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Clinical decision-making for open-apex teeth: Material and technique selection - A review

Vidushi Gilhotra, Ajay Chhabra*, Arpita Banerjee, Shilpa Raveendran, Shraddha Gupta & Ambritha Pari

Department of Dentistry, All India Institute of Medical Sciences (AIIMS), Kalyani, West Bengal, India; *Corresponding author

Affiliation URL:
https://aiimskalyani.edu.in

Author contact:
Vidushi Gilhotra - E-mail: drvidushi.gilhotra@gmail.com
Ajay Chhabra - E-mail: ajay.dental@aiimskalyani.edu.in
Arpita Banerjee - E-mail: arpita.dental_acjr25@aiimskalyani.edu.in

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Shilpa - E-mail: Shilpa.dental_acjr25@aiimskalyani.edu.in
Shraddha Gupta - E-mail: gshraddha1801@gmail.com
Ambritha Pari - E-mail: ambritha1509@gmail.com

Abstract:
Teeth with open, immature apices are challenging to treat because of the absence of an apical stop and thin dentinal walls. Therefore, it is of interest to evaluate the evidence on calcium hydroxide apexification, calcium silicate apical barriers and regenerative endodontic procedures. Regenerative procedures may promote root development, whereas calcium hydroxide and calcium silicate materials provide predictable apical barrier formation. Treatment selection should be individualized according to root maturity, infection status, patient factors and tooth restorability. This review advances knowledge by emphasizing an individualized, biologically based approach for selecting treatment strategies and improving the long-term prognosis of immature permanent teeth.

Keywords: Open apex, immature permanent tooth, apexification, regenerative endodontics, mineral trioxide aggregate, calcium hydroxide, randomized controlled trial

Background:
Management of permanent teeth with open and immature apices remains a significant challenge in clinical endodontics **[1]**. An open apex is commonly observed when root development is interrupted by trauma, deep caries, pulpal necrosis, or developmental abnormalities before physiological completion of root formation. In immature teeth, the root canal system is characterized by thin and fragile dentinal walls, a wide apical opening and incomplete root development. These anatomical features make conventional root canal instrumentation and obturation difficult because a natural apical constriction is absent and an adequate apical stop cannot be readily established. Consequently, treatment must aim not only to control infection but also, whenever possible, to preserve or promote continued root development and strengthen the remaining tooth structure **[2]**. Dental trauma is one of the important causes of pulpal necrosis and arrested root development in young permanent teeth. When pulpal necrosis occurs before completion of root formation, further deposition of dentin and development of the root may cease **[3]**. The resulting short root with thin dentinal walls has a greater susceptibility to fracture and may have a compromised long-term prognosis. Similar clinical challenges can occur in teeth affected by extensive carious lesions or developmental anomalies such as dens invaginatus and dens evaginatus. Therefore, management of immature teeth requires consideration of both infection control and the biological potential of the developing root **[4]**. Historically, calcium hydroxide apexification has been widely used for the management of necrotic immature teeth. The technique involves repeated placement of calcium hydroxide within the canal to stimulate formation of a calcified apical barrier. Although this approach can provide an apical stop that facilitates subsequent obturation, long treatment periods and multiple appointments may be required. Prolonged exposure to calcium hydroxide has also raised concerns regarding alteration of dentinal properties and increased susceptibility to cervical root fracture. These limitations have encouraged the development of alternative techniques capable of producing a predictable apical barrier within a shorter treatment period **[5]**. The introduction of mineral trioxide aggregate and other calcium silicate-based materials provided an alternative approach through artificial apical barrier formation. In an apical plug technique, a biocompatible material is placed at the apical portion of the root canal to create an immediate barrier against which the remaining canal can be obturated. Calcium silicate materials possess favorable biological and physical properties, including biocompatibility, sealing ability and the capacity to release calcium ions and promote hard tissue responses. Their use has therefore, reduced dependence on prolonged calcium hydroxide therapy and has facilitated more predictable treatment of immature teeth with necrotic pulps **[6]**. Regenerative endodontic procedures have further expanded the treatment options available for immature permanent teeth. Unlike conventional apexification, regenerative approaches aim to control infection while promoting continued development of the root. These procedures generally involve conservative disinfection of the canal, induction of bleeding or use of a biological scaffold, placement of a suitable coronal barrier and appropriate restoration of the tooth. Continued root maturation may result in increased root length and dentinal wall thickness, potentially improving the structural strength and long-term survival of the tooth. However, outcomes can vary according to patient age, degree of root development, infection status, treatment protocol and the biological environment of the root canal **[7]**. The increasing number of available materials and techniques has made clinical decision making more complex. The choice between traditional apexification, calcium silicate apical barriers and regenerative endodontic procedures should not be based solely on material properties **[8]**. Therefore, it is of interest to examine the current evidence regarding clinical decision-making in the management of teeth with open apices, with particular emphasis on material selection and treatment technique.

Biological basis of teeth with open apices:
Teeth with open apices are commonly encountered when pulpal necrosis occurs before completion of root development. Trauma and deep caries are important causes, while developmental anomalies such as dens invaginatus and dens evaginatus may also result in early pulpal involvement. An immature permanent tooth typically has a short root, thin dentinal walls, a large canal space and a wide apical opening. The absence of a natural apical constriction makes conventional instrumentation and obturation

difficult. Therefore, treatment should focus on adequate infection control while preserving the remaining tooth structure and where possible, promoting continued root development **[9].** The biological characteristics and clinical challenges associated with teeth with open apices are summarized in **Table 1**, including incomplete root development, thin dentinal walls, wide apical openings and difficulties associated with conventional endodontic treatment **[9]**. The principles, advantages and limitations of calcium hydroxide apexification are presented in **Table 2**, while **Table 3** summarizes regenerative endodontic procedures, their potential to promote continued root development and factors influencing clinical outcomes. The patient-related, biological and clinical considerations guiding treatment selection, including root maturity, apical diameter, infection status, restorability, patient compliance, financial constraints and clinician expertise, are outlined in **Table 4**.

.Table 1: Biological basis and clinical characteristics of teeth with open apices

Aspect	Description
Common causes	Pulpal necrosis before completion of root development, commonly associated with trauma and deep caries
Developmental causes	Developmental anomalies such as dens invaginatus and dens evaginatus may cause early pulpal involvement
Root morphology	Short and incompletely developed root
Dentinal walls	Thin and structurally weak dentinal walls
Root canal anatomy	Large canal space with a wide, open apical diameter
Apical anatomy	Absence of a natural apical constriction
Endodontic challenge	Conventional instrumentation and obturation are difficult because of the open apex
Risk during treatment	Increased risk of weakening the root and extrusion of irrigants or obturation materials
Primary treatment objective	Effective infection control while preserving the remaining tooth structure
Biological objective	Where possible, promote continued root development and maturation

Table 2: Calcium hydroxide apexification: principles, advantages and limitations

Aspect	Description
Indication	Traditionally used for necrotic immature permanent teeth with open apices
Basic technique	Calcium hydroxide is placed inside the root canal to stimulate formation of a calcified apical barrier
Definitive obturation	The canal is obturated after an adequate apical barrier has developed
Clinical experience	Extensive history of clinical use and established treatment approach
Apical barrier formation	Generally provides predictable formation of a calcified barrier
Long-term acceptance	Widely accepted and supported by substantial clinical experience
Treatment duration	Barrier formation may require several months
Number of visits	Multiple treatment appointments may be required
Patient compliance	Regular follow-up is important, particularly in young patients
Effect on dentin	Prolonged exposure to calcium hydroxide may affect dentinal mechanical properties
Fracture concern	Prolonged treatment has raised concerns regarding increased susceptibility to cervical root fracture
Need for newer approaches	Limitations have encouraged shorter treatment protocols and development of alternative biomaterials

Table 3: Regenerative endodontic procedures: principles, benefits and limitations

Aspect	Description
Treatment approach	Biologically based approach for managing immature necrotic permanent teeth
Primary objective	Promote continued root development and maturation rather than simply closing the open apex
Canal disinfection	Conservative disinfection is performed to control infection while preserving biological potential
Intracanal medicament	An intracanal medicament may be used when clinically indicated
Scaffold formation	Bleeding may be induced to create a biological scaffold, or an alternative scaffold may be used
Coronal seal	A suitable coronal seal is essential to prevent reinfection and support treatment success
Root length	May increase following regenerative treatment
Dentinal wall thickness	May increase, potentially improving structural strength
Apical development	Progressive narrowing of the apical opening may occur
Potential benefit	Continued root development may improve the structural integrity and long-term prognosis of the tooth
Technique sensitivity	Treatment requires careful control of disinfection, bleeding, scaffold formation and sealing
Factors affecting outcome	Stage of root development, infection control, patient age, treatment protocol and biological conditions of the root canal
Major limitation	Clinical outcomes can vary between patients and treatment protocols

Table 4: Clinical factors influencing treatment selection for teeth with open apices

Factor	Clinical Consideration
Stage of root development	Very immature roots may have greater potential to benefit from regenerative procedures.
Apical diameter	The size of the open apex should be evaluated when selecting an appropriate treatment technique.
Infection status	Presence and severity of infection should be assessed before treatment selection.
Periapical status	The extent of periapical inflammation or pathology should be considered.
Dentinal wall thickness	Thin dentinal walls require conservative treatment to minimize the risk of root fracture.
Patient age	Age may influence the biological potential for regenerative responses.
Patient compliance	Ability to attend follow-up visits is important, particularly for multi-visit procedures.
Tooth position	Location of the tooth may influence treatment accessibility and functional demands.
Restorability	The ability to adequately restore and protect the tooth should be evaluated before treatment.
Occlusal function	Functional and occlusal loading should be considered when assessing long-term prognosis.
Periodontal condition	Periodontal health may influence treatment planning and prognosis.
Long-term prognosis	Expected tooth survival and functional outcome should guide the choice of treatment.
Financial considerations	Treatment cost and affordability may influence the selection of available options.

Material availability	Availability of appropriate regenerative or apical barrier materials can affect treatment choice.
Clinician experience	Operator expertise and familiarity with the selected technique are important for predictable outcomes.
Treatment duration	The expected duration and number of appointments should be considered according to patient and clinical circumstances.

Clinical challenges in management:

The anatomy of an immature tooth creates important clinical challenges. Thin dentinal walls increase the risk of weakening and fracture during mechanical instrumentation. The wide apical opening also makes it difficult to contain irrigants and obturation materials within the root canal. Excessive instrumentation can further reduce dentinal thickness and compromise the long-term prognosis of the tooth. For this reason, contemporary approaches emphasize conservative instrumentation, effective chemical disinfection and techniques that establish an apical barrier without unnecessarily removing dentin.

Calcium hydroxide apexification:

Calcium hydroxide apexification has traditionally been used for necrotic immature permanent teeth. The technique involves placement of calcium hydroxide inside the root canal to encourage formation of a calcified apical barrier. Once a suitable barrier is established, the canal can be obturated. The major advantages of this approach include extensive clinical experience, relatively predictable barrier formation and long-term clinical acceptance **[10].** Despite these advantages, conventional calcium hydroxide apexification has several limitations. Formation of the apical barrier may require several months and repeated treatment visits. Patient compliance is therefore important, particularly in young patients. Prolonged exposure of dentin to calcium hydroxide has also been associated with concerns regarding changes in dentinal mechanical properties and increased susceptibility to cervical root fracture. These limitations have encouraged the development of shorter treatment protocols and alternative biomaterials.

Calcium silicate-based apical barriers:

Calcium silicate-based materials, including mineral trioxide aggregate and newer bioceramic materials, have substantially changed the management of teeth with open apices. Instead of waiting for a biological barrier to develop, these materials can be placed directly at the apical portion of the canal to create an artificial apical stop. The remaining canal can subsequently be obturated. The principal advantages of calcium silicate materials include biocompatibility, favorable sealing properties, dimensional stability and their ability to interact with biological tissues. Apical barrier techniques can generally be completed more rapidly than traditional calcium hydroxide apexification and may reduce the number of treatment appointments. However, the technique primarily creates an artificial barrier and does not aim to restore physiological root development. Therefore, although it provides predictable control of the apical end of the canal, it may not provide the same potential for continued root maturation associated with regenerative procedures **[11]**.

Regenerative endodontic procedures:

Regenerative endodontic procedures have introduced a biologically based approach to the management of immature necrotic teeth. The primary objective is not simply to close the open apex but to encourage continued root development and maturation. These procedures generally involve conservative disinfection of the canal, the use of an intracanal medicament when indicated, induction of bleeding or placement of a scaffold and establishment of a coronal seal **[12].** One of the major potential benefits of regenerative treatment is continued development of the root. Clinical studies have reported increases in root length, dentinal wall thickness and apical narrowing following regenerative procedures. Such changes may improve the structural strength of the tooth and potentially reduce its susceptibility to fracture. However, regenerative treatment is technique-sensitive and outcomes may vary according to the stage of root development, infection control, patient age, treatment protocol and biological conditions within the root canal.

Comparative evidence:

Comparative studies and systematic reviews have generally reported greater radiographic root development following regenerative endodontic procedures than following conventional apexification. Improvements in root length, root thickness and apical diameter have been demonstrated in several clinical studies. However, greater radiographic development does not necessarily mean that regenerative procedures provide superior overall clinical success or long-term tooth survival **[13]**. Apexification remains a reliable option when the primary objective is to establish an apical barrier and permit predictable obturation. Calcium silicate-based materials have further improved this approach by allowing relatively rapid barrier formation. Regenerative procedures may be particularly attractive when preservation of the biological potential for continued root development is considered important. Thus, treatment selection should be based on the individual characteristics of the tooth and patient rather than on the assumption that one technique is universally superior.

Role of infection control:

Effective infection control is fundamental to the success of all treatment approaches for immature teeth. However, aggressive mechanical preparation should generally be avoided because the dentinal walls are already thin. Chemical disinfection therefore plays an important role. Irrigants and intracanal medicaments should be selected carefully to achieve adequate microbial reduction while minimizing damage to dentin and, in regenerative procedures, to cells involved in tissue repair. The balance between microbial control and preservation of biological potential is particularly important in regenerative endodontics. Excessively strong or prolonged exposure to antimicrobial agents may negatively affect the viability and function of stem

cells and other cells involved in regenerative processes. Consequently, contemporary regenerative protocols emphasize conservative canal preparation and controlled disinfection.

Factors influencing clinical decision-making:
The choice of treatment should consider several clinical factors. The stage of root development is particularly important because teeth with very immature roots may have greater potential to benefit from regenerative procedures. The diameter of the apical opening, presence and severity of infection, periapical status and thickness of the remaining dentin should also be assessed **[14].** Patient related factors are equally important. Age may influence the biological potential for regenerative responses, while compliance determines whether a patient can reliably attend multiple appointments. The position of the tooth, its restorability, occlusal function, periodontal condition and expected long-term prognosis should also influence treatment planning. Financial considerations, availability of materials, clinician experience and treatment duration may further affect the final decision.

Restorative considerations:
Endodontic treatment alone does not determine the long-term prognosis of an immature tooth. Because the remaining root structure may be thin and fragile, preservation of tooth structure and provision of an effective coronal seal are essential. The definitive restoration should protect the tooth from reinfection and minimize the risk of structural failure. Conservative restorative approaches are generally desirable because unnecessary removal of dentin can further weaken an already compromised root. The clinician should therefore consider the restorative requirements at the beginning of treatment rather than after completion of the endodontic procedure.

Current evidence and research gaps:
Current evidence supports calcium hydroxide apexification, calcium silicate apical barriers and regenerative endodontic procedures as useful approaches for managing teeth with open apices. However, their objectives differ. Traditional apexification focuses on formation of an apical barrier, calcium silicate materials provide a predictable artificial barrier and regenerative procedures aim to facilitate continued biological root development **[15].** Although regenerative procedures demonstrate promising improvements in radiographic root development, differences in treatment protocols, patient characteristics, outcome measures and follow-up periods make direct comparison between studies difficult. Long term evidence regarding fracture resistance, tooth survival and functional outcomes is also less extensive than the evidence for radiographic changes. Further well-designed randomized clinical trials with standardized protocols and long-term follow-up are therefore required. Overall, the management of teeth with open apices should follow an individualized, evidence based approach. Rather than selecting a treatment solely according to the material available, clinicians should integrate root maturity, apical anatomy, infection status, patient factors, restorability, treatment feasibility and long-term prognosis when selecting the most appropriate technique.

Comparision with previous studies:
The comparative evidence published between 2022 and 2026 generally supports regenerative endodontic procedures (REPs) as a biologically favorable option for immature permanent teeth with open apices, although their superiority over apexification is not consistent for overall treatment success. Adel and Asgari (2025) [16] reported that REPs and apexification showed comparable overall success and survival, while regenerative treatment demonstrated greater potential for continued root development. Similarly, Stefanidou *et al*. (2024) **[17]** found that revitalization produced significantly greater increases in root length and dentinal wall thickness than conventional apexification, supporting its potential advantage in teeth with thin and fragile roots. Pendse *et al.* (2025) **[18]** further demonstrated that outcomes of regenerative treatment can vary according to the scaffold and treatment protocol, emphasizing the importance of appropriate technique selection. In contrast, Sabeti *et al.* (2024) [19] concluded that both regenerative procedures and apexification can achieve favorable clinical and radiographic outcomes, but highlighted the heterogeneity and variable quality of the available evidence. More recently, Alqedairi *et al.* (2026) [20] reported that regenerative procedures were associated with greater continued root maturation, particularly in terms of root length and dentinal wall development, although a consistent advantage in overall clinical success was not established **[21, 22]**. Taken together, these five studies indicate that REPs may provide an important biological advantage by promoting continued root maturation, whereas apexification remains a predictable approach for establishing an apical barrier and controlling periapical disease **[23, 24]**. Therefore, treatment should be individualized according to root maturity, apical anatomy, infection status, patient factors, restorability and the clinician's ability to achieve effective disinfection and follow-up **[25, 26].**

Limitations:
This narrative review did not use a reproducible systematic search protocol, PRISMA-based study selection, or independent risk-of-bias assessment, limiting the reproducibility and certainty of its conclusions. Heterogeneity in outcome definitions, follow-up periods, study populations and limited comparative evidence for posterior teeth and long-term outcomes restrict direct comparisons between treatment approaches. Evidence on emerging technologies remains predominantly preclinical and the English-language restriction may have excluded relevant studies; therefore, the proposed clinical framework should be interpreted cautiously rather than as a definitive treatment ranking.

Conclusion:
Management of open apices has evolved toward evidence-based, patient-specific strategies that balance continued root development, treatment predictability and cost-effectiveness.

Regenerative endodontic procedures offer greater potential for root maturation, whereas apexification remains a reliable alternative with predictable outcomes. Ultimately, individualized treatment selection and emerging advances in biomaterials, biofabrication and AI-assisted diagnostics may further improve long-term tooth preservation.

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