The evaluation of apical plug formation during endodontic treatment of immature teeth: a case report

Bryan Wangidjaja[1]
Wiena Widyastuti[2*]
Elline Istanto[2]
Dinie Qyrratuaini Zulkifly[3]

[1]Specialis Dental Program Conservative Dentistry, Faculty of Dentistry Universitas Trisakti, Indonesia
[2]Department of Conservative Dentistry Faculty of Dentistry, Universitas Trisakti. Indonesia
[3]Department of Restorative Dentistry, Kulliyyah of Dentistry, Internasional Islamic University Malaysia, Malaysia

***Correspondence**
Email | wiena@trisakti.ac.id

Submitted | 10 Februari 2026
Revised | 15 March 2026
Accepted | 19 April 2026
Published | 31 April 2026
DOI: 10.24198/jkg.v38i1

p-ISSN 0854-6002
e-ISSN 2549-6514

Citation | Wangidjaja B, Widyastuti W, Elline I. The evaluation of apical plug formation during endodontic treatment of immature teeth: Case report. J. Kedokt. Gigi Univ. 2026;38(1):1-8.
DOI: 10.24198/jkg.v38i1

ABSTRACT

Introduction: Trauma can cause significant changes in pulpal blood microcirculation, leading to pulp necrosis, arrested root formation, and the development of an open apex. One of the materials recommended for creating an apical plug is mineral trioxide aggregate (MTA). Apical plug formation using biomaterials such as MTA is a common technique for inducing apical closure and facilitating healing. The aim of this case report is to describe the use of the apical plug technique in immature teeth after trauma and to evaluate its effectiveness in achieving apical closure and healing. **Case report:** A 26-year-old woman visited the Department of Conservative Dentistry due to pain in her upper right anterior tooth. She had dental trauma. Tooth 11 presented with a Class IV composite restoration, and periapical radiographic examination revealed an open apex. A diagnosis of pulp necrosis with symptomatic apical periodontitis and an open apex was established. The apical size of the teeth was determined to be #80. Biomechanical preparation involved circumferential filling technique up to size #100 K-file. MTA with a 4 mm thickness was applied at the open apex, followed by continued obturation. The final restoration was completed using a direct composite restoration. Trauma can result in pulp necrosis, leading to incomplete root development in the immature teeth, which is characterized by thin apex wall and open apex. MTA offers advantages such as antibacterial properties, high marginal adaptation, and a pH of 12.5. In this case, a 6-month follow-up demonstrated healing progression in the periapical region. **Conclusion:** MTA is an excellent material for use in cases of immature teeth. The success of apical plug formation in this case can be evaluated by the resolution of patient complaints and the healing progress of the periapical region.

Keywords

apical plug, endodontic treatment, immature teeth, mineral trioxide aggregate, trauma

Evaluasi pembentukan apikal plug selama perawatan endodontik pada gigi imatur: Laporan kasus

ABSTRAK

Pendahuluan: *Trauma dapat menyebabkan perubahan signifikan pada mikrosirkulasi darah pulpa, menyebabkan kematian pulpa, terhentinya pembentukan akar, dan apeks terbuka. Salah satu material yang direkomendasikan untuk membuat apikal plug adalah mineral trioxide aggregate (MTA). Pembentukan apical plug menggunakan biomaterial seperti MTA merupakan teknik umum untuk menginduksi penutupan apikal dan memfasilitasi penyembuhan. Tujuan laporan kasus ini untuk mendeskripsikan penggunaan teknik apical plug pada gigi imatur paska trauma dengan mengevaluasi efektivitasnya selama penyembuhan.* ***Laporan kasus:*** *Seorang perempuan berusia 26 tahun mengunjungi departemen konservasi karena rasa sakit pada gigi depan atas kanan. Pasien tersebut mengalami trauma dental. Pemeriksaan gigi 11 terdapat restorasi komposit kelas IV, dan melalui pemeriksaan radiograf terlihat adanya apeks terbuka. Ukuran apikal gigi adalah #80. Preparasi biomekanis dilakukan dengan teknik circumferential filing sampai dengan K-file #100. MTA dengan ketebalan 4 mm diaplikasikan pada apeks yang terbuka dilanjutkan dengan obturasi. Restorasi akhir dilakukan dengan komposit direk. Trauma menyebabkan kematian pulpa, sehingga perkembangan akar menjadi tidak sempurna pada gigi yang imatur. Akar yang tidak sempurna terlihat memiliki dinding yang tipis dan apeks terbuka. MTA memiliki kelebihan di antara lain sifat antibakteri, adaptasi marginal yang baik, dan pH 12.5. Pasca perawatan 6 bulan pada kasus ini ditemukan adanya penyembuhan pada bagian apikal dari radiograf.* ***Simpulan:*** *MTA adalah material yang sangat baik yang dapat digunakan pada gigi yang imatur. Keberhasilan pembentukan apical plug pada kasus ini dapat dievaluasi dengan hilangnya keluhan pasien dan adanya proses penyembuhan pada regio periapikal.*

Kata kunci

apikal plug, gigi imatur, mineral trioxide aggregate, perawatan endodontik, trauma

INTRODUCTION

Trauma can cause pulp necrosis, the development of incomplete tooth roots, or external resorption, which leads to a shortened or narrowed tooth root with an exposed apex. The lack of a barrier at the open apex allows filling materials to penetrate the periapex tissue and induce tissue damage. Furthermore, the lack of an apical stop might result in the canal being entirely void of filling material, making it vulnerable to leakage.[1–6]

Apexification treatments can be used to create a solid tissue barrier and seal the apex. Another way to close an open apical foramen is to use a Mineral trioxide aggregate (MTA) as an apical barrier instead of calcium hydroxide in an apexification treatment. The technique of apexification stimulates the growth of non-vital, immature tooth roots. This method grows osteo-cementum producing or similar bone-like tissue to seal off one-third of the apical root canal or create an "apical calcium boundary" in the apical area. This makes it easier to fill the root canal properly.[3,4,7–9]

MTA has various applications in endodontics as a material used to fill root canals. MTA in dentistry is also used for the regeneration of periradicular tissues, including bone, cementum, and periodontal ligament. The MTA has exceptional sealing capability due to its composition as a hydraulic cement that can harden even when exposed to moisture.[2,4,10,11]

The bioactive components of MTA are composed of silicate oxide, dicalcium silicates, and tricalcium silicates. Upon being mixed with sterile water, the MTA powder will undergo a chemical reaction and transform into a colloidal gel. Tricalcium silicate (Ca_3S), calcium disilicate (Ca_2S), tricalcium aluminate, tetra-calcium alumina-ferrite, aluminum oxide (Al_2O_3), hydrated calcium sulphate, magnesium oxide (MgO), potassium sulphate (K_2SO_4), and sodium sulphate (Na_2SO_4) are all components of this MTA mixture. The radio-opaque effect is achieved by using bismuth oxide (Bi_2O_3).[5,7,10,12–16]

To facilitate the process of hardening, MTA is applied at the apex of the tooth in a damp state with a thickness of 3–4 mm. MTA will then take around three to four hours to fully set. The MTA has a low rate of leakage, superior antibacterial capabilities, excellent marginal adaptability, a pH of 12.5, and is biocompatible. After the MTA has been strengthened, the entire root canal can be filled with filler material. The presence of calcium and phosphate ions induces the attraction of odontoblast cells. This process facilitates platelet-derived growth factor regrowth of periapical tissues under normal conditions, thereby creating optimal conditions for bone formation.[5,7,10,12–16]

This case report examines an application of MTA as an apical plug for the treatment of a post-traumatic root canal, followed by the final restoration using composite resin. By evaluating the formation of an apical plug and its outcome in endodontic treatment. This study addresses the limited clinical evidence and detailed case-based documentation regarding the effectiveness of this treatment approach in similar conditions. The novelty of this report lies in its detailed description of the clinical procedure and evaluation of treatment outcomes, thereby providing additional insight into its practical application. Therefore, the aim of this case report is to document the implementation of the apical plug technique on immature teeth after trauma and provide insight into its effectiveness in achieving apical closure and promoting healing.

CASE REPORT

A 26-year-old female patient came to the Dental and Oral Teaching Hospital of Universitas Trisakti with a complaint of pain in her upper right anterior tooth, which was associated with previous dental trauma and had previously received a composite restoration. The extraoral clinical examination revealed no abnormalities, with no facial asymmetry or tenderness. The intraoral clinical examination revealed a class IV resin composite restoration located at one-third of the incisors on the mesiodistal region, with

apparent discoloration along the margins of the restoration (Figure 1). The percussion test was positive, whereas the palpation test and vitality test were negative. The radiograph of tooth 11 showed radiopaque restoration on the mesial aspect and a radiolucent area located at one-third of the incisive edge and one-third of the center of the tooth crown. Additionally, in the periapical region, there was a wide root canal area of radiolucency with a diffuse boundary and open apex.

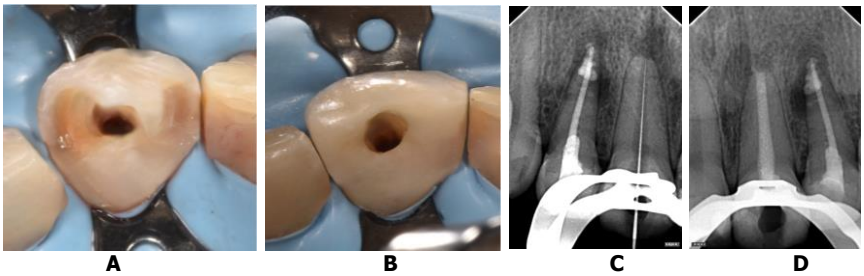
The clinical examination and radiographic results indicated that tooth 11 was diagnosed with pulp necrosis with symptomatic apical periodontitis and an open apex. The proposed course of action was to proceed with apexification while also performing a class IV resin composite restoration. The prognosis for this case was favorable.

A B

Figure 1. A. Preoperative condition and B. Preoperative radiograph.

During the initial visit, following a thorough examination of both subjective and objective factors, the patient was provided with a comprehensive explanation regarding the condition of her teeth, the proposed treatment plan, the expected outcome, and an assessment of risk factors. Additionally, the patient received dental health education and scaling treatment to effectively remove plaque and calculus. Tooth 11 was isolated using a rubber dam. The cavity was cleaned with an excavator, a round diamond bur, and a round carbide bur (SS white). After that, the access cavity was opened using an endo access bur (Dentsply) (Figure 2.A). Artificial walls were built using resin composite (Micerium, Ena HRI) (Figure 2.B).

The working length tooth 11 was measured using an electronic apex locator (Morita) and verified using a radiograph (Figure 2.C). The measured distance from the tip of the root to the reference point of tooth 11 is 20 mm. The initial apical file was determined using a K-File #80. Biomechanical preparation was performed using an H-file with circumferential filing up to a #100 size, depending on the working length. Irrigation the root canal with a 2% sodium hypochlorite solution and 17% ethylenediaminetetraacetic acid (EDTA), and distilled water as intermediate irrigation. To achieve additional sterilization, the entire wall of the root canal was treated with calcium hydroxide (calciplex), and then the cavity was sealed with a temporary filling (Caviton, GC), which was verified by a radiograph (Figure 2.D).

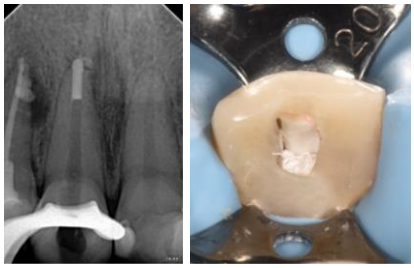


A B C D

Figure 2. A. Removal of caries and old resin composite restoration, B. Artificial wall constructed using resin composite, C. Radiographic verification of working length, D. Radiographic verification of canal sterilization calcium hydroxide.

At the second visit, seven days after the initial visit, a subjective examination revealed no complaints, and objective examination included percussion, palpation, and a bite test showed no abnormal findings, with the temporary restoration remaining intact. A rubber dam was installed to isolate the working area, and remove temporarily filling with an ultrasonic scaler (Satelec).

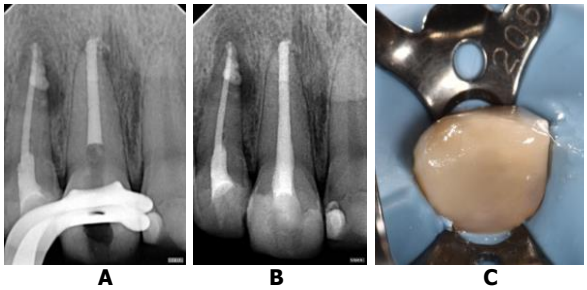
Calcium hydroxide cleansing using 2% sodium hypochlorite solution of 2 ml irrigation and rinse with aquades and 17% ethylenediaminetetraacetic acid (EDTA) and distilled water as intermediate irrigation. Then the root canal was dried with a sterile paper point (Dentply) and the apical plug material of the 11-tooth root canal was applied using a carrier (Nexton) and Mineral trioxide aggregate (BioMTA+) 4 mm long and confirmed with a radiograph. (Figure 3). Next, place a small, moist cotton pellet to help the MTA setting process perfectly, then close with a temporary filling (Caviton, GC).



A B

Figure 3. A. Radiographic verification of the 4-mm apical plug, B. Placement of a moist cotton pellet.

At the third visit (eight days after the second visit), two-thirds coronal obturation was performed using the thermal injection technique up to 3 mm below the canal orifice, followed by vertical compaction using a hand plugger (VDW). The rest of the siler and gutta-percha were cleaned with cotton pellets in alcohol (OneMed) (Figure 4.A). After etching and bonding agent, an intra-radicular retention barrier 3 mm was applied using SDR flow+ bulk fill (Dentsply) (Figure 4.B).Thirty-five percent phosphoric acid (Any Etch) was applied to the cavity surface for 15 seconds, then rinsed with water from the three-way syringe and dried under low pressure. Applied universal bonding (Kerr) using a micro brush with rubbing movements on the cavity surface, given a low-pressure three-way syringe, then polymerized using light cure (Blue phase) for 20 seconds. The restoration using nanohybrid composite resin material (Micerium, Ena HRI) on tooth surface 11 with the incremental layering technique with plastic filling (LM-Arte) (Figure 4.C). Articulating paper (hydrophilic paper) was used for occlusal evaluation. Finishing was performed using a superfine bur (SS white), followed by polishing with polishing disc (3M) and diacomp (EVE).



A B C

Figure 4. A. Radiographic verification of obturation, B. Postoperative radiograph and C. Composite resin restoration.

Six months after the third visit, an apexification evaluation was performed. The evaluation included subjective and objective tests, as well as assessments of restoration

conditions and clinical radiographs. The patient's symptoms improved as previous pain complaints had resolved, and the area around the tooth root showed signs of healing with a reduced size of the lesion seen on a radiograph (Figure 5).

Figure 5. Six-month follow-up radiograph**.**

DISCUSSION

Trauma during tooth development can disrupt root apical formation, leading to pulpal inflammation and potentially necrosis. This disease interrupts the process of root development and the tooth becomes immature. The process of incomplete root growth causes the root canal to widen, resulting in thin walls and open apical roots. This makes the root canal highly vulnerable to root fractures or crowns. When dealing with an open apex, there is no obstruction that prevents the filling material from reaching the end of the root canal apex. As a result, the filling material might enter the periapex tissue and lead to irritation in that area. In cases of open apex, there are two types of treatments available: apexogenesis, which involves vital pulp therapy, or apexification, which involves closure of the apex. If the pulp is necrotic or has irreversible pulpitis likely to become necrotic, with thick dentinal walls, the most appropriate treatment is apexification rather than regenerative endodontics. There is no obvious benefit to providing regenerative endodontic treatment to teeth which already have thick enough dentinal walls to withstand a fracture.[4,5,10,17,18]

The clinical findings in this case involve an immature tooth following trauma, characterized by incomplete root development and the presence of an open apex. Clinically, the tooth may present with discoloration and a negative response to pulp vitality tests, indicating pulp necrosis. Radiographic examination typically demonstrates a blunderbuss canal configuration, thin dentinal walls, and a wide apical foramen, often accompanied by periapical radiolucency suggestive of periapical pathology. These anatomical and pathological features complicate conventional endodontic treatment and increase the risk of root fracture.[12,13,19,20-24]

The apical plug technique is indicated based on these clinical findings to establish an artificial apical barrier, facilitating effective obturation and promoting periapical healing. Mineral trioxide aggregate (MTA) is utilized as an apical plug material to stimulate the development of apical calcific barriers. MTA is positioned 3 to 4 mm from the apex while in a moist condition. Damp cotton pellets are placed on the MTA to aid in the calcification process. Subsequently, the cavity is sealed using a temporary filling. The MTA exhibits a low rate of leakage, superior antibacterial characteristics, a high degree of marginal adaptation, an appropriate setting time, a pH of 12.5, and excellent biocompatibility. Radiographs are utilized to verify the successful filling of the root ends with MTA. Once the MTA has completely set, the entire root canal can be obturated with filling material. Patients are advised to return once the MTA has hardened for the purpose of obturation and the placement of a permanent repair.[5,7,10,15,18,21,25]

MTA was initially created in 1990 at the University of Loma Linda for the repair of root perforations. MTA is utilized for several purposes in its development, including root perforation, guiding, pulpotomy, apexification, apex closure in endodontic surgery, and

enhancement of external root resorption. This article describes a case of a permanent tooth that has undergone permanent necrosis with an open apex following a traumatic event. To address this, an apexification treatment is being performed using MTA. The closure of the apex can be achieved through a process that results in the formation of a rigid tissue barrier. Apical barrier installation utilizing MTA serves as a viable substitute for the prolonged application of calcium hydroxide, resulting in a reduction in treatment duration.[2,4,10,18,26]

MTA is recommended for teeth with necrotic pulp and open apices. The recommendations for forming an MTA apical plug were derived from the favorable characteristics of the material, including its exceptional biocompatibility and reduced cytotoxicity resulting from its heightened alkalinity. Calcium silicate materials are attributed to its ability to produce surface apatite crystals when in contact with the phosphates available in tissue fluids. Phosphates and calcium and hydroxyl ions released from the set material combine to create the crystalline precipitates. The precipitates of B-type carbonated apatite, low in calcium, that resulted from an amorphous calcium phosphate phase have been identified as the apatite crystals can induces the attraction of odontoblast cells. These apatite crystals can facilitate growth factors such as transforming growth factor, vascular endothelial growth factor, insulin-like growth factor, and platelet-derived growth factor. [2,11,16,18,27]

The MTA application procedure refers to the specific process followed in this case. The MTA possesses the capacity to stimulate the formation of hard tissue. MTA is a chemical that shows great potential as a sealing material due to its exceptional properties, including its ability to mix well with blood and its biocompatibility. Apexification typically involves a challenge with other substances when fluid becomes polluted at the apex region of the tooth. However, this is not an issue with MTA due to its hydrophilic characteristics.[2,4,10,11,23,28]

MTA promotes the regeneration of periapical tissues and creates ideal conditions for bone formation without inducing an inflammatory response. Additionally, radiographic findings demonstrated the presence of newly formed cementum surrounding the MTA material. The treatment outcome was satisfactory in terms of function and patient comfort, with no reported post-treatment complaints. However, this case report has limitations because it is based on a single case and therefore cannot be generalized. In addition, the follow-up period was relatively short, limiting comprehensive evaluation of long-term outcomes.[27,30,31]

The limitations of this treatment approach include the prolonged time required for apical barrier formation, the need for multiple visits to complete treatment, the possibility of coronal microleakage during treatment, and the lower fracture resistance of the teeth.[5,7,10,12]

CONCLUSION

For immature teeth, Mineral trioxide aggregate (MTA) is an excellent material. By forming an apical plug at the apex of the open tooth, apexification using MTA can expedite treatment time and enable immediate root canal filling. At the 6-month postoperative evaluation, the patient's complaints had resolved and the periapical region is healing. The implication of this case report is the potential use of MTA apexification as an effective treatment approach for teeth with incomplete root development and open apices by promoting apical barrier formation, facilitating obturation, and supporting periapical healing. However, clinicians should consider its disadvantages, including long setting time, potential tooth discoloration, particularly in anterior teeth, and challenging handling characteristics.

Acknowledgment: None.
Author Contribution: Conceptualization, B.W., W.W., and E.E.; validation, B.W., W.W., and E.E.; data curation, B.W.; writing original draft preparation, B.W.; writing review and editing, B.W.; visualization, B.W.; supervision, W.W. and E.E. All authors have read and agreed to the published version of the manuscript.
Funding: This research received no external funding.
Ethical Approval: This research was carried out in accordance with the Helsinki Statement.
Informed Consent Statement: Written Informed consent was obtained from the patient.
Data Availability Statement: The availability of research data will be permitted by all researchers via email correspondence with due observance of ethics in research.
Conflicts of Interest: There are no conflicts of interest.

REFERENCES

1. Lin LM, Huang GTJ. Pathobiology of apical periodontitis. In: Hargreaves KM, Berman LH, editors. Cohen's pathways of the pulp. 12th ed. St. Louis: Elsevier; 2021. p. 96-113.
2. Annanmalai S, Harihavel VP, Ramar K, Samuel V. Apexification and repair of root fracture with mineral trioxide aggregate: a case report with 5-year follow-up. J Pharm Bioallied Sci. 2021;13:881-885. https://doi.org/10.4103/jpbs.JPBS_789_20
3. Mohamed Kamel KA, Abuzied RM. Management of immature apex: a review. Med Res Dev. 2017;1(1):7-21. https://doi.org/10.31031/MRD.2017.01.000503
4. Kakani AK, Chandrasekhar V, Muralidhar T, Chandrakanth M, Rakesh D. Mineral trioxide aggregate as an apical plug material in tooth with open apex: a case report. Int J Sci Stud. 2015;2(11):218-221. https://doi.org/10.17354/ijss/2015/88
5. Cervino G, Laino L, D'Amico C, et al. Mineral trioxide aggregate applications in endodontics: a review. Eur J Dent. 2020;14:683-691. https://doi.org/10.1055/s-0040-1713073
6. Panda P, Mishra L, Govind S, et al. Clinical outcome and comparison of regenerative and apexification intervention in young immature necrotic teeth—a systematic review and meta-analysis. J Clin Med. 2022;11:3909. https://doi.org/10.3390/jcm11133909
7. Sureshchandra B, Gopikrishna V. Grossman's endodontic practice. 14th ed. 2021. p. 455.
8. Veedu RP, Joseph M, George E. Endodontic management of tooth with open apex using MTA as an apical barrier: a case report. Conserv Dent Endod J. 2019;4:14-17.
9. Samal N. Apexification: a comprehensive review. Indian J Forensic Med Toxicol. 2020;14:8551-8555. https://doi.org/10.37506/ijfmt.v14i4.13042
10. Muhamad AH, Abdulghani A, Hanali AS. Apexification with mineral trioxide aggregate (MTA): a case report. J Res Med Dent Sci. 2014;10:10-13.
11. Tokgöz Kaplan T, Botsalı MS. Micro-computed tomographic evaluation of the sealing quality and bond strength of different MTA apical plugs. Eur J Ther. 2024;30(1):29-38.
12. Endang S. Material bioaktif dalam ruang lingkup perawatan konservasi gigi. 1st ed. Jakarta: Fakultas Kedokteran Gigi Universitas Indonesia; 2018. p. 42-52.
13. Torabinejad M, Walton RE. Endodontics: principles and practice. 6th ed. St. Louis: Saunders; 2020. p. 186-189, 211, 368-375.
14. Gill I, Mittal S, Kumar T, et al. Open apex and its management: review article. J Pharm Bioallied Sci. 2024;16:S31-S34. https://doi.org/10.4103/jpbs.jpbs_615_23
15. Shukla A, Dewan R, Kumar P, et al. Apexification with apical plug of MTA: report of cases. J Community Health Manag. 2016;3:144-147. https://doi.org/10.5958/2394-2738.2016.00030.3
16. Machut K, Żołtowska A. Plasma rich in growth factors in the treatment of endodontic periapical lesions in adult patients: a retrospective cohort study. J Clin Med. 2022;11:6092. https://doi.org/10.3390/jcm11206092
17. Dixit S. Root end generation: an unsung characteristic property of MTA—a case report. J Clin Diagn Res. 2014;8(1):291-293. https://doi.org/10.7860/JCDR/2014/7760.3920
18. Dwiandhany WS, Zaelan A, Nugroho J, et al. MTA apical plug in non-vital permanent tooth with an open apex: a case report. J Dentomaxillofac Sci. 2023;8(4):2. https://doi.org/10.15562/jdmfs.v8i2.1584
19. Gill I, Mittal S, Kumar T, et al. Open apex and its management: review article. J Pharm Bioallied Sci. 2024;16:S31-S34. https://doi.org/10.4103/jpbs.jpbs_615_23
20. Silveira CM, Sebrão CC, Vilanova LS, Sánchez-Ayala A. Apexification of an immature permanent incisor with calcium hydroxide: 16-year follow-up of a case. Case Rep Dent. 2015;2015:984590. https://doi.org/10.1155/2015/984590
21. Setyabudi Y, Yohana Y. Management open apex using bioceramic root repair material: a case report of permanent anterior teeth. Conserv Dent J. 2023;13:64-68. https://doi.org/10.20473/cdj.v13i2.2023.64-68
22. Dwiandhany WS, Zaelan A, Nugroho J, et al. MTA apical plug in non-vital permanent tooth with an open apex: a case report. J Dentomaxillofac Sci. 2023;8(4):2. https://doi.org/10.15562/jdmfs.v8i2.1584
23. Harndamrong N, Wichai W, Jindachot S, et al. Micro-CT analysis of MTA apical plug placement. J Endod. 2026;52:658-663. https://doi.org/10.1016/j.joen.2026.01.004
24. Öznurhan F, Keskus B. Evaluation of long-term results of two different calcium silicate-based materials in primary molar teeth vital pulpotomies: an in vivo study. Cumhuriyet Dent J. 2020;23(1):45-51. https://doi.org/10.7126/cumudj.648723
25. Silujjai J, Linsuwanont P. Treatment outcomes of apexification or revascularization in nonvital immature permanent teeth: a retrospective study. J Endod. 2017;43(2):238-245. https://doi.org/10.1016/j.joen.2016.10.030
26. Murray PE. Review of guidance for the selection of regenerative endodontics and other treatments for immature permanent teeth. Int Endod J. 2023;56:188-199. https://doi.org/10.1111/iej.13809
27. Palczewska-Komsa M, Kaczor-Wiankowska K, Nowicka A. Mineral trioxide aggregate repair high plasticity (MTA HP): a systematic review. Materials. 2021;14:4573. https://doi.org/10.3390/ma14164573

28. Dawood AE, Parashos P, Wong RHK, et al. Calcium silicate-based cements: composition, properties, and clinical applications. J Investig Clin Dent. 2015;6:1-15. https://doi.org/10.1111/jicd.12195
29. Zafar K, Jamal S, Ghafoor R. Bioactive cements—mineral trioxide aggregate-based calcium silicate materials: a narrative review. J Pak Med Assoc. 2020;70(3):497-501. https://doi.org/10.5455/JPMA.16942
30. Nayak G, Hasan MF. Biodentine: a novel dentinal substitute for single visit apexification. Restor Dent Endod. 2014;39(2):120-125. https://doi.org/10.5395/rde.2014.39.2.120