Cumhuriyet Dental Journal, 28(3): 462-468, 2025
DOI: https://doi.org/10.7126/cumudj.1728795

Cumhuriyet Dental Journal

| cdj.cumhuriyet.edu.tr | Founded: 1998 Available online, ISSN: 1302-5805 Publisher: Sivas Cumhuriyet Üniversitesi

Management Strategies for Teeth with Open Apex: From Apexification to Regenerative Endodontics

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Review

History

Received: 30/06/2025
Accepted: 09/07/2025

ABSTRACT

The management of teeth with open apices, typically resulting from trauma or developmental anomalies, remains a clinical challenge in endodontics. Historically, apexification with long-term calcium hydroxide therapy was the primary approach to induce apical closure. However, this method is associated with extended treatment duration and increased risk of root fracture. Bioceramic materials such as mineral trioxide aggregate (MTA), artificial apical barriers have gained popularity due to their reduced treatment time and favorable sealing properties. More recently, regenerative endodontic procedures (REPs) have emerged as a biologically based alternative aiming to restore the pulp–dentin complex and promote continued root development. This review provides a comprehensive overview of current treatment strategies for immature permanent teeth, comparing traditional apexification with modern regenerative techniques. Clinical indications, protocols, advantages, limitations, and prognosis are discussed in detail to guide evidence-based clinical decision-making.

Keywords: Open apex, apexification, regenerative endodontics, MTA, calcium hydroxide, immature teeth, apical barrier

Açık Apeksli Dişler İçin Yönetim: Apeksifikasyondan Rejeneratif Endodontiye

Derleme

Süreç

Geliş: 30/06/2025
Kabul: 09/07/2025

ÖZ

Travma veya gelişimsel anomaliler sonucu ortaya çıkan açık apeksli dişlerin yönetimi, endodontide önemli bir klinik zorluk olmaya devam etmektedir. Geleneksel olarak, apeksifikasyon amacıyla uzun süreli kalsiyum hidroksit tedavisi apikal kapanmayı sağlamak için standart yöntem olarak uygulanmıştır. Ancak bu yaklaşım, uzun tedavi süresi ve kök kırığı riskinde artış ile ilişkilidir. Biyoseramik materyallerden mineral trioksit agregat (MTA) kullanılarak yapay apikal bariyer oluşturulması, tedavi süresini kısaltmış ve güvenilir bir sızdırmazlık sağlamıştır. Daha yakın zamanda, rejeneratif endodontik prosedürler, pulpa–dentin kompleksini yeniden oluşturmayı ve kök gelişiminin devamını desteklemeyi hedefleyen biyolojik temelli bir alternatif olarak ortaya çıkmıştır. Bu derlemede, immatür daimi dişlerin yönetimine yönelik güncel stratejiler sunulmakta; geleneksel apeksifikasyon ile çağdaş rejeneratif yaklaşımlar karşılaştırılmaktadır. Klinik endikasyonlar, tedavi protokolleri, avantajlar, sınırlılıklar ve prognoz konuları kanıta dayalı klinik karar vermeyi desteklemek amacıyla ayrıntılı olarak tartışılmaktadır.

Anahtar Kelimeler: Açık apeks, apeksifikasyon, rejeneratif endodonti, MTA, kalsiyum hidroksit, immatür daimi dişler, apikal bariyer.

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How to Cite: Aksoy D, Kocak S. (2025) Management Strategies for Teeth with Open Apex: From Apexification to Regenerative Endodontics, Cumhuriyet Dental Journal, 28(3): 462-468.

Introduction

Immature permanent teeth with open apices present a unique challenge in endodontic therapy, especially when pulp necrosis occurs before root development is complete. The absence of a natural apical constriction complicates effective obturation and increases the risk of treatment failure.[1] Traditionally, apexification using long-term calcium hydroxide was the gold standard for inducing apical closure. While this technique can be effective, it requires multiple visits over several months and may weaken the dentinal structure over time.[1,2]

The introduction of mineral trioxide aggregate (MTA) and other bioceramic materials has revolutionized the field by enabling the creation of artificial apical barriers in a single or limited number of visits.[3] This has improved treatment outcomes and reduced patient burden. More recently, regenerative endodontic procedures (REPs), which harness the body's healing potential, have gained traction. These biologically based treatments aim not only to resolve infection but also to promote continued root maturation and revascularization.[4,5]

This review aims to compare and critically analyze current management options for teeth with open apices, from traditional apexification to modern regenerative approaches. By evaluating their biological basis, clinical protocols, advantages, and limitations, the article seeks to assist clinicians in selecting the most appropriate treatment modality for each individual case.

1. Etiology and Diagnosis of Open Apex

An open apex refers to a condition where the apical foramen of a tooth remains unusually wide and lacks the natural apical constriction necessary for conventional root canal obturation. This situation often arises in immature permanent teeth when root development is interrupted due to various causes. The etiology of open apex can be broadly divided into developmental and acquired factors. Developmentally, an open apex occurs when pulpal necrosis ensues before completion of root formation, most commonly due to dental trauma, caries, or developmental anomalies such as dens invaginatus.[1,2] Acquired causes include extensive apical root resorption, over-instrumentation during endodontic procedures, or root-end resection during surgical treatment.[6]

Clinically and radiographically, open apices can be classified into two main morphologic types:

- Blunderbuss apex: This form is characterized by *flaring, divergent canal walls*, and a *funnel-shaped* apical opening. It is typically observed in immature teeth where the root development was arrested abruptly.
- Non-blunderbuss apex: In this configuration, canal walls may be *parallel or slightly convergent*, and the apex appears open but less dramatically than the blunderbuss type.[7]

Diagnosis of an open apex is primarily radiographic. Periapical radiographs are the standard initial tool, but cone-beam computed tomography (CBCT) provides superior accuracy in evaluating canal morphology, dentinal wall thickness, and the presence of periapical lesions.[8]

1.1. Clinical Challenges Associated with Open Apex

Teeth with open apices, especially those that are non-vital and associated with periapical pathology, present numerous treatment challenges:

➤Susceptibility to Root Fracture

Immature teeth typically exhibit *thin dentinal walls* and large, open apices, making them highly prone to fracture under masticatory forces or during instrumentation. The risk is particularly high in teeth previously medicated long-term with calcium hydroxide, which can compromise dentin structure.[1]

➤Difficulty in Canal Disinfection

Standard chemomechanical preparation protocols using endodontic files may not be effective or safe in open apex cases. The canal's anatomy is reversed, with the apical diameter often being wider than the coronal, posing a risk of over-instrumentation or extrusion of irrigants. Additionally, complete disinfection is hindered by the inability to apply mechanical debridement aggressively.[9,10]

➤ Challenges in Obturation

Successful endodontic therapy requires the creation of a 3-dimensional apical seal to prevent reinfection. However, in open apex cases, the lack of a natural apical stop makes it difficult to confine the root filling material within the canal system. Without adequate apical barrier formation, obturating materials like gutta-percha may be extruded into periapical tissues, leading to potential inflammation or failure.[3]

2. Apexification with Calcium Hydroxide: Indications, Protocol, Advantages and Limitations

Apexification refers to a biologically based method of inducing a calcified barrier at the apex of a tooth with an open root end. For decades, long-term calcium hydroxide therapy has been the conventional approach to achieve this outcome in immature permanent teeth with necrotic pulps.[11]

2.1. Indications

Calcium hydroxide apexification is primarily indicated in:

- Non-vital immature teeth with an open apex
- Teeth where regenerative endodontic procedures are not feasible (e.g., patient non-compliance or lack of bleeding for scaffold formation)
- Cases requiring time-tested and cost-effective treatment options

It is particularly useful when there is no periapical pathology contraindicating the use of a long-term medicament.[12]

2.2. Protocol

The classical apexification protocol using calcium hydroxide involves the following steps:

1. Access opening and working length determination using radiographs and/or apex locators.
2. Minimal mechanical instrumentation, given the fragile dentinal walls.
3. Copious irrigation with sodium hypochlorite and saline.
4. Placement of a calcium hydroxide paste (often in aqueous or viscous formulation) into the entire canal system.
5. Temporary sealing of the access cavity.
6. Recall visits every 3–6 months to monitor barrier formation.
7. Once a calcified apical barrier is radiographically visible, obturation with gutta-percha and sealer is completed.

Barrier formation generally occurs within 6 to 18 months, although this may vary depending on the case.[2]

2.3. Advantages

- Proven clinical success over many decades
- Biocompatible and antimicrobial properties of calcium hydroxide
- Does not require expensive biomaterials or complex instrumentation
- Suitable for resource-limited settings

2.4. Limitations

Despite its historical value, calcium hydroxide apexification presents several drawbacks:[1,13,14]

- Extended treatment time with multiple visits over several months
- Risk of coronal leakage due to prolonged temporary restorations
- Potential weakening of dentin due to long-term exposure to calcium hydroxide, increasing fracture risk
- Lack of continued root development; while an apical barrier may form, root length and wall thickness do not increase, leaving the tooth structurally compromised

- Inconsistent barrier formation; in some cases, no hard tissue barrier forms even after prolonged treatment

Due to these disadvantages, calcium hydroxide apexification has gradually been replaced by MTA-based apical barrier techniques and regenerative endodontic procedures in many modern clinical settings. However, it remains a viable treatment option in specific cases.

3. Artificial Apical Barrier Techniques Using MTA and Bioceramics

In response to the limitations of long-term calcium hydroxide apexification—namely prolonged treatment duration, risk of coronal leakage, and lack of continued root development—artificial apical barrier techniques have emerged as a more efficient alternative for managing teeth with open apices. These techniques involve the placement of biocompatible materials at the apical third of the root canal to create an immediate barrier, facilitating prompt obturation.[15,16]

3.1. Concept of Using MTA and Bioceramics

An artificial apical barrier acts as a mechanical stop that allows the clinician to compact obturation materials safely without risk of extrusion. This approach is especially useful in cases where:

- Immediate sealing is preferred
- The patient cannot commit to multiple visits
- Calcium hydroxide has failed to induce a barrier

The most widely used material for artificial apical barriers is Mineral Trioxide Aggregate (MTA), followed by other bioceramic materials such as Biodentine, EndoSequence BC RRM, and BioAggregate.[17]

3.2. Mineral Trioxide Aggregate (MTA)

First introduced in the 1990s, MTA has become the gold standard for apical barrier techniques due to its favorable properties:

- Excellent biocompatibility
- Superior sealing ability
- Promotion of periapical healing and hard tissue formation.[3]

Clinical Protocol:

1. After canal disinfection, a 3–5 mm plug of MTA is placed at the apical third using a carrier or MAP system.
2. A moist cotton pellet is placed over the MTA, and the cavity is temporarily sealed to allow setting.
3. After 24–48 hours, the canal is checked for hardness, and the remaining space is filled with gutta-percha and sealer.

The success rate of MTA apexification has been reported to exceed 90%, with predictable periapical healing and apical sealing.[18]

3.3. Newer Bioceramic Materials

In recent years, bioceramic-based materials such as Biodentine and EndoSequence BC RRM have been developed to address some of the shortcomings of MTA (e.g., long setting time, discoloration potential):

- Biodentine offers a shorter setting time (~12 minutes), high compressive strength, and bioactivity.
- EndoSequence BC RRM is pre-mixed, hydrophilic, and designed specifically for root repair procedures.

These materials have demonstrated similar or improved outcomes compared to MTA, although long-term studies are still ongoing.[19,20]

3.4. Advantages of Artificial Apical Barrier Technique

- Shorter treatment duration compared to calcium hydroxide
- Reduced risk of tooth fracture
- One- or two-visit protocol, improving patient compliance
- Promotes healing and hard tissue formation
- Suitable for non-vital immature teeth with or without periapical lesions

3.5. Limitations and Considerations

- Requires precise placement of the apical plug to avoid overfilling
- Cost and material availability may be limitations in some regions
- Moisture control is critical for optimal setting of MTA and some bioceramics
- Discoloration potential, especially with older formulations of MTA (e.g., gray MTA)

4. Regenerative Endodontic Procedures (REPs): Biological Basis and Clinical Protocol

Regenerative endodontic procedures (REPs) represent a paradigm shift in the treatment of necrotic immature permanent teeth. Unlike apexification or apical plug techniques that aim to create a barrier for obturation, REPs focus on the biological regeneration of the pulp–dentin complex, promoting continued root development and apical closure.[4]

4.1. Biological Basis

REPs are based on the principles of tissue engineering, which include:[21]

- Stem cells: Primarily stem cells from the apical papilla (SCAP), which are capable of differentiating into odontoblast-like cells
- Growth factors: Released from dentin during irrigation (e.g., TGF-β, BMPs)
- Scaffold: Usually the blood clot induced by apical bleeding serves as a natural scaffold for tissue ingrowth

These three components support the repopulation of the canal space with functional cells that may contribute to root maturation and potentially restore pulpal vitality.[5,22]

4.2. Indications

- Non-vital immature permanent teeth with open apices
- Absence of severe calcification or extensive internal resorption
- Compliance for follow-up and proper coronal seal

4.3. Clinical Protocol (According to AAE 2021 Guidelines)

The American Association of Endodontists (AAE) provides structured clinical considerations for regenerative endodontic procedures (REPs), emphasizing biological preservation,

patient safety, and long-term success. The procedure typically involves two or more appointments, and patient selection and compliance are essential to achieving optimal outcomes.[23,24]

First Appointment

1. *Anesthesia and Isolation*

- Use local anesthesia with a vasoconstrictor.
- Achieve rubber dam isolation and access the pulp chamber.

2. *Irrigation*

- Irrigate gently with 20 mL of 1.5–3% NaOCl per canal for 5 minutes.
- Follow with 20 mL of saline or EDTA to neutralize residual sodium hypochlorite and protect apical stem cells.

3. *Intracanal Medicament Placement*

- Dry the canal with sterile paper points.
- Place low-concentration triple antibiotic paste (TAP) (ciprofloxacin, metronidazole, minocycline mixed to 1–5 mg/mL) or calcium hydroxide.
- To reduce staining, consider:
- Using double antibiotic paste (DAP) without minocycline.
- Substituting minocycline with clindamycin or amoxicillin.
- Applying a dentin bonding agent to the pulp chamber.

4. *Temporary Sealing*

- Seal with 3–4 mm of temporary material (e.g., Cavit™, IRM™, or glass-ionomer).
- Recall after 1–4 weeks.

Second Appointment

1. *Assessment*

- If signs of infection persist, repeat disinfection with medicament.

2. *Anesthesia Without Vasoconstrictor*

- Use 3% mepivacaine to allow bleeding induction.

3. *Final Irrigation*

- Irrigate with 17% EDTA (20 mL per canal) to release growth factors and support stem cell survival.
- Dry the canal with paper points.

4. *Induction of Bleeding / Scaffold Placement*

- Over-instrument 2 mm beyond the apex using a pre-curved K-file to induce bleeding up to the CEJ.
- Allow a blood clot to form naturally, or use PRP, PRF, or AFM as alternative scaffolds.

5. *Barrier and Coronal Seal*

- Place a resorbable matrix (e.g., CollaPlug™, CollaTape™) over the clot.
- Cover with white MTA or a bioceramic alternative (e.g., Biodentine®, EndoSequence® BC RRM).
- Complete with a 3–4 mm layer of glass ionomer cement, followed by permanent restoration.

Follow-Up Schedule

1. *6, 12, and 24 months:*

- Assess clinical signs (pain, swelling, sinus tract).
- Evaluate radiographic signs (resolution of apical radiolucency, root wall thickening, root lengthening).
- Perform vitality testing (although not always reliable).

2. *Long-Term:*

- Annual follow-up after the first 2 years is recommended.
- CBCT is advised for initial evaluation and follow-ups.

Goals of REPs (per AAE)

1. *Primary Goal:* Elimination of symptoms and evidence of bone healing.
2. *Secondary Goal*: Root development (increased wall thickness and/or length).
3. *Tertiary Goal*: Return of pulp vitality (positive response to pulp testing).

4.4. Advantages

- Continued root development (increased root length and wall thickness)
- Restoration of pulp-like tissue and potential neurogenesis
- Minimal instrumentation, preserving dentin structure
- Reduced risk of fracture compared to traditional techniques.[25]

4.5. Limitations and Considerations

- Unpredictable histologic outcome: The tissue formed is often not true pulp but fibrous tissue
- Tooth discoloration, especially with minocycline-containing TAP
- Case selection is critical; success depends on the presence of stem cells and an intact apical papilla
- Need for patient compliance and follow-up.[25]

4.6. Clinical Outcomes

Several studies have shown high survival and healing rates with REPs, though the rates of continued root development and positive pulp vitality response vary. Jeeruphan et al.[19] found significantly more root development and increased dentinal thickness in REPs compared to MTA apexification.

5. Clinical Decision-Making: Case Selection and Comparative Considerations

Successful management of teeth with open apices requires careful evaluation of clinical and radiographic findings, patient age, tooth vitality status, and the availability of treatment resources. Choosing among calcium hydroxide apexification, artificial apical barriers, or regenerative endodontic procedures depends on individual case variables, each method offering unique benefits and limitations (Table 1).

5.1. Factors Influencing Treatment Choice

Key clinical parameters to consider:

- Pulpal status (vital vs. necrotic)
- Stage of root development
- Presence of periapical pathology
- Patient compliance and follow-up feasibility
- Financial and material availability
- Operator experience and equipment Access

5.2. Suggested Decision Guidelines

- Calcium Hydroxide Apexification: Preferred when regenerative techniques are not feasible, and cost or access to materials is limited. Also used when minimal root growth is acceptable.[26]
- Apical Barrier with MTA/Bioceramics: Ideal for patients needing faster treatment completion,

particularly when regeneration is not possible or is declined. Best when the root length is already sufficient.[27]

- Regenerative Endodontic Procedures (REPs): Indicated in younger patients (typically under 18) with necrotic pulp and a wide-open apex, where root development is incomplete. Requires bleeding induction and follow-up.[28]

Table 1. Comparative overview of treatment modalities for open apex management

Criteria	Calcium Hydroxide Apexification	MTA/Bioceramic Apical Barrier	Regenerative Endodontics (REP)
Treatment duration	Long (6–18 months)	Short (1–2 visits)	Moderate (2–3 visits with follow-up)
Root development	No continued root length or wall thickening	No root development	Possible root lengthening and wall thickening
Apical Barrier Formation	Yes (via calcific tissue overtime)	Immediate artificial barrier (3–5 mm plug)	Biological closure through tissue ingrowth
Risk of Root Fracture	High (due to long-term CH exposure and thin dentin	Moderate	Low (preservation of dentin structure)
Biocompatibility	Good	Excellent	Excellent
Discoloration Potential	Low	Moderate (especially with gray MTA)	Moderate to High (especially with TAP use)
Technique Sensitivity		Moderate	High (requires case selection and biologic bleeding control)
Clinical Success Rate	Good (but lower in long-term survival)	High (>90%)	High (clinical and radiographic success up to 93 %)
Root Strength Improvement	No	No	Yes (via tissue reinforcement)
Histologic Outcomes	Apical calcific tissue (non-vital)	Non-vital barrier with periapical healing	Variable: pulp-like, PDL-like, osteodentin, cementum or intracanal bone

5.3. Prognosis and Clinical Considerations

All three techniques have high survival and healing rates, but regenerative procedures are the only option offering potential for further root development and possible restoration of pulpal function. Operator training, patient age, and clinical setting significantly influence the choice.[28]

6. Prognosis and Outcome Comparisons

The prognosis of endodontic treatment in teeth with open apices has significantly improved with the advent of bioceramic materials and regenerative techniques. While all three primary treatment strategies—calcium hydroxide apexification, artificial apical barriers, and regenerative endodontic procedures (REPs)—have demonstrated favorable clinical outcomes, their long-term prognoses differ in terms of structural reinforcement, healing potential, and functional restoration.

6.1. Apexification with Calcium Hydroxide

Long-term studies show that calcium hydroxide apexification has a success rate between 74% and 100% in terms of periapical healing and barrier formation.[29] However, the tooth remains structurally compromised due to:

- Lack of continued root development
- Prolonged exposure to calcium hydroxide, which can reduce dentin elasticity and increase the risk of fracture.[30]

Therefore, although the periapical outcome may be favorable, the long-term survival rate of the tooth is reduced, particularly in anterior teeth subjected to occlusal forces.

6.2. Artificial Apical Barriers (MTA / Bioceramics)

MTA and newer bioceramic-based barrier techniques have shown predictable outcomes with >90% clinical and radiographic success rates.[31] These materials allow for:

- Efficient apical sealing
- One- or two-visit treatment
- Reduced risk of reinfection

However, like apexification, these methods do not promote continued root development, and thus, the treated tooth may remain prone to future structural compromise if the root is short or has thin walls.[3]

Table 2. Summary of outcomes and prognosis

Treatment Modality	Periapical Healing	Root Development	Tooth Reinforcement	Long-Term Prognosis
Calcium Hydroxide Apexification	High	None	Low	Moderate to poor (fracture risk)
MTA/Bioceramic Barrier	Excellent	None	Moderate	Good
Regenerative Endodontics	Excellent	Possible (length + width)	High	Very good (case-dependent)

6.3. Regenerative Endodontic Procedures (REPs)

REPs have demonstrated high healing success (up to 95%) and significantly better root development outcomes compared to apexification and apical barrier.[33,34] Benefits include:

- Increased root length
- Thickening of dentinal walls
- Potential recovery of pulp vitality and neurogenesis

However, REPs also show:

- Variability in tissue regeneration (true pulp vs. fibrous tissue)
- Unpredictable vitality response
- Technique sensitivity and dependence on patient biology.[35]

Despite these limitations, REPs are increasingly considered the first-line approach for suitable cases and selection criteria in managing immature necrotic permanent teeth due to their biological potential.[36] Their biologically driven potential to promote root development and reinforce fragile immature teeth makes them particularly advantageous in young patients. However, clinicians must be aware of several key limitations when considering REPs:

- Unpredictable histological outcomes: While periapical healing is common, the intracanal tissue may not regenerate as true pulp tissue. Instead, PDL-like or fibrotic tissue is often formed, which may limit long-term vitality and function.
- Technique sensitivity*:* REPs require strict adherence to biologically based protocols, especially regarding irrigation, medicament selection, and apical bleeding induction. Small deviations can significantly affect outcomes.
- Patient compliance: At least two visits and close follow-up are required to monitor healing, which may not be ideal for non-compliant or medically compromised patients.
- Limited evidence on long-term success: Although short- and medium-term results are promising, there is a need for more longitudinal data to confirm the durability of REPs, especially regarding pulp vitality and continued root maturation.

Given these factors, careful case selection remains essential. Teeth with adequate apical diameter, absence of extensive resorption, intact Hertwig's epithelial root sheath, and cooperative patients are ideal candidates. In contrast, cases with poor prognosis for bleeding induction, compromised systemic conditions, or unfavorable canal anatomy may benefit more from apical barrier techniques or traditional apexification (Table 2).[37-39]

Conclusions and Future Directions

The management of teeth with open apices has evolved significantly over the past decades—from traditional long-term apexification with calcium hydroxide to the use of artificial apical barriers and, more recently, biologically driven regenerative endodontic procedures. Each approach offers unique advantages and limitations, and no single technique is universally superior for all clinical situations.

While calcium hydroxide apexification remains a valid and cost-effective option in specific cases, its drawbacks—particularly extended treatment time and increased fracture risk—limit its use in modern endodontic practice. Apical barrier techniques using MTA and bioceramics have dramatically improved treatment efficiency and predictability but do not facilitate further root development.

In contrast, regenerative endodontic procedures have introduced a biologically based paradigm that aligns with the principles of tissue engineering. REPs not only promote periapical healing but also offer the potential for continued root maturation and even partial restoration of pulp-like function. However, their clinical outcomes still show variability, and long-term histological evidence remains an area of ongoing investigation.

Ultimately, the selection of an appropriate treatment strategy should be individualized, taking into account the stage of root development, pulpal and periapical status, patient compliance, and the clinician's expertise. The integration of advanced biomaterials, stem cell therapy, and molecular biology into endodontics holds great promise for the future-shifting the focus from repair to true regeneration.

As research in regenerative science continues to grow, future advancements are expected to refine treatment protocols, enhance tissue specificity, and improve long-term outcomes, ultimately bridging the gap between biology and clinical success.

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