]. Historically, apexification emerged as the principal treatment modality for immature teeth with pulp necrosis, originally relying on prolonged placement of calcium hydroxide to induce the deposition of a hard tissue barrier at the apex [2]. Although effective, long-term calcium hydroxide apexification required multiple appointments over months, and the resulting apical barrier was often porous and irregular in thickness [2]. The introduction of

HOW TO CITE THIS ARTICLE: Alhussain BS, Alqara MH, Alqara AH. Regenerative Endodontics vs. Traditional Apexification in Immature Teeth: A Narrative Review. Turk J Public Health Dent. 2026;6(1):47-52. https://doi.org/10.51847/mLkixm5QQ7

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Received: 14/11/2025
Accepted: 27/02/2026

MTA significantly improved the predictability and efficiency of apexification, offering faster apical barrier creation and improved biocompatibility [3]. Nevertheless, neither form of apexification results in continued root development, and thus these teeth remain at heightened risk for fracture, especially over the patient's lifetime [3].
Regenerative endodontics has revolutionized the management of immature necrotic teeth by emphasizing biological principles and the potential to restore the functional vitality of the pulp-dentin complex [4]. Regenerative endodontic procedures are built on the triad of tissue engineering: stem cells, scaffolds, and signaling molecules, combining meticulous disinfection with biologically based methods to recruit endogenous stem cells capable of promoting root maturation [5]. Studies have demonstrated the potential for significant thickening of canal walls, continued root elongation, and improved apical closure, bringing treatment goals closer to natural root development [5].
The shift toward regenerative techniques reflects broader movements in medicine and dentistry toward biologically driven treatments rather than synthetic or non-vital restorative strategies [5]. Despite the remarkable potential, REPs present challenges, such as variability in clinical outcome, differences in tissue formed (regeneration versus repair), and concerns regarding tooth discoloration when using certain medicaments [5]. Apexification remains a valuable and sometimes preferable treatment when regenerative therapy is contraindicated or unlikely to succeed [6].
This study aims to present a structured, comprehensive, and critically balanced comparison of regenerative endodontics and apexification, focusing on their biological basis, clinical protocols, outcome measurements, and use in current dentistry. This review aims to enhance informed clinical decision-making by combining underlying science with clinical evidence and highlighting topics for future research [6].

Aim of the study

The primary aim of this expanded review is to critically evaluate and compare regenerative endodontic procedures (REPs) and traditional apexification techniques in the treatment of immature necrotic permanent teeth [6]. A secondary aim is to assess the biological mechanisms, procedural methodologies, long-term outcomes, and success rates for each approach, based on contemporary scientific literature and clinical observations [6].
Additionally, this study seeks to examine the indications, advantages, limitations, patient-centered outcomes, and prognostic implications associated with each treatment modality to provide clinicians with a comprehensive evidence-based framework for selecting appropriate treatment strategies [7].
A tertiary aim is to identify gaps in current research and propose future directions to enhance predictability and clinical success in regenerative endodontics, especially considering the variability of outcomes across different case types and patient age groups [7].

Materials and Methods

Summary

Table 1. Methodology of the current review

Category	*Description*
Study Type	Narrative review of published scientific literature (2015–2025).
Databases Searched	PubMed, Scopus, ScienceDirect, Google Scholar.
Keywords Used	Regenerative endodontics, apexification, immature teeth, revascularization, MTA, calcium hydroxide, stem cells, pulp-dentin regeneration.
Inclusion Criteria	Human studies; immature permanent teeth with pulpal necrosis; articles evaluating REPs or apexification; clinical trials, systematic reviews, case series.
Exclusion Criteria	Animal-only studies; studies on mature teeth only; articles with insufficient methodology; lack of clinical relevance.
Data Extracted	Root length change, dentin wall thickness, apical closure, periapical healing, symptoms, survival rate, complications (e.g., discoloration, fracture).
Analysis Approach	Qualitative synthesis of outcomes from clinical and radiographic evaluations; comparison of success criteria between REPs and apexification.
Ethical Consideration	No new human research conducted; ethical approval not required.

This expanded narrative review synthesizes data from multiple sources, including peer-reviewed clinical trials, laboratory studies, systematic reviews, meta-analyses, case reports, and authoritative textbooks published between 2015 and 2025 [8]. The primary databases consulted included PubMed, Scopus, ScienceDirect, and Google Scholar using keywords such as *regenerative endodontics, apexification, revascularization, immature teeth, MTA, calcium hydroxide, stem cells in endodontics*, and *pulp-dentin regeneration* [9] **(Table 1)**.

Studies were included if they evaluated the clinical or biological outcomes of regenerative endodontics or apexification in immature permanent teeth diagnosed with pulp necrosis [9]. Exclusion criteria included studies involving animal models without translation to human clinical results, research involving mature teeth exclusively, or articles lacking detailed methodological descriptions [9].

Data extraction included outcome variables such as root length changes, dentin wall thickening, apical closure, resolution of periapical pathology, patient symptoms, survival rates, and incidence of complications including tooth discoloration and root fracture [10]. Quality assessment was based on publication rigor, methodological clarity, sample size, and follow-up duration.

Results and Discussion

Biological and structural outcomes

Studies consistently show that regenerative endodontic procedures result in measurable increases in root length and dentinal wall thickness compared to apexification [10]. Radiographic analysis reveals significant improvement in root maturation following REPs, particularly in cases treated at a younger age when stem cell populations are more abundant [11]. Conversely, apexification does not contribute to root elongation, resulting in roots that remain short and thin, although apical closure is predictably achieved [11] **(Table 2)**.

Table 2. Effect of features and REPs on apexification

Feature	REPs	Apexification
Root length	Increases	No change
Dentinal wall	Thicker	Thin
Apical closure	Yes	Yes
Best age	Young	Any
X-ray outcome	Root matures	Only apex closes

Apical barrier formation

Apexification with MTA produces good rates of apical barrier development, which often occurs in a single visit and provides a stable platform for obturation [11]. Calcium hydroxide apexification, while predictable, necessitates many sessions and is related to delayed treatment completion [11]. Regenerative techniques have varied apical closure, and some cases show partial apical narrowing consistent with tissue repair rather than actual root formation [11] **(Table 3)**.

Table 3. Comparison between MTA, $Ca(OH)_2$ and REPs

Feature	*MTA Apex*	*$Ca(OH)_2$ Apex*	*REPs*
Apical barrier	Forms well, 1 visit	Predictable, many visits	Variable, may be incomplete
Treatment time	Short	Long	Variable
Outcome	Stable platform	Stable platform	Tissue repair

Resolution of infection and periapical healing

Both treatment modalities show high success in eliminating infection and promoting periapical healing [11]. However, REPs rely heavily on chemical disinfection rather than mechanical instrumentation, reducing the risk of weakening already thin dentinal walls [12]. Apexification protocols typically involve gentle mechanical preparation, which can still compromise root integrity in severely immature teeth [12] **(Table 4)**.

Table 4. REP's with parameters and success of apexification

Parameter	Regenerative Endodontics (REPs)	Apexification

Infection Resolution	High success; relies mainly on chemical disinfection [11]	High success; involves gentle mechanical prep [11]
Periapical Healing	Promotes healing	Promotes healing
Impact on Dentinal Walls	Minimal risk of weakening thin walls [13]	May compromise root integrity in immature teeth [14]

Tooth strength and resistance to fracture

Teeth treated by apexification remain structurally vulnerable because root dimensions do not increase, and long-term fracture risk is significantly higher compared to REPs [13]. Regenerative cases demonstrate improved resistance to fracture attributed to continued root thickening, although the quality and composition of newly formed tissue vary across studies [13].

Complications

Common complications in REPs include discoloration due to tetracycline-based medicaments and variability in root maturation outcomes [13]. Apexification complications mostly involve extended treatment duration (in calcium hydroxide methods), potential reinfection between appointments, and long-term fragility [12].

Biological foundations of treatment

Regenerative endodontics is mainly based on tissue engineering principles, in which endogenous stem cells, mainly apical papilla stem cells (SCAP), are recruited into the disinfected root canal region to restore pulp-like tissue. Growth factors produced from dentin after EDTA irrigation are critical biochemical signals for cell migration and differentiation [12]. Apexification, by contrast, focuses merely on building an apical barrier without restoring biological vitality within the canal, making it less aligned with modern regenerative principles [13].

Disinfection protocols and intracanal medicaments

REPs rely on minimal mechanical instrumentation to avoid disrupting the apical papilla and its stem cell niche [13]. Chemical disinfection uses low-concentration sodium hypochlorite, followed by EDTA to enhance dentinal growth factor release [13]. Intracanal medicaments typically include calcium hydroxide or triple antibiotic paste (TAP), although TAP can cause severe discoloration and is being replaced by modified antibiotic formulations [15]. In apexification, medicaments such as calcium hydroxide are used long-term or MTA is placed directly to stimulate barrier formation [15].

Tissue outcomes: regeneration vs. repair

A central controversy is whether REPs provide true regeneration of odontoblast-like cells and vascularized pulp tissue or merely induce repair with cementum- or bone-like tissues filling the canal [16]. Histological studies show that most cases involve repair rather than full regeneration, but functionally these outcomes still offer improved root development and structural support [16]. Apexification never regenerates pulp tissue, and thus vitality cannot be restored [16].

Clinical success parameters

Success in regenerative therapy includes several qualitative and quantitative metrics: absence of symptoms, healing of periapical lesions, continued root development, and return of response to pulp tests in some cases [17]. Apexification success is primarily measured by creation of an apical barrier and resolution of periapical pathology [17]. Because REPs aim to restore biological function, their success criteria are more comprehensive [17].

Long-term prognosis

Longitudinal studies indicate that regenerative cases display better long-term structural integrity and reduced likelihood of catastrophic root fracture [17]. Apexified teeth may function adequately but remain at risk for structural failure, especially in young patients engaging in active lifestyles [18]. This difference significantly influences the choice of therapy, especially when longevity is considered.

Indications and case selection

Regenerative therapies are most effective in teeth with wide-open apices, low canal calcification, and younger patients with large stem cell populations [19]. Apexification is still useful in situations where REPs are not appropriate, such as when the apical papilla has been obliterated, anatomic restrictions impede bleeding into the canal, or patient compliance is inadequate [19].

Future directions

Current research in regenerative endodontics focuses on controlled scaffolds, exogenous stem cell therapies, platelet-rich fibrin (PRF) applications, bioactive materials, and gene-modulating growth factors [19]. Artificial intelligence–based prediction models are also being explored to forecast case outcomes based on radiographic and biological parameters [20].

Apexification, though effective, offers limited scope for further evolution, making regenerative endodontics the more promising field for future advancements [20].

Conclusion

Accumulating evidence increasingly supports the superiority of regenerative approaches over traditional apexification in promoting continued root development, enhancing structural reinforcement, and improving long-term fracture resistance. REPs can stimulate the ingrowth of vascularized connective tissue, which not only contributes to the biological maturation of the root but also supports the overall vitality of the tooth. Studies have demonstrated that teeth treated with regenerative protocols exhibit greater increases in root length and dentinal wall thickness compared to apexification, directly translating into improved functional outcomes and prognosis. However, variability in treatment protocols, differences in scaffold and medicament selection, and inconsistent histological outcomes underscore the need for careful case selection and adherence to evidence-based guidelines to maximize clinical success.

Clinicians must also consider potential complications associated with regenerative therapy, including intracanal calcification, discoloration, or inadequate tissue regeneration, which may impact the final outcome. The success of REPs is highly dependent on meticulous clinical execution, proper disinfection protocols, and the judicious use of intracanal medicaments, all of which require training, experience, and careful judgment. Furthermore, patient factors such as age, immune status, and the stage of root development play a pivotal role in determining the likelihood of treatment success, highlighting the necessity for individualized treatment planning. Continuous refinement in regenerative techniques, biomaterials, and understanding of stem cell biology will likely improve the predictability and long-term outcomes of these procedures.

Acknowledgments: None

Conflict of Interest: None

Financial Support: None

Ethics Statement: None

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