

Changing Concepts of Management of an Immature Apex

Dr. Saloni Tyagi¹, Dr. Padmanabh Jha², Dr. Vineeta Nikhil³

^{1,2,3}Department of Conservative Dentistry and Endodontics,
Subharti Dental College and Hospital, Swami Vivekanand University, Meerut, Uttar Pradesh.

Corresponding Author: Saloni Tyagi

DOI: <https://doi.org/10.52403/ijrr.20250907>

ABSTRACT

Dentistry has significantly evolved with advancements in technology over the years. These innovations have enhanced the precision, efficiency, and comfort of various dental treatments, leading to a paradigm shift in treatment approaches. An open apex is a dental condition characterized by the incomplete formation of a tooth's root, particularly in young individuals whose teeth are still developing. The lack of a fully developed root canal system complicates dental health and treatment. An open apex typically results from disruptions in the normal process of tooth development and root formation. The absence of a fully developed root canal system complicates procedures, making it harder to achieve effective outcomes. Additionally, the risk of pulp pathology and compromised structural integrity further underscores the complexities of managing such cases.

Keywords: Apexification, Apexogenesis, Open apex, Regenerative Endodontics

INTRODUCTION

Managing an open apex case requires precision and strategic approaches to promote proper root development and preserve tooth integrity. The general consensus for the clinical treatment of immature teeth with vital pulps is to preserve the remaining normal vital tissue to

allow continued physiological development and complete formation of the root end through the apexogenesis procedure.

Previously, techniques for managing non-vital immature teeth involved establishing an apical barrier. Apexification, traditionally done with calcium hydroxide, is a procedure to promote the formation of an apical barrier to close the open apex of an immature tooth with a nonvital pulp so that the filling materials can be contained within the root canal space. The introduction of materials like mineral trioxide aggregate (MTA) and biodentine offers improved efficacy. Regenerative endodontics aims to stimulate tissue regeneration within the tooth, reflecting a shift in treatment approaches. This evolution highlights the ongoing commitment to advancing dental care for better patient outcomes worldwide.

ETIOLOGY

An open apex occurs when the root development of a tooth is incomplete, often due to disruptions caused by various factors. These factors include dental anomalies, pulp necrosis, resorption, and iatrogenic factors. Understanding these influences is crucial for accurate diagnosis and appropriate treatment planning. [1]

Dental Anomalies:

Teeth affected by dental anomalies such as dens invaginatus, dens evaginatus, and

odontodysplasia may also show the presence of an immature apex. [2]

Trauma and Infection:

Trauma, especially in young individuals, can sever the apical blood supply, leading to pulp necrosis if revascularization is inadequate. Caries, involving bacteria, can penetrate the pulp, causing inflammation and eventually necrosis, stopping further root development. Trauma to teeth between ages 8 and 10 significantly affects root development. Different types of dental trauma have varying rates of pulp necrosis: enamel infraction (0%), concussion (3%), extrusion (26%), lateral luxation (58%), avulsion (92%), and intrusion (94%). [3]

Resorption:

Caused by factors such as orthodontic treatment, impacted teeth, and cysts or tumors. Excessive orthodontic forces can lead to apical resorption, affecting teeth years after treatment. Cysts and tumors like ameloblastomas have a high resorptive potential due to their aggressive nature. [4]

PATHOGENESIS OF AN IMMATURE TOOTH

Radicular morphogenesis, the process of root formation, is regulated by Hertwig's epithelial root sheath (HERS). The shape, length, and number of the root is determined by HERS. It is also responsible for the genesis of dentin of the root and participates in the formation of root cementum. An immature apex arises when apical growth of HERS is impaired or prematurely halted, leading to radicular dysplasia. [5] This condition can result from:

Disruption in Cell Signaling

Tooth development relies on complex signaling pathways between epithelial and mesenchymal cells. The Wnt signaling pathway forms a pivotal part of migration, cell fate determination, neural patterning, polarity, and organogenesis, including tooth development. Disruptions in signaling

molecules involved in root formation can hinder root formation. [6]

Inhibition of Growth Factors

Growth factors are essential for regulating various aspects of tooth development, including root formation. Fibroblast Growth Factors (FGFs) are expressed in the dental epithelium throughout tooth development. Deficiencies in growth factors like BMPs (bone morphogenetic proteins) or FGFs can result in stunted root growth. [7]

Role of Pulpal Inflammation

Inflammatory conditions within the dental pulp can negatively impact root development. Bacteria and their products invade dentinal tubules, triggering inflammatory reactions through pattern recognition receptors (PRRs) on odontoblasts and production of pro-inflammatory mediators, attracting inflammatory cells and initiating antibacterial responses. Chronic inflammation can impair odontoblast function and dentin deposition, affecting root formation and apex closure. [8]

Vascular Disruptions

Proper vascularization is crucial for providing nutrients, oxygen, and regulatory factors to the developing tooth and surrounding tissues. Vascular disruptions, such as trauma or inflammation, can compromise blood flow to the developing root, leading to ischemia (reduced blood supply) or avascular necrosis (tissue death due to lack of blood flow), compromising root development. [9]

DISCUSSION

CLASSIFICATION OF AN IMMATURE APEX

It can be classified as:

1. Non-blunderbuss type
2. Blunderbuss type

Non-blunderbuss type:

- Parallel or slightly convergent walls
- Broad (cylinder shape) apex or slightly tapered (convergent)

- Corresponds to Stage 4, 5, and 6 of Cvek's classification. [10]

Blunderbuss type:

- Radiographically, canal walls are divergent and flaring in the buccolingual direction
- Funnel-shaped apex
- Corresponds to Stage 1, 2, and 3 of Cvek's classification
- Wider apex results in thinner dentin walls surrounding the root canal and pulp chamber
- Thinner dentin walls make them more prone to fracture or damage, especially during chewing or trauma. [11]

DIAGNOSIS AND CASE ASSESSMENT

Careful case assessment and precise pulpal diagnosis is required in the management of an immature apex. It includes obtaining a detailed history of symptoms, conducting meticulous radiographic and clinical examinations, and performing diagnostic tests. Patients often present with symptoms like swelling, pain, or the appearance of a fistula, and the affected tooth may exhibit slight mobility. [12]

Clinical Assessment and Pain History

Accurate pain history is crucial. The duration, nature, and factors affecting the pain should be considered. Pain lasting more than a few seconds in a tooth with a pulp that is vital may indicate irreversible pulpitis. Spontaneous, severe, and prolonged pain often confirms this diagnosis. Throbbing pain and tooth tenderness suggest pulpal necrosis with apical periodontitis or an acute abscess. Objective tests, including visual examination, thermal and electric pulp testing, and percussion testing are necessary to confirm the diagnosis. [12]

Limitations of Vitality Testing in Immature Teeth

Vitality testing in immature teeth is unreliable due to unpredictable responses. The subodontoblastic sensory nerve network

is not fully developed until after the root formation is finished. Therefore, electric pulp testing (EPT) is not recommended for these teeth. [13]

A study by Jafarzadeh and Abbott found that EPT had a higher false-negative rate in immature teeth compared to mature teeth, indicating its unreliability in detecting pulp vitality in immature teeth with open apices. [14]

Advanced Diagnostic Tools

Laser Doppler Flowmetry (LDF) measures blood flow in traumatized teeth, and pulse oximetry accurately monitors pulp sensibility by recording pulpal blood flow oxygenation. [15] Research by Jazarbek et al. showed that LDF demonstrated higher sensitivity and specificity in detecting pulp vitality compared to traditional tests like EPT and cold testing. [16]

Radiographic examination is essential. Radiographs may exhibit radiolucency in the periapical area. Differentiating between the radiolucent area surrounding an immature tooth with a healthy pulp and a pathological radiolucency from a necrotic pulp can be challenging. Comparing with the contralateral tooth's periapex may help. CBCT provides accurate measurements of root length, identification of the apical foramen, assessment of root and root canal anatomy, and bone defects. [17]

Challenges in Treating Teeth with an Open Apex

1. Difficulty in Assessing Pulp Sensibility
Diagnosing pulp status in immature teeth is challenging due to their unique physiology and the unreliability of traditional pulp tests. [15] The Electronic Pulp Test (EPT) often gives unreliable results for immature teeth since the plexus of Raschkow is not fully developed until about five years after tooth eruption. Pulse oximetry offers better specificity and accuracy in these cases. [18]

2. Risk of Overinstrumentation

Overinstrumentation is a major concern in open-apex teeth. Instruments may extend beyond the apex, causing complications like dentin defects and increased fracture risk. Apex locators are essential to determine the correct working length. [19]

3. Reduced Irrigation Efficiency

Irrigation is critical for bacterial and debris removal, but in open apices, shaping should be minimal to avoid irrigant extrusion. Techniques like negative apical pressure offer safer irrigation. [20]

4. Risk of Root Fracture

Immature teeth with open apices and thin dentin walls are fracture-prone. The risk increases in non-vital immature teeth. [21] Studies using finite element analysis confirm reduced fracture resistance in such teeth. [22]

5. Risk of Resorption

Overinstrumentation may trigger external inflammatory or replacement resorption. Trauma, overfilling, and excessive instrumentation are major contributors. [23]

6. Difficulty in Obtaining an Apical Seal

Apex closure is lacking, so mineralized tissue formation is needed. The open apex prevents an apical stop, making obturation difficult and increasing the risk of material impingement into periapical tissues. [24]

7. Extrusion of Obturating Material

Open apices increase the risk of material extrusion into periapical areas, causing inflammation and treatment failure. [25]

Management of an Immature Tooth

Treatment depends on pulp status, root development stage, and the potential for continued root maturation. [26]²⁶

Teeth with vital pulp and open apices benefit most from apexogenesis, supporting continued root development and preserving pulp vitality. [27]

APEXOGENESIS

Apexogenesis, per the American Academy of Pediatric Dentistry (AAPD), promotes continued physiological root development and a favorable crown-to-root ratio. [28] The goal is to preserve Hertwig's epithelial root sheath and remove only the infected portion of the pulp to prevent necrosis spread. [25]

Typically, the coronal pulp is removed, and calcium hydroxide is applied to the remaining pulp. Inflammation is often limited to 2–3 mm of the coronal pulp following mechanical exposure. [29]

Goals of Apexogenesis (Webber):

- Sustain Hertwig's sheath viability for root development
- Maintain pulp vitality to support dentin deposition
- Encourage natural apical constriction
- Possibly generate a dentinal bridge at the pulpotomy site. [30]

Vital pulp therapies (VPT) used include:

- Indirect pulp capping
- Direct pulp capping
- Partial or complete pulpotomy

Pulp Capping

Definition: Treating exposed vital pulp by sealing the wound with materials like calcium hydroxide or MTA, promoting dentin bridge formation and pulp vitality. [28]

This is applicable for immature permanent teeth and primary teeth before exfoliation. Recent trends favor VPT in mature permanent teeth as a less invasive, longer-lasting option. [31]

Indirect Pulp Capping

Definition (AAPD): Procedure for deep carious lesions near the pulp without degeneration signs. [28]

Indications: Mild discomfort, no spontaneous pain, large lesion, and no lymphadenopathy. [32]

PROCEDURE

1. One-Appointment Technique:

- Affected dentin left over pulp
- Sealed with liner
- Aims to arrest microbial activity and support remineralization. [33]

2. Stepwise Excavation (Two Appointments):

- First visit: Remove infected dentin, apply calcium hydroxide, and seal
- Second visit: Evaluate dentin bridge formation and place final restoration. [34]

Outcome Assessment:

Success is judged by:

- Maintained vitality
- No symptoms
- Radiographic evidence of dentin bridge
- No pathologic signs

Materials: Calcium hydroxide, resin-modified glass ionomers have shown good outcomes. [35-37]

Direct Pulp Capping

Definition: Placing medicament directly on mechanical/traumatic pulp exposure to form reparative dentin and maintain vitality. [28]

Objective: Prevent bacterial invasion and stimulate dentin formation

Indications (AAE):

- Vital, asymptomatic pulp
- Bleeding controllable
- Exposure during isolation
- Adequate coronal seal achievable
- Future RCT remains an option

Advantages:

1. Preserves vitality
2. Encourages reparative dentin
3. Time- and cost-efficient

Procedure:

1. **Diagnosis & Hemostasis:** Assess pulp and achieve hemostasis
2. **Caries Removal:** Use smart burs and magnification for minimal trauma
3. **Hemorrhage Control:** Agents like NaOCl, saline, chlorhexidine, ferric sulfate, etc. used⁴¹

4. **Pulp Capping:** Apply material (Ca (OH)₂, MTA, resin)

5. **Permanent Restoration:** Critical to ensure seal and prevent microleakage

Outcome Assessment:

- Reassess at 6–12 weeks, then at 6 and 12 months
- Check for: No pain, swelling, or apical pathology; positive pulp tests

Success Factors:

- Younger age
- Capping material choice
- Exposure size and site
- Type of caries
- Timing of final restoration [38-44]

Pulpotomy

Definition: Removal of coronal pulp while preserving radicular pulp.

Common in primary molars and immature permanent teeth, with emerging use in mature teeth. [45]

Partial Pulpotomy (Cvek Pulpotomy)

Definition: Surgical removal of coronal vital pulp to preserve deeper pulp tissue. [46]

Indications:

- Carious pulp exposure with immature apex
- Controllable bleeding
- Traumatically exposed young permanent teeth

Procedure:

1. Local anesthesia and rubber dam
2. Caries removal
3. Coronal pulp removal
4. Hemostasis (within 5 min using 2.5% NaOCl)
5. Apply medicament:
 - Formocresol, MTA, Calcium hydroxide, or Biodentine
6. Final restoration (e.g., ZOE base + composite/amalgam)
7. Follow-up: 3-month intervals, with radiographs at 6, 12, and 24 months

Success: >85% for vitality preservation. [47]

Full Pulpotomy

Indications:

- Immature permanent teeth with carious exposure
- Emergency management
- Also effective in mature teeth [48]

Procedure:

1. Local anesthesia and isolation
2. Full coronal pulp removal
3. Hemostasis and medicament (e.g., MTA, Ca (OH)₂)
4. Final restoration and follow-up assessments [49]

Success Rate: ~90%+ in preserving vitality in immature permanent teeth [50]

Management of Immature Teeth with Non-vital Pulp

Immature permanent teeth with necrotic pulps present challenges for conventional root canal treatments due to their increased risk of root fracture. Various treatments have been proposed, including custom filling materials like gutta-percha and paste fills into wide canals. [51]

Treatment Techniques

- **Multi-step apexification:** Calcium hydroxide is used over multiple visits to induce apex closure.
- **Single-step apexification:** Mineral trioxide aggregate (MTA) is used to create an artificial barrier.
- **Apical plug techniques:** A biocompatible barrier material (e.g., MTA) is placed to facilitate obturation.
- **Root strengthening interventions:** Techniques used to reinforce fragile root walls.
- **Regenerative endodontic procedures (REPs):** Aim to stimulate new tissue growth inside the canal.

Apexification

Definition:

The process of inducing a calcified barrier in a root with an open apex or promoting

continued root development in teeth with necrotic pulp. [52]

Materials Used

• Calcium Hydroxide

- Promotes dentinogenesis and periapical healing.
- Requires multiple sessions over 6–24 months.
- Disadvantages: High pH may harm periapical tissues; incomplete barrier formation. [53]

• Mineral Trioxide Aggregate (MTA)

- Reduces treatment time and allows for immediate restoration.
- Integrates well with surrounding tissues.
- Disadvantages: Difficult to manipulate, long setting time, high cost. [54]

• Biodentine

- A calcium silicate-based cement that promotes hydroxyapatite crystal deposition.
- Superior sealing and biocompatibility.
- Disadvantages: Low radiopacity; difficult consistency. [55]

Techniques of Apexification

Apexification with Calcium Hydroxide

This traditional method involves placing long-term calcium hydroxide dressings to form a hard tissue barrier at the apex, preventing overextension of root filling materials. Barrier formation usually occurs within 4–9 months. [56]

Available products:

- *Saline-based:* EndoCal, Calasept
- *Methylcellulose-based:* Pulpdent, TempCanal (less soluble, better suited for canals)

Clinical Steps:

1. Local anesthesia and rubber dam placement.
2. Straight-line access and visualization of the apical foramen under microscope.
3. Chemomechanical debridement with NaOCl (ultrasonic or sonic activation optional).

4. Minimal canal shaping; working length via apex locator and radiograph.
5. Drying canal and placing calcium hydroxide (e.g., Ultracal XS).
6. Interim dressing (e.g., Ledermix, or Ledermix + Pulpdent) and temporary restoration (Cavit + GIC).
7. At second visit: Re-irrigate, dry, reapply calcium hydroxide, confirm placement radiographically.
8. Review at 3-month intervals, replacing calcium hydroxide as needed.
9. Upon barrier formation, fill canal (cold lateral/warm vertical compaction) and place final restoration.

One-Step Apexification

Based on Kumar SM et al. [57]

1. Local anesthesia, rubber dam isolation, microscope-assisted access.
2. Chemomechanical debridement with NaOCl, minimal instrumentation.
3. Confirm symptom resolution; clean canal and remove residual calcium hydroxide if any.
4. Mix MTA with saline, place 1 mm short of apex. Use resorbable matrix to prevent extrusion. Confirm radiographically.
5. Place moist cotton pellet for 24 hours to set MTA.
6. Fill the remaining canal with gutta-percha and complete with composite restoration.

Regenerative Endodontics

A cutting-edge field focused on restoring pulp vitality and promoting continued root development in immature, necrotic teeth. Traditional apexification does not encourage root maturation, increasing fracture risk. [58]

Clinical Considerations:

- Disinfection of root canal system.
- Use of a scaffold (e.g., blood clot) to encourage stem cell activity.
- Adequate coronal seal to prevent reinfection. [59]

Terminology & Background

- **Definition:** Replacement of damaged dentin, pulp, and root structures. [60]
- **Regeneration vs. Repair:** True regeneration restores original tissue; repair replaces with different function. [61]
- **History:** First explored by Nygaard-Östby (1961), revascularization introduced by Iwaya et al. (2001), later called revitalization. [62]
- **Histology:** Tissues resemble cementum, bone, and periodontal ligament—more reparative than regenerative. [58]

Goals of REPs [63]

- Eliminate clinical symptoms
- Promote bone healing
- Increase root wall thickness/length
- Positive vitality test response

The Triad of Regenerative Endodontics Stem Cells

1. Postnatal mesenchymal stem cells:
 - SCAPs (stem cells of apical papilla), dental pulp stem cells. [64]
2. Scaffold
 - Must be biocompatible, non-cytotoxic; e.g., dentin matrix, platelet-rich plasma. [65]
3. Growth Factors
 - Sourced from dentin and platelets; they guide differentiation and tissue development. [66]

Technique of Revascularization

First Appointment:

- Anesthesia and rubber dam isolation
- Determine working length
- Gentle irrigation with 20 mL NaOCl
- Dry canals with paper points
- Place calcium hydroxide or low-concentration triple antibiotic paste
- Seal with temporary restoration (Cavit™, IRM™, or GIC)

Second Appointment (1–4 weeks later):

- Reassess clinical response
- Anesthesia and rubber dam isolation

- Irrigate with 20 mL NaOCl + 17% EDTA
- Induce bleeding into the canal (periapical laceration)
- Place resorbable matrix (e.g., CollaPlug™, Collacote™, CollaTape™)
- Cap with white MTA and layer flowable composite over it

Follow-Up Evaluation:

- Assess for pain, swelling, sinus tract
- Radiographic signs: Healing, apical closure, root elongation
- Positive pulp vitality test response

Periapical Surgery

- Considered only if non-surgical methods fail
- Final resort due to drawbacks: Root loss, trauma, arrested development
- Success possible with obturation + periapical curettage

Retrograde Filling Materials

- Historical: Amalgam, zinc phosphate cement, gold foil
- Modern: MTA, Biodentine, Bioaggregate
- Notes: MTA may cause discoloration
- These materials aim to reduce leakage and tissue irritation. [67]

Outcomes

- **Revascularization:** Success includes:
 - Primary goal: Symptom resolution and bony healing
 - Secondary goal: Root maturation
 - Tertiary goal: Positive pulp test
- **Periapical Surgery:** 96.3% success at 1-year follow-up for immature teeth with periapical periodontitis. [68]

CONCLUSION

Dentistry has significantly advanced with modern technology, improving precision, efficiency, and patient comfort. Managing open apices in immature teeth remains complex due to incomplete root formation. The key goals are:

Vital pulp preservation with apexogenesis
Apical barrier formation with apexification in non-vital teeth

Traditional calcium hydroxide apexification has been enhanced by bioceramic materials like MTA and Biodentine. Regenerative endodontics represents a major shift by focusing on tissue regeneration rather than replacement, embodying the profession's commitment to improving patient outcomes.

Declaration by Authors

Ethical Approval: Not applicable

Acknowledgement: None

Source of Funding: None

Conflict of Interest: No conflicts of interest declared.

REFERENCES

1. Li J, Parada C, Chai Y. Cellular and molecular mechanisms of tooth root development. *J Dev.* 2017;144(3):374-84.
2. Kallianpur S, Sudheendra US, Kasetty S et al. Dens invaginatus (type III B). *J Oral Maxillofac Pathol.* 2012;16(2):262-5.
3. Aidos H, Diogo P, Santos JM. Root resorption classifications: A narrative review and a clinical aid proposal for routine assessment. *Eur Endod J.* 2018;3(3):134-45.
4. Von Arx T. Apical surgery: A review of current techniques and outcome. *Saudi Dent J.* 2011;23(1):9-15.
5. Lu X, Yang J, Zhao S, Liu S. Advances of Wnt signalling pathway in dental development and potential clinical application. *Organogenesis.* 2019;15(4):101-10.
6. Huang XF, Chai Y. Molecular regulatory mechanism of tooth root development. *Int J Oral Sci.* 2012;4(4):177-81.
7. Du W, Du W, Yu H. The role of fibroblasts in tooth development and incisor renewal. *Stem Cells Inte.* 2018;34(12):34-9.
8. Yumoto H, Hirao K, Hosokawa Y et al. The roles of odontoblasts in dental pulp innate immunity. *Jpn Dent Sci Rev.* 2018;54(3):105-17.
9. Rombouts C, Giraud T, Jeanneau C et al. Pulp vascularization during tooth development, regeneration, and therapy. *J Dent Res.* 2017;96(2):137-44.

10. Patil N, Jain A, Hegde D et al. Management of teeth with blunderbuss canals and its esthetic rehabilitation. *Int J Med Dent Case Rep.* 2019;6(1):1-5.
11. Gupta R, Tomer AK, Cecilia LL. Challenges and treatment strategies of open apex. *J Dent Med Sci.* 2021;20(3):20-4.
12. Rafter M. Apexification: A review. *Dent Traumatol.* 2005;21(1):1-8.
13. Klein H. Pulp response to an electric pulp stimulator in the developing permanent anterior dentition. *J Dent Child.* 1978;4(5):23-5.
14. Jafarzadeh H, Abbott PV. Review of pulp sensibility tests. Part II: electric pulp tests and test cavities. *Int Endod J.* 2010;43(11):945-58.
15. Igna A, Mircioagă D, Boariu M et al. A diagnostic insight of dental pulp testing methods in pediatric dentistry. *Med.* 2022;58(5):665-78.
16. Jarzabek A, Gońda-Domin M, Węsierska K et al. Multidisciplinary management of a double immature permanent tooth: A case report. *Iran Endod J.* 2020;15(4):253.
17. Shekhar V, Shashikala K. Cone beam computed tomography evaluation of the periapical status of nonvital tooth with open apex obturated with mineral trioxide aggregate: A Case Report. *Case Rep Dent.* 2013;19(5):45-51.
18. Molaasadolah F, Zargar N, Bargrizan M, et al. Comparison of pulse oximeter, cold test, and electric pulp test for assessment of pulp vitality in permanent immature teeth. *Folia Med.* 2022;64(1):134-42.
19. Souza RA, Silva-Sousa YT, Colombo S et al. Healing of a tooth with an overinstrumented apex, extensive transportation and periapical lesion using a 5 mm calcium hydroxide apical plug: An 8-year follow-up report. *Braz Dent J.* 2012;23(2):608-11.
20. Peeters HH, Suardita K, Mooduto L et al. Extrusion of irrigant in open apex teeth with periapical lesions following laser-activated irrigation and passive ultrasonic irrigation. *Iran Endod J.* 2018;13(2):169-75.
21. Trope M. Treatment of immature teeth with non-vital pulps and apical periodontitis. *Endod Topics.* 2006;14(1):51-9.
22. Hargreaves KM, Giesler T, Henry M et al. Regeneration potential of the young permanent tooth: what does the future hold? *Pediatr Dent.* 2008;30(3):253-60.
23. Hassouneh L, Matoug-Elwerfelli M, Al-Omari T et al. Assessment of biomechanical behavior of immature non-vital incisors with various treatment modalities by means of three-dimensional quasi-static finite element analysis. *Sci Rep.* 2023;13(1):17491.
24. Gutierrez JH, Brizuela C, Villota E. Human teeth with periapical pathosis after overinstrumentation and overfilling of the root canals: A scanning electron microscopic study. *Int Endod J.* 1999;32(1):40-8.
25. Murray PE. Review of guidance for the selection of regenerative endodontics, apexogenesis, apexification, pulpotomy, and other endodontic treatments for immature permanent teeth. *Int Endod J.* 2023;56(3):188-99.
26. Zeng Q, Zhang J, Guo J et al. Preoperative factors analysis on root development after regenerative endodontic procedures: A retrospective study. *BMC Oral Health.* 2022;22(1):374-81.
27. Srinivasan S, Vengidesh R, Ramachandran A et al. An immature traumatic teeth management with apical pathology using the novel biodentine™ obturation: A case report. *Cureus.* 2021;13(12):2018-25.
28. Winters J, Cameron AC, Widmer RP. Pulp therapy for primary and immature permanent teeth. *Pediatr Dent.* 2013;14(1):103-22.
29. Musani I, Goyal V, Singh A. Complete management of a mutilated young permanent central incisor. *Int J Clin Pediatr Dent.* 2011;4(1):49-53.
30. Akhlaghi N, Khademi A. Outcomes of vital pulp therapy in permanent teeth with different medicaments based on review of the literature. *Dent Res J.* 2015;12(5):406-17.
31. Philip N, Suneja B. Minimally invasive endodontics: A new era for pulpotomy in mature permanent teeth. *Br Dent J.* 2022;233(12):1035-41.
32. John I Ingle. *Pediatric Endodontics. Endodontics, 2nd Edn, Philadelphia, BC Decker* 2002. p- 861- 903.
33. Bjørndal L, Thylstrup A. A practice-based study on stepwise excavation of deep carious lesions in permanent teeth: A 1-year follow-up study. *Community Dent Oral Epidemiol.* 1998 ;26(2):122-8.

34. Hilton TJ. Keys to clinical success with pulp capping: A review of the literature. *Oper Dent.* 2009;34(5):615-25.
35. Bjørndal L, Reit C, Bruun G et al. Treatment of deep caries lesions in adults: Randomized clinical trials comparing stepwise vs. direct complete excavation, and direct pulp capping vs. partial pulpotomy. *Eur J Oral Sci.* 2010;118(3):290-7.
36. Beetke E, Wenzel B, Lau B et al. Direct capping of the artificial exposed pulp in teeth with deep caries. *Stomatol.* 1990;40(4):246-9.
37. Nordstrom DO, Wei SH, Johnson R. Use of stannous fluoride for indirect pulp capping. *J Am Dent Assoc.* 1974;88(5):997-1003.
38. Suhag K, Duhan J, Tewari S et al. Success of direct pulp capping using mineral trioxide aggregate and calcium hydroxide in mature permanent molars with pulps exposed during carious tissue removal: 1-year follow-up. *J Endod.* 2019;45(7):840-7.
39. Strassler HE. Caries removal using polymer burs. *J Dent.* 2011;7(3):7-12
40. Komabayashi T, Ebhira A, Aoki A. The use of lasers for direct pulp capping. *J Oral Sci.* 2015;57(4):277-86.
41. Accornite MD, Loguerico AD, Reis A et al. Response of human pulp capped with a bonding agent after bleeding control with hemostatic agents. *Oper Dent.* 2005;30(2):147-55.
42. Baume LJ, Holz J. Long term clinical assessment of direct pulp capping. *Int Dent J.* 1981;31(4):251-60.
43. Lipski M, Nowicka A, Kot K et al. Factors affecting the outcomes of direct pulp capping using biodentine. *Clin Oral Investig.* 2018;22(5):21-9.
44. Barthel CR, Strobach A, Briedigkeit H et al. Leakage in roots coronally sealed with different temporary fillings. *J Endod.* 1999;25(11):731-4.
45. Heling I, Rotstein I, Dinur T et al. Bactericidal and cytotoxic effects of sodium hypochlorite and sodium dichloroisocyanurate solutions *in vitro*. *J Endod.* 2001;27(4):278-80.
46. Komabayashi T, Zhu Q. Innovative endodontic therapy for anti-inflammatory direct pulp capping of permanent teeth with a mature apex. *Oral Surg Oral Med Oral Path Oral Radiol.* 2010;109(5):75-81.
47. Camoni N, Cagetti MG, Cirio S et al. Partial pulpotomy in young permanent teeth: A systematic review and meta-analysis. *Children.* 2023;10(9):1447-56.
48. Silva AF, Tarquinio SB, Demarco FF et al. The influence of haemostatic agents of healthy human dental pulp tissue capped with calcium hydroxide. *Int Endod J.* 2006;39(4):309-16.
49. Divya G, Prasad MG, Vasa Aam et al. Evaluation of the efficacy of caries removal using polymer bur, stainless steel bur, Carisolv, Papacarie—An *in vitro* comparative study. *J Clin Diagn Res.* 2015;9(7):42-9.
50. Bogen G, Chandler NP. Pulp preservation in immature permanent teeth. *Endod Topics.* 2010;23(1):131-52.
51. Shabahang S, Torabinejad M, Boyne PP et al. A comparative study of root-end induction using osteogenic protein-1, calcium hydroxide and mineral trioxide aggregate in dogs. *J Endod.* 1999;25(1):1-5.
52. Gawthaman M, Vinodh S, Mathian VM et al. Apexification with calcium hydroxide and mineral trioxide aggregate: Report of two cases. *J Pharm Bioallied Sci.* 2013;5(2):131-4.
53. Silva RV, Silveira FF, Nunes E. Apexification in non-vital teeth with immature roots: Report of two cases. *Iran Endod J.* 2015;10(1):79-86.
54. Solanki NP, Venkappa KK, Shah NC. Biocompatibility and sealing ability of mineral trioxide aggregate and biodentine as root-end filling material: A systematic review. *J Conserv Dent.* 2018;21(1):10-5.
55. Malkondu Ö, Kazandağ MK, Kazazoğlu E. A review on biodentine, a contemporary dentine replacement and repair material. *BioMed Res Int.* 2014;16(4):201-9.
56. Abbott PV. Apexification with calcium hydroxide-when should the dressing be changed? The case for regular dressing changes. *Aust Endod J.* 1998;24(1):27-32.
57. Mahajan T, Kochhar R, Kumari M. Apexification using MTA: A challenging approach. *Int J Sci Res Publ.* 2020;10(2):184-201.
58. Kahler B, Lin LM. A review of regenerative endodontics: Current protocols and future directions. *J Istan Uni Faculty Dent.* 2017;51(11):41-51.
59. Lenzi R, Trope M. Revitalization procedures in two traumatized incisors with different biological outcomes. *J Endod.* 2012;38(3):411-4.

60. Banchs F, Trope M. Revascularization of immature permanent teeth with apical periodontitis: New treatment protocol? J Endod. 2004;30(4):196-200.
61. Rutherford RB, Wahle J, Tucker M et al. Induction of reparative dentine formation in monkeys by recombinant human osteogenic protein-1. Arch Oral Biol. 1993;38(7):571-6.
62. Shimizu E, Ricucci D, Albert J et al. Clinical, radiographic, and histological observation of a human immature permanent tooth with chronic apical abscess after revitalization treatment. J Endod. 2013;39(8):1078-83.
63. American association of endodontists. <https://www.aae.org/specialty/wp-content/uploads/sites/2/2017/06/currentregenerativeendodonticconsiderations.pdf>. 2016.
64. Kabir R, Gupta M, Aggarwal et al. Imperative role of dental pulp stem cells in regenerative therapies: A systematic review. Niger J Surg. 2014;20(1):1-8.
65. Hotwani K, Sharma K. Platelet rich fibrin-A novel acumen into regenerative endodontic therapy. Restor Dent Endod. 2014;39(1):1-6.
66. Duncan HF, Kobayashi Y, Shimizu E. Growth factors and cell homing in dental tissue regeneration. Curr Oral health Reps. 2018;5(8):276-85.
67. Rafter M. Apexification: A review. Dent Traumatol. 2005;21(1):1-8.
68. Tang Y, Xu K, Chen Y et al. Evaluating the efficacy of endodontic microsurgery for teeth with an undeveloped root apex and periapical periodontitis after nonsurgical treatment failure. BMC Oral Health. 2023;23(1):414-9.

How to cite this article: Saloni Tyagi, Padmanabh Jha, Vineeta Nikhil. Changing concepts of management of an immature apex. *International Journal of Research and Review*. 2025; 12(9): 40-50. DOI: <https://doi.org/10.52403/ijrr.20250907>
