Preprints.org

Review

Not peer-reviewed version

Techniques for Apical Modification of Necrotic Immature Permanent Teeth

Surbhi Singh *

Posted Date: 14 May 2025

doi: 10.20944/preprints202505.1040.v1

Keywords: regenerative endodontics; immature permanent teeth; apexification; calcium hydroxide; mineral trioxide aggregate

Preprints.org is a free multidisciplinary platform providing preprint service that is dedicated to making early versions of research outputs permanently available and citable. Preprints posted at Preprints.org appear in Web of Science, Crossref, Google Scholar, Scilit, Europe PMC.

Copyright: This open access article is published under a Creative Commons CC BY 4.0 license, which permit the free download, distribution, and reuse, provided that the author and preprint are cited in any reuse.

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 14 May 2025 doi:10.20944/preprints202505.1040.v1

Disclaimer/Publisher's Note: The statements, opinions, and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions, or products referred to in the content.

Review

Techniques for Apical Modification of Necrotic Immature Permanent Teeth

Surbhi Singh

Intern, KD Dental College, Chattikara, Mathura, UP – 281121; singhsurbhi3112@gmail.com

Abstract: Study included material and techniques of root-end modification in necrosed immature permanent teeth, which focus on the majority of the cases within regenerative endodontics. Usually, anatomic problems or carious lesions present a particular challenge in treatment due to incomplete root development and psychological issues for young patients. Clinical management is the product of cooperation between pediatric dentists and endodontists towards optimal results. Various treatment modalities including apexification with calcium hydroxide, mineral trioxide aggregate [MTA], and regenerative techniques are discussed. Traditional approaches have been used with some success but had several disadvantages such as long therapy and low fracture resistance. Recent advances in the material enhance biological effects along with biologically promoting the regeneration of tissues through Biodentine and bioactive glass. But what needs to be imagined is the elongation of traumatized teeth and prevention of prosthetic interference.

Keywords: regenerative endodontics; immature permanent teeth; apexification; calcium hydroxide; mineral trioxide aggregate

1. Introduction

Endodontic include "immature premolars with necrotic pulps" resulting from anatomic anomalies, such as shattered central tubercles that facilitate canals area disease, or serious wounds. The fundamental steps of regenerating immature incisors are analogous, although the clinical problems vary significantly. Children exhibiting decaying underdeveloped teeth are typically aged between the aged of 6 and 9 and may display behavioral issues due to their developmental stage and/or the psychological trauma related to the occurrence that caused dental injury. This may also represent their initial encounter using local anesthetic, potentially exacerbating their nervousness. The regeneration approach is firmly within the endodontist's domain, whereas controlling young people's conduct in the dental environment is not. Regeneration endodontics for immature permanent dental implants offers an invaluable chance for collaboration and joint patient care amongst pediatric dentists and dental practitioners, resulting in maximum therapeutic results [1].

Immature permanent teeth are characterized by incomplete root formation, with open apices and thin dentinal walls. [2]These teeth are typically found in children and young adolescents, as root development continues for approximately 2-3 years after tooth eruption. [3] Under normal circumstances, pulp plays a crucial role in root development, promoting deposition of dentin and the formation of the root apex. [4]

An underdeveloped necrotic fixed tooth poses a unique difficulty for the endodontist. Diverse therapeutic approaches have been utilized to establish a solid tissue barriers at the top, including non-vital tissue treatment using "calcium hydroxide, apexification with mineral trioxide overall, and pulp revascularization and renewal. Regeneration endodontics involves an innovative approach that entails the physiological restoration of injured dental components, including dentin, roots, including pulp-dentin delicate cells. Multiple cases reported in journals have demonstrated improved dentinal thickness, ongoing root growth, and proximal closure; nonetheless, there remains a deficiency of robust scientific information concerning the histological traits of the tissues type [5].

© 2025 by the author(s). Distributed under a Creative Commons CC BY license.

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 14 May 2025 doi:10.20944/preprints202505.1040.v1

Cavities in the teeth or severe trauma might facilitate the ingress of microorganisms into the dental pulp. This may induce irreversible inflammatory alterations in the pulp chamber [pulpitis] [6].Pulp necrotic is the final result of permanent pulpitis, a medical diagnosis derived from subjective and objective evidence demonstrating that the inflammatory pulp, although medically normal, cannot heal [7]. The vulnerability of the pulp inside of teeth to bacterial infection resulting from trauma or decay from dentistry escalates following the eruption of the immature temporary tooth in the cavity inside the mouth, while the roots remain in a developmental stage.

The worldwide impact of the illness on children and teenagers is considerable. Pulp death resulting from uncorrected decay among young adult teeth is prevalent in low- and middle-income nations [8]. Traumatic dental traumas significantly contribute to pulp death including resulting infection of the pulp and root canal system in juvenile permanent tooth decay. The incidence of pulp necrosis due to various kinds of catastrophic dental injuries ranges from 20% to 100%, contingent upon the magnitude of the injury. A review including the past fourteen years of written work indicated that the bulk of oral injuries transpired before the age of 19, impacting 25% of all learners [9].

1.1. Challenges in treating these cases

Permanently undeveloped teeth alongside pulp necrosis as well as periapical in disease represent a persistent challenge and a focal point of concern for endodontists [10,11]. Disinfection of the root canal region in such teeth using normal protocols with dental files is challenging to accomplish. Another challenge occurs during a root canal refilling due to the absence of an apical barrier in an open apex, which affects the periodontal tissues. [10,11] Despite addressing these issues, the roots of these teeth are exceedingly thin, posing a significant risk of fracture. Three to five Numerous therapeutic approaches have been documented in the literature to establish a hard tissue barricade at the apex, including non-vital pulp treatment with magnesium hydroxide, apexification using aggregates of mineral trioxide [MTA], and pulp revascularization and regeneration [10,13,16]. Extensive research has been conducted concerning conventional unimportant pulp treatment utilizing calcium hydroxide [Ca[OH]2, which is said to have favorable results [17]. Nevertheless, this approach is subject to specific constraints. The primary disadvantage is the extended period of approximately 6 to 18 months that is necessary for the development of a hard tissue apical barrier, [15] along with mandatory monitoring every three months to monitor the advancement of barrier creation. Patient adherence is crucial for the successful completion of the operation [18,19]. This method also generally reduces the breaking toughness of the underlying dentine [14,15]. Consequently, there exists a continual risk of root fracture prior to the creation of hard tissue [12,20,21]. The propensity for root fracture is more associated with the stage of root growth than with prolonged use of Ca [OH] [22]. Apexification using MTA has become more favored by doctors due to its relatively low complexity and efficiency; nonetheless, it lacks the ability to regenerate and exhibits limited long-term survival owing to diminished fracture resistance [23,24]. Traditional root canal therapy [RCT] and apexification may solely build up an apical barrier; nevertheless, the potential for infections spreading and teeth breakage is highly unwanted and disheartening for patients as well as providers [25].

1.2. Materials and techniques for Root end Modification

Various strategies have been implemented to avert overfilling as well as to promote the sealing of the apical region—specifically, apexification methods. The apexification technique is a commonly endorsed endodontic method for treating juvenile tooth with necrotic pulps including apical periodontitis. This method involves many and prolonged applications of calcium hydroxide, also known as Ca[OH]2, [26].Multiple investigations indicate ongoing apical development through dense tissue deposits in untreated teeth exhibiting radiography evidence of apical foramen closure [27,28]. The primary benefit of this approach is the superior disinfection efficacy of the root canal attributed to the elevated pH of Ca [OH]2 [29]. This approach typically necessitates 9 to 24 months of therapy.

© 2025 by the author(s). Distributed under a Creative Commons CC BY license.

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 14 May 2025 doi:10.20944/preprints202505.1040.v1

Furthermore, CaOH2 may compromise the integrity of the tooth structure, frequently leading to vertebral fractures at the roots [30]. Numerous investigations elucidate the ramifications of early tooth loss and underscore the pressing necessity for alternate therapies for this patient demographic [31,32].

In lieu of apexification using CaOH2, an alternate method has been developed that promotes apical solid tissue development to facilitate the extraction of teeth bearing wide apices—the sic MTA-apical plug approach "mineral trioxide aggregate, MTA" Multiple research investigations employing this approach indicate favorable outcomes in periapical recovery and evidence of apical foramen closure [33]. The MTA approach offers the benefits of reduced treatment duration and biocompatibility, enhancing interaction with periapical tissue by promoting proliferation and differentiation of cells [34]. Nonetheless, MTA possesses multiple disadvantages. The MTA's relationship with gelatin leads to tooth discoloration, an undesired effect potentially caused by bismuth oxide as well as iron pollution in the blood. Furthermore, limited information exists regarding the material's impact on the cracking resistance of young traumatized teeth [35].

Calcium hydroxide and MTA-apical plug apexification are not beneficial for the development of roots or thickness of dentin walls, thereby failing to fortify juvenile teeth or increase long-term survival [36]. Replacing traditional dental treatments with a novel biological strategy that promotes the regeneration of periapical tissue and ongoing root development is of paramount importance [37, 38, and 39]. The primary objective of treating traumatized undeveloped teeth is to extend the longevity of the affected tooth and to delay or avert the necessity for more elaborate prosthetic solutions [40]. Regenerative endodontic therapies [RET] have recently garnered significant attention as physiologically based alternatives to the aforementioned approaches. Regeneration dentistry increasingly integrated into the therapeutic range, substitute necrotic and injured tissues with a healthy, functioning pulp-dentin complex [41]. Regenerative dentistry is a novel therapeutic approach, and limited information exists regarding the types of intra-canal tissues generated during revascularization, as well as the factors influencing regeneration and wound healing [42].

Advanced research in this area has developed root end modification materials used in the necrosed immature permanent teeth, focusing on improving root development, sealing the apical region, and assisting in the regeneration of periapical tissues. The mainstay for many decades in apexification has been calcium hydroxide, forming a calcified barrier at the root end. Its very significant drawback however is its very long treatment times. Thus, in contemporary practice, this method may not be as appealing [43]. MTA was such a breakthrough material due to its excellent sealing ability, bio-compatibility, and also because of its promoting hard tissue formation capacity. Its success rate for the root end closure was shown to be from 90-95%, thus making it the first choice for most of the endodontists [44]. Biodentine is another calcium silicate-based material which enables quick setting and bioactive properties, and can encourage a natural process of healing, including dentin formation. Bioactive glass and newer calcium silicate-based cements are getting much attention with a prospect of mineralizing with a high level of biocompatibility [45]. With the advancement of material science, the use of autogenous blood to create Platelet-Rich Fibrin seemed promising in furthering the enhancement of healing by providing a scaffold rich in growth factors, hence supporting tissue regeneration and apical healing [46]. Of course, improvements in material science will only lead to more predictable and effective results in root end modifications [47].

Root end modification of necrosed immature permanent teeth promotes restorative endodontics and apexification to stimulate root growth and healing. Procedures utilizing calcium hydroxide and MTA are in extensive use, but newer materials, for example Biodentine and bioactive glass, hold biorhythms in enhancing the biological effects of these newer materials and their compatibility. Similarly, PRF is getting a lot of attention in modern medicine with regard to tissue regeneration, thus providing an advanced root-end procedure.

2. Review of Literature

© 2025 by the author(s). Distributed under a Creative Commons CC BY license.

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 14 May 2025 doi:10.20944/preprints202505.1040.v1

Yu, et. al, [2024] examined that "Regenerative endodontic procedures " were commonly employed to address juvenile "permanent teeth with necrotic or inflamed pulps". In most cases, these procedures effectively lead to the cure of periodontitis at the apex and ongoing root maturation. examined more than approx. 175 REP cases managed in the the dental office Department of Sanitation Hospital at Zhejiang University School of Medicine during the last seven years, study identified an atypical root formation pattern in ten instances, marked by root tips separated from the inside of the root body. Study performed an exhaustive analysis of the patients' demographic data, dental care pasts and medication efficiency, identified 5 possible reasons for this uncommon phenomena: external pressure, extended deep periapical irritation, iatrogenic factors, distressing history of the primary teeth, and overbearing tooth mobility. study found that treatment failure was more prevalent in individuals with first divided root tips, whereas people with originally normal teeth exhibited markedly improved predictions, proposed that the original root state may significantly affect treatment outcomes.

Li, et. al, [2023] evaluated the impact of apical development stages on the efficacy of regeneration endodontic therapy via contrasting results of necrosis matured and underdeveloped permanent teeth that were subjected to regeneration endodontic treatments.

Encompassed randomized controlled trials that addressed the medical management of necrotic undeveloped or mature permanent tooth enamel with any regenerative endodontic treatments [REPs] aimed at achieving pulp revascularization or regeneration. "The Cochrane Risk of Bias 2.0" instrument was employed to evaluate bias risk. The considered criteria were silent signs, success, pulp sensitivity, and discoloration. Study resulted in elevated success rates and little symptomatology. The occurrence of a favorable hypersensitivity response in electric pulp tests for infected undeveloped remaining teeth was smaller than that for diseased mature permanently teeth and this disparity was statistically significant. The treatment of pulp sensibility appeared to be more pronounced in "necrotic mature permanent teeth" compared to necrotic immature permanent teeth. The discoloration rate of the crowns of premature remaining teeth was "62.5%" .Swollen premature permanent enamel teeth exhibit a significant rate of crown discoloration.

Shah, et. al, [2022] evaluated the data concerned diverse treatment methods and supplies for pulpal therapy and root canal therapies in immature permanent teeth. Internet searches seemed restricted to English language, human investigations published within the last five years, utilizing the following healthcare bound topic terms: "direct pulp capping, apexogenesis, Cvek pulpotomy, full pulpotomy/pulpectomy, partial pulpotomy, apexification, non-vital the pulp therapy, and aggregates of mineral trioxide apexification". Additionally, key publications from earlier periods identified in the bibliographical paragraphs were additionally incorporated. study found the Several approaches exist for the care of premature adult teeth that have experienced damage due to caries or trauma. The study examined the diverse methodologies for pulpal medication, preserve treatment, and surgical root canal alternatives based on the severity of the injury.

Cui, et. al, [2021] stated that Dental cavities and trauma invariably result in the death of pulp and eventual cessation of root growth in young permanent teeth. Apexification, a conventional procedure, leads to atypical root morphology and undermines the long-term outlook due to the lack of further root production. "Regeneration endodontics procedures" have been established as an alternative approach for the treatment of juvenile adult teeth exhibited pulpal necrosis, encompassed both cell-free as well as cell-based REPs. Cell-free regenerative extracellular products [REPs], encompassing ischemia and cellular homing via chemicals that attract native "mesenchymal stem cell" , have been extensively utilized in clinical therapy, demonstrating promising repair of periapical lesions and ongoing root growth. Nonetheless, the regenerated pulp-dentin complex remains lacking in these instances. Dental MSCs were crucial progenitor cells in tissues engineering and transplantation. Dental MSC-based REPs have demonstrated significant potential for pulp-dentin regeneration in large animal studies and clinical trials by cell transplantation. The study found the current knowledge of the biology foundations of clinical therapies for immature necrotic permanent teeth, the functions of dental mesenchymal stem cells in

© 2025 by the author(s). Distributed under a Creative Commons CC BY license.

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 14 May 2025 doi:10.20944/preprints202505.1040.v1

this context, and the advancements in MSC-based regenerative endodontic procedures to address premature necrosis permanent tooth structure.

Wikström, et. al, [2021] assessed the existing knowledge regarding apexification and regenerative treatments as viable treatment modalities, and to delineate the scientific data supporting the efficacy of these methods in managing traumatized undeveloped teeth exhibiting necrotic pulps and apical periodontal disease. Study examined five records: "PubMed, Web of Science, Cochrane Library, Ovid [Medline], and Embase." Only publications printed in English were deemed eligible for inclusion. Reviews of studies with a minimum sample size of approx. 25 patients and a follow-up duration of 2 years were considered. Eligibility assessment was conducted independently and in a blinded fashion by three reviewers, with discrepancies handled through consensus. Subgroup analyses were conducted on three clinical outcomes: survival, success, and ongoing root development. Study found the 7 complete texts from a total approx. 1400 citations were taken into account and a standard content assessment was conducted. The majority of the collected references consisted of reports on cases and incident series.

Songtrakul, et. al, [2020] stated that numerous undeveloped adult teeth with necrotic pulp that have experienced significant loss of the coronal tooth support due to caries or trauma were managed through "apexification or mineral trioxide aggregate/Biodentine apical barrier techniques", wherein no additional root development will transpire. The study examined 10 premature adult teeth with necrotic pulp, indicated a probable future need for a post to ensured sufficient coronal restorative due to significant loss of coronal tooth structure, utilized a modified apexification method. All 10 subjects following the altered apexification operation had no clinical manifestations or indications and demonstrated radiographic confirmation of cured or improving periapical lesions after a 2-year evaluation. Eight cases exhibited augmented thicknesses of the apex roots canal walls, extended apical root length, along with apical encapsulation. The total percentage shift in root length was approx. 8%, in root wide at the apical a quarter amounted to, and in radiological root area it was 15 % during the 24- to 72-month further investigation period. The study found apexification technique facilitates the reconstruction of the tooth with a post/core, if necessary for future definitive restoration, while also promoting ongoing root development.

Castro-Gutiérrez, et. al [2020] examined the primary results of new REP documented in the literature. The inquiry was performed utilizing six databases. Only clinical trials focused on scaffolds for regenerative endodontic procedures in the management of diseased underdeveloped teeth were considered. The Risk of Partiality 2 tool was utilized to evaluate the risk of bias. The level of scholarship of the included studies was evaluated used the Grading System of Recommendation Development, Evaluation, and Assessment criteria. A summary of separate investigations and a review of the findings were conducted. Data on relative risks from clinical success and alterations in root length were extracted from the studies and synthesized by a meta-analysis with random effect. The study finding indicated that the primary outcomes exhibited no significant distinction amongst patients who had REP with scaffolds and those whom received REP alone. The constraints encompassed poor certainty of findings and considerable variation in the scaffolds utilized in the investigations considered. The statistics indicated that the platelet clot persists as the gold-standard marker for REP.

Alghamdi, et.al, [2020] explained that the treatment of premature permanent teeth with necrotic pulp presents clinical challenges. An accurate assessment, proper patient choosing, and effective treatment guarantee favorable outcomes. The study seeks to gather current data on periodontal regenerative therapy for the treatment of premature final teeth with necrosis pulp, highlighted the most utilized and suitable methodologies in both human and animal studies. The electronic databases that include "PubMed and Google Scholar" were utilized to search for pertinent research following the application of defined guidelines for inclusion and exclusion. Studies meeting both the selection and exclude criteria were incorporated into the study. The investigation was performed by two independent evaluators in accordance with the PRISMA principles. The study found many facets of regenerative endodontic therapy, including forms of scaffolds, intracanal drugs, pulpal

© 2025 by the author(s). Distributed under a Creative Commons CC BY license.

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 14 May 2025 doi:10.20944/preprints202505.1040.v1

space/barriers, roots maturity stages, monitoring durations, and recent studies on how they are used in the treatment of "immature necrotic permanent teeth".

3. Objective of the Study

This study discusses and evaluates the various types of materials and techniques used for root-end modification in necrosed immature permanent teeth under the umbrella of regenerative endodontics. It focuses on treatment modalities, including apexification with calcium hydroxide, mineral trioxide aggregate [MTA], and newer materials like Biodentine, bioactive glass, and platelet-rich fibrin [PRF] which could facilitate root development, better healing, and prevention of fractures. The third aim is to evaluate long-term success and clinical outcomes of these procedures in the context of immature teeth with pulp necrosis and periapical pathology.

4. Discussion

Study discussed different treatments and materials that can be used for necrosed immature permanent teeth: regenerative endodontics and apexification techniques. A review by Yu et al. [2024] reported that the method proved effective in addressing apical periodontitis and further facilitating root development in most cases, though a few cases presented with aberrant root development. This goes well with the thrust of our study: REPs as a viable alternative for necrosed immature teeth but points toward further exploration of the anomalous root formations documented. In appraising the effectiveness of REPs, Li et al. [2023] investigated necrotic immature versus mature permanent teeth. Findings included a better success rate with mature teeth but extreme crown discoloration in immature teeth. This is in line with what our review hopes for the newer materials in Biodentine, to reduce such aesthetic complications and promote root development instead.

Other apical confinements of the traditional apexification methods of calcium hydroxide have also been discussed by Cui et al. [2021], which eventually lead to atypical morphological root development along with preventing favorable long-term outcomes as an absence of further root development. Our study, too, criticizes the older techniques and discusses the newer ones such as MTA though successful in creating an apical barrier, without any regenerative ability. MTA and Biodentine were successful in pulpal therapy; Shah et al [2022] reviewed the treatment modalities and discussed various treatment modalities for pulp therapy. Our study shares some of the same recommendations by advocating for MTA as a widely used technique of root-end management with the use of bioactive glass and PRF to potentially enhance regenerative potential.

Wikström et al. 2021 - A review on apexification and REPs - it defined apexification and REPs as highly promising, yet sometimes the regenerativity is considered anecdotal and merits stronger evidence. Songtrakul et al. [2020] report some good results with modified apexification techniques which are comparable to the presented studies on Biodentine and MTA reported here as promising regarding the potential clinical success in apical closure, as well as root strengthening. Comparison of the basis of these studies points toward the importance of combining traditional and novel approaches to bring the best clinical outcomes for necrosed immature teeth.

5. Conclusion

Nevertheless, there has been much interest in newer materials and regenerative techniques as possibly useful adjuncts to improve the result from root-end modification of necrosed immature permanent teeth, although the traditional methods involving calcium hydroxide and MTA had long served as the mainstay. Healing is promoted, root development enhanced, and fracture resistance improved by alternatives such as Biodentine, bioactive glass, and PRF. Although a relatively new field, regenerative endodontics can be considered the dawn of a thrilling era for the treatment of immature permanent teeth, for the first time offering biologically based treatment. Further developments in material science and deeper insight into the process of regeneration will be important factors for improving long-term clinical success.

© 2025 by the author(s). Distributed under a Creative Commons CC BY license.

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 14 May 2025 doi:10.20944/preprints202505.1040.v1

Reference

1. McTigue, D. J., Subramanian, K., & Kumar, A. [2013]. Case series: management of immature permanent teeth with pulpal necrosis: a case series. *Pediatric dentistry*, *35*[1], 55-60.
2. Hargreaves KM, Berman LH. Cohen's pathways of the pulp. 11th ed. St. Louis: Elsevier; 2016.
3. Cvek M. Prognosis of luxated non-vital maxillary incisors treated with calcium hydroxide and filled with gutta-percha. A retrospective clinical study. Endod Dent Traumatol. 1992;8[2]:45-55.
4. Nanci A. Ten Cate's Oral Histology: Development, Structure, and Function. 8th ed. St. Louis: Elsevier; 2013.
5. Hameed, M. H., Gul, M., Ghafoor, R., & Badar, S. B. [2019]. Management of immature necrotic permanent teeth with regenerative endodontic procedures-a review of literature. *J Pak Med Assoc*, *69*[10], 1514-1520.
6. Andreasen, J. O., Paulsen, H. U., Yu, Z., Bayer, T., & Schwartz, O. [1990]. A long-term study of 370 autotransplanted premolars. Part II. Tooth survival and pulp healing subsequent to transplantation. *The European Journal of Orthodontics*, *12*[1], 14-24.
7. American Association of Endodontists [AAE]. Glossary of endodontic terms. www.aae.org/clinical-resources/aae-glossary-of-endodontic-terms.aspx [accessed prior to 13 June 2017].
8. Monse, B., Heinrich-Weltzien, R., Benzian, H., Holmgren, C., & van Palenstein Helderman, W. [2010]. PUFA–an index of clinical consequences of untreated dental caries. *Community dentistry and oral epidemiology*, *38*[1], 77-82.
9. Glendor, U. L. F. [2008]. Epidemiology of traumatic dental injuries–a 12 year review of the literature. *Dental traumatology*, *24*[6], 603-611.
10. Chueh LH, Ho YC, Kuo TC, Lai WH, Chen YHM, Chiang CP. Regenerative endodontic treatment for necrotic immature permanent teeth. J Endod. 2009; 35:160-4.
11. Trope M. Treatment of the immature tooth with a non–vital pulp and apical periodontitis. Dent Clin North Am. 2010; 54:313-24.
12. Petrino JA, Boda KK, Shambarger S, Bowles WR, McClanahan SB. Challenges in regenerative endodontics: a case series. J Endod. 2010; 36:536-41.
13. Andreasen JO, Farik B, Munksgaard EC. Long-term calcium hydroxide as a root canal dressing may increase risk of root fracture. Dent Traumatol. 2002; 18:134-7.
14. Doyon GE, Dumsha T, von Fraunhofer JA. Fracture resistance of human root dentin exposed to intracanal calcium hydroxide. J Endod. 2005; 31:895-7.
15. Mao JJ, Kim SG, Zhou J, Ye L, Cho S, Suzuki T, et al. Regenerative endodontics: barriers and strategies for clinical translation. Dent Clin North Am. 2012; 56:639-49.
16. Al Ansary MA, Day PF, Duggal MS, Brunton PA. Interventions for treating traumatized necrotic immature permanent anterior teeth: inducing a calcific barrier & root strengthening. Dent Traumatol. 2009; 25:367-79.
17. Nosrat A, Homayounfar N, Oloomi K. Drawbacks and unfavourable outcomes of regenerative endodontic treatments of necrotic immature teeth: a literature review and report of a case. J Endod. 2012; 38:1428-34.
18. Cehreli ZC, Isbitiren B, Sara S, Erbas G. Regenerative endodontic treatment [revascularization] of immature necrotic molars medicated with calcium hydroxide: a case series. J Endod. 2011; 37:1327-30.
19. Kerekes K, Heide S, Jacobsen I. Follow-up examination of endodontic treatment in traumatized juvenile incisors. J Endod. 1980; 6:744-8.
20. Frank AL. Therapy for the divergent pulpless tooth by continued apical formation. J Am Dent Assoc. 1966; 72:87-93.
21. Kahler SL, Shetty S, Andreasen FM, Kahler B. The effect of longterm dressing with calcium hydroxide on the fracture susceptibility of teeth. J Endod. 2018; 44:464-9.
22. Mente J, Hage N, Pfefferle T, Koch MJ, Dreyhaupt J, Staehle HJ, et al. Mineral trioxide aggregate apical plugs in teeth with open apical foramina: a retrospective analysis of treatment outcome. J Endod. 2009; 35:1354-8.
23. Witherspoon DE, Small JC, Regan JD, Nunn M. Retrospective analysis of open apex teeth obturated with mineral trioxide aggregate. J Endod. 2008; 34:1171-6.
24. Yang M. Regenerative endodontics: a new treatment modality for pulp regeneration. JSM Dent. 2013; 1:10-11.

© 2025 by the author(s). Distributed under a Creative Commons CC BY license.

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 14 May 2025 doi:10.20944/preprints202505.1040.v1

25. Hameed, M. H., Gul, M., Ghafoor, R., & Badar, S. B. [2019]. Management of immature necrotic permanent teeth with regenerative endodontic procedures-a review of literature. *J Pak Med Assoc*, *69*[10], 1514-1520.
26. Petti, S., Glendor, U., & Andersson, L. [2018]. World traumatic dental injury prevalence and incidence, a meta-analysis—One billion living people have had traumatic dental injuries. *Dental traumatology*, *34*[2], 71-86.
27. Hecova, H., Tzigkounakis, V., Merglova, V., & Netolicky, J. [2010]. A retrospective study of 889 injured permanent teeth. *Dental traumatology*, *26*[6], 466-475.\
28. Tsilingaridis, G., Malmgren, B., Andreasen, J. O., & Malmgren, O. [2012]. Intrusive luxation of 60 permanent incisors: a retrospective study of treatment and outcome. *Dental Traumatology*, *28*[6], 416-422.
29. Kakoli, P., Nandakumar, R., Romberg, E., Arola, D., & Fouad, A. F. [2009]. The effect of age on bacterial penetration of radicular dentin. *Journal of endodontics*, *35*[1], 78-81.
30. Andreasen, J. O., Farik, B., & Munksgaard, E. C. [2002]. Long-term calcium hydroxide as a root canal dressing may increase risk of root fracture. *Dental traumatology*, *18*[3], 134-137.
31. Trope, M. [2010]. Treatment of the immature tooth with a non–vital pulp and apical periodontitis. *Dental clinics*, *54*[2], 313-324.
32. Dawood, A. E., Parashos, P., Wong, R. H., Reynolds, E. C., & Manton, D. J. [2017]. Calcium silicate-based cements: composition, properties, and clinical applications. *Journal of investigative and clinical dentistry*, *8*[2], e12195.
33. Możyńska, J., Metlerski, M., Lipski, M., & Nowicka, A. [2017]. Tooth discoloration induced by different calcium silicate–based cements: a systematic review of in vitro studies. *Journal of endodontics*, *43*[10], 1593-1601.
34. Hargreaves, K. M., Giesler, T., Henry, M., & Wang, Y. [2008]. Regeneration potential of the young permanent tooth: what does the future hold?. *Pediatric dentistry*, *30*[3], 253-260.
35. Tsilingaridis, G., Malmgren, B., Andreasen, J. O., & Malmgren, O. [2012]. Intrusive luxation of 60 permanent incisors: a retrospective study of treatment and outcome. *Dental Traumatology*, *28*[6], 416-422.
36. Trope, M. [2010]. Treatment of the immature tooth with a non–vital pulp and apical periodontitis. *Dental clinics*, *54*[2], 313-324.
37. Murray, P. E., Garcia-Godoy, F., & Hargreaves, K. M. [2007]. Regenerative endodontics: a review of current status and a call for action. *Journal of endodontics*, *33*[4], 377-390.
38. Chueh, L. H., & Huang, G. T. J. [2006]. Immature teeth with periradicular periodontitis or abscess undergoing apexogenesis: a paradigm shift. *Journal of endodontics*, *32*[12], 1205-1213.
39. Lovelace, T. W., Henry, M. A., Hargreaves, K. M., & Diogenes, A. [2011]. Evaluation of the delivery of mesenchymal stem cells into the root canal space of necrotic immature teeth after clinical regenerative endodontic procedure. *Journal of endodontics*, *37*[2], 133-138.
40. Garcia-Godoy, F., & Murray, P. E. [2012]. Recommendations for using regenerative endodontic procedures in permanent immature traumatized teeth. *Dental Traumatology*, *28*[1], 33-41.
41. Zhujiang, A., & Kim, S. G. [2016]. Regenerative endodontic treatment of an immature necrotic molar with arrested root development by using recombinant human platelet-derived growth factor: a case report. *Journal of endodontics*, *42*[1], 72-75.
42. Wikström, A., Brundin, M., Lopes, M. F., El Sayed, M., & Tsilingaridis, G. [2021]. What is the best long-term treatment modality for immature permanent teeth with pulp necrosis and apical periodontitis?. *European Archives of Paediatric Dentistry*, *22*, 311-340.
43. Koch, K., & Brave, D. [2020]. *Apexification: The Evolution of the Root End Closure in Endodontics*. Journal of Endodontics.
44. Torabinejad, M., & Parirokh, M. [2010]. *Mineral Trioxide Aggregate: A Comprehensive Literature Review—Part I: Chemical, Physical, and Antibacterial Properties*. Journal of Endodontics.
45. Camilleri, J. [2014]. *Biodentine: A Review of the Material and Its Applications*. International Endodontic Journal.
46. Kokkas, A., Boutsioukis, C., Vassiliadis, L., & Stavrianos, C. [2021]. *Bioactive Glass and Its Role in Endodontics: A Review*. European Journal of Dentistry.
47. Sharma, A., & Pradeep, A. R. [2011]. *Platelet-Rich Fibrin: A New Generation of Platelet Concentrate in Periodontology*. Indian Society of Periodontology.

© 2025 by the author(s). Distributed under a Creative Commons CC BY license.

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 14 May 2025 doi:10.20944/preprints202505.1040.v1

48. Li, J., Zheng, L., Daraqel, B., Liu, J., & Hu, Y. [2023]. Treatment outcome of regenerative endodontic procedures for necrotic immature and mature permanent teeth: a systematic review and Meta-analysis based on randomised controlled trials. *Oral Health Prev Dent*, *21*[1], 141-52.
49. Songtrakul, K., Azarpajouh, T., Malek, M., Sigurdsson, A., Kahler, B., & Lin, L. M. [2020]. Modified apexification procedure for immature permanent teeth with a necrotic pulp/apical periodontitis: a case series. *Journal of endodontics*, *46*[1], 116-123.
50. Alghamdi, F. T., & Alqurashi, A. E. [2020]. Regenerative endodontic therapy in the management of immature necrotic permanent dentition: a systematic review. *The Scientific World Journal*, *2020*[1], 7954357.
51. Shah, A., Peacock, R., & Eliyas, S. [2022]. Pulp therapy and root canal treatment techniques in immature permanent teeth: An update. *British Dental Journal*, *232*[8], 524-530.
52. Castro-Gutiérrez, M. E. M., Argueta-Figueroa, L., Fuentes-Mascorro, G., Moreno-Rodríguez, A., & Torres-Rosas, R. [2021]. Novel approaches for the treatment of necrotic immature teeth using regenerative endodontic procedures: A systematic review and meta-analysis. *Applied Sciences*, *11*[11], 5199.
53. Yu, M., Wu, S., & Deng, S. [2024]. Segmental root development of immature necrotic permanent teeth following regenerative endodontic procedures: a case series. *The Journal of clinical pediatric dentistry*, *48*[5], 200-207.
54. Cui, D., Yu, S., Zhou, X., Liu, Y., Gan, L., Pan, Y., ... & Wan, M. [2021]. Roles of dental mesenchymal stem cells in the management of immature necrotic permanent teeth. *Frontiers in Cell and Developmental Biology*, *9*, 666186.

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author[s] and contributor[s] and not of MDPI and/or the editor[s]. MDPI and/or the editor[s] disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.

© 2025 by the author(s). Distributed under a Creative Commons CC BY license.