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RESEARCH ARTICLE

CLINICAL AND RADIOGRAPHIC OUTCOMES OF TRIOXIDENT AND MINERAL TRIOXIDE AGGREGATE FOR VITAL PULPOTOMY IN IMMATURE PERMANENT TEETH WITH INCOMPLETE ROOT DEVELOPMENT

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ABSTRACT

Background: Vital pulp therapy is an important treatment strategy for immature permanent teeth with pulp inflammation because preservation of the remaining vital radicular pulp may permit continued physiological root development, increasing root length, thickening of dentinal walls, and eventual closure of the apical foramen. Calcium silicate-based biomaterials, particularly mineral trioxide aggregate (MTA), are widely used because of their biocompatibility, bioactivity, sealing ability, and capacity to promote hard-tissue formation. However, the clinical evidence concerning alternative calcium silicate materials remains comparatively limited, particularly in immature permanent teeth.

Objective: To clinically and radiographically evaluate the outcomes of vital pulpotomy using Trioxident (VladMiVa) and ProRoot MTA (Dentsply) in immature permanent molars with incomplete root formation.

Materials and Methods: Twenty children aged 7–13 years with a clinical diagnosis of pulpitis involving immature permanent molars were treated in two dental clinics of Yerevan State Medical University. Twenty-seven permanent molars were included in the analysis. Fourteen teeth (51.9%) received Trioxident (VladMiVa), while 13 teeth (48.1%) were treated with ProRoot MTA (Dentsply). Following local anesthesia and rubber dam isolation, carious dentin was removed, coronal pulpotomy was performed, and hemostasis was achieved before placement of the calcium silicate-based material over the canal orifices. The teeth were subsequently restored with glass-ionomer cement, compomer, or composite restorative materials. Clinical and radiographic follow-up examinations were performed at approximately 3 months, 6 months, and 2 years, depending on the stage of root development. Clinical success was assessed according to the absence of spontaneous or provoked pain, percussion tenderness, and clinical signs of soft-tissue inflammation. Radiographic outcomes included absence of pathological root resorption or periapical/furcation bone destruction and evidence of continued root development and apical closure.

Results: The mean age of the patients was 9.5 ± 1.59 years. The treated teeth comprised 10 maxillary molars (37.0%) and 17 mandibular molars (63.0%). During follow-up, clinical and radiographic findings demonstrated continued root development in successfully treated teeth. Periodontal/periapical complications were identified in 4 of 27 treated teeth (14.8%). One complication occurred among the 13 teeth treated with ProRoot MTA (7.7%), compared with three among the 14 teeth treated with Trioxident (21.4%); this difference was not statistically significant ($p > 0.10$). Crown discoloration was observed in 8 of 14 teeth (57.1%) treated with Trioxident. Among the successfully treated teeth, radiographic examination demonstrated continued root elongation, progressive narrowing of the root canal space, and apical maturation; complete root formation was documented in 13 teeth.

Keywords: immature permanent teeth; vital pulp therapy; pulpotomy; apexogenesis; mineral trioxide aggregate; MTA; Trioxident; calcium silicate cement; pediatric dentistry; pulpitis.

INTRODUCTION

The management of pulpal disease in immature permanent teeth remains a particular clinical challenge in pediatric dentistry. Unlike fully developed permanent teeth, immature teeth have an incompletely formed root, relatively thin dentinal walls, and a wide apical foramen. Consequently, treatment should not be directed solely toward elimination of pulpal symptoms or

infection but, whenever biologically feasible, toward preservation of the remaining vital pulp and continuation of physiological root development. Maintenance of pulp vitality may allow further root elongation, progressive thickening of the dentinal walls, narrowing of the root canal space, and physiological closure of the apical foramen, thereby improving the structural and functional prognosis of the developing tooth [1–3].

The treatment concept for immature permanent teeth has changed considerably over the past decade. Conventional endodontic approaches, including root canal treatment and apexification, can provide control of pulpal and periapical disease but do not preserve the biological potential of the remaining pulp for continued physiological root maturation. Contemporary endodontic practice therefore increasingly emphasizes biologically conservative treatment approaches that aim to preserve viable pulp tissue whenever the clinical condition of the tooth permits. Vital pulp therapy (VPT), including partial and complete pulpotomy, has consequently become an important treatment option for selected permanent teeth [1,2].

The American Association of Endodontists recognizes vital pulp therapy as a group of procedures intended to preserve the vitality and function of the dental pulp following injury caused by caries, trauma, or restorative procedures. Although VPT was historically associated primarily with immature permanent teeth, where preservation of radicular pulp was intended to facilitate apexogenesis, contemporary concepts have expanded its indications to appropriately selected mature permanent teeth as well [2]. Current treatment decisions are based on the overall clinical and radiographic assessment of the tooth, rather than on symptoms alone, and include consideration of pulp status, restorability, bleeding control, and the possibility of maintaining viable radicular pulp tissue [2,3].

Pulpotomy is particularly relevant in immature permanent teeth because removal of the inflamed coronal pulp while preserving the vital radicular pulp may provide a biologically favorable environment for continued root formation. Successful treatment therefore involves more than the resolution of pain or the absence of periapical pathology. Radiographic evidence of continued root development, progressive maturation of the root canal system, and closure of the apical foramen are important indicators of the biological success of treatment in developing permanent teeth[1,3].

The development of calcium silicate-based biomaterials has substantially influenced the clinical application of vital pulp therapy. Mineral trioxide aggregate (MTA) became one of the most extensively studied materials because of its biocompatibility, hydraulic setting reaction, sealing ability, high alkalinity, and capacity to promote hard-tissue formation. These characteristics have supported its use in pulp capping and pulpotomy procedures and have made MTA an important reference material for the evaluation of newer calcium silicate-based cements [4,5].

Evidence accumulated during the last several years supports the use of calcium silicate-based materials in vital pulp therapy. A 2021 systematic review and meta-analysis of randomized controlled trials reported a pooled VPT success rate of approximately 93% when contemporary materials, including MTA and other calcium silicate-based materials, were used. Importantly, no significant difference was identified between MTA and other calcium silicate materials at the evaluated follow-up periods, although the certainty of evidence was considered low [4]. These findings support the biological potential of calcium silicate-based materials while also indicating that further comparative clinical studies are required.

More recent evidence has reinforced the role of calcium silicate materials in VPT. A 2024 systematic review and meta-analysis evaluating 40 randomized controlled trials and 3,168 teeth found generally favorable clinical and radiographic outcomes for calcium silicate-based cements used in vital pulp therapy in both primary and permanent dentitions. However, substantial variation among materials, treatment procedures, follow-up periods, and outcome definitions was observed, making direct comparisons between individual materials difficult [5].

The contemporary evidence is particularly relevant to immature permanent teeth. A systematic review and meta-analysis published in 2022 emphasized that preservation of pulpal vitality in immature permanent posterior teeth is essential for continued root development and apical closure. The available evidence supported vital pulp therapy as a biologically rational approach for selected immature teeth with deep carious lesions, although the authors also highlighted limitations in the quality and quantity of available clinical evidence [6]. More recently, a 2026 meta-analysis comparing VPT with root canal treatment in immature permanent teeth found higher odds of clinical and radiographic success following VPT, particularly in immature teeth and in cases treated with complete or coronal pulpotomy. Nevertheless, the cumulative evidence was considered insufficient to establish definitive superiority because the number and size of comparative studies remained limited [7].

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Despite the favorable biological and clinical properties of MTA, its use is associated with certain practical and clinical limitations. Handling characteristics, setting behavior, material manipulation, and the potential for discoloration of tooth structure may influence material selection, particularly in anterior teeth and in situations where esthetic considerations are important. Recent evidence has confirmed that tooth discoloration remains an important adverse outcome associated with some MTA formulations. A 2025 systematic review and meta-analysis of premixed calcium silicate-based materials reported clinical success rates ranging from 76.6% to 97.1%, with no significant overall differences compared with MTA or calcium hydroxide; however, MTA was associated with greater tooth discoloration in permanent teeth [8].

The continued development of calcium silicate-based materials has therefore focused not only on biological activity but also on handling properties, setting characteristics, accessibility, and clinical applicability. Current evidence suggests that newer calcium silicate materials may achieve clinical outcomes comparable to MTA in selected VPT procedures, although the available evidence does not consistently demonstrate superiority of one calcium silicate material over another [5,8,9].

A recent network meta-analysis of bioactive materials similarly found high success rates across contemporary VPT materials, while differences among calcium silicate-based materials remained uncertain [9].

Trioxident (VladMiVa) is a calcium-containing dental material that has been used for vital pulp therapy and other endodontic procedures. Its clinical use has been proposed as an alternative to conventional MTA-based materials, particularly where accessibility, handling characteristics, and cost are important considerations. However, compared with ProRoot MTA, the contemporary clinical evidence supporting the use of Trioxident in immature permanent teeth remains limited. In particular, there is a lack of clinical studies directly evaluating the ability of Trioxident to maintain the vitality of the radicular pulp and support continued physiological root development after pulpotomy in young permanent teeth with incomplete root formation.

The outcome of vital pulpotomy depends not only on the biological properties of the pulp-capping material but also on several clinical factors. Accurate diagnosis, appropriate case selection, effective isolation of the operative field, complete removal of inflamed coronal pulp tissue, adequate control of pulpal bleeding, correct placement of the biomaterial, and an effective coronal seal are essential components of the treatment protocol [2,3]. In immature permanent teeth, these factors are particularly important because the therapeutic objective extends beyond short-term symptom control to preservation of the developmental capacity of the tooth.

Clinical and radiographic follow-up is therefore essential for evaluating treatment success. The absence of spontaneous or provoked pain, percussion sensitivity, swelling, or other clinical signs of inflammation represents an important component of clinical success. Radiographically, successful treatment should be associated with the absence of pathological internal or external root resorption and periapical or furcation bone destruction, together with evidence of continued physiological root maturation. In immature permanent teeth, continued root development and apical closure provide particularly meaningful evidence of successful preservation of pulp vitality [3,6,7].

Although the evidence base for contemporary vital pulp therapy has expanded substantially, direct clinical comparisons between individual calcium silicate-based materials in immature permanent teeth remain limited. Most recent systematic reviews evaluate calcium silicate materials collectively or focus predominantly on mature permanent teeth, while relatively few clinical investigations have specifically examined continued root development following pulpotomy in young permanent teeth [4,5,7].

This evidence gap is clinically relevant because the biological objective of treatment in an immature permanent tooth is not simply the elimination of symptoms but preservation of the tooth's capacity for physiological maturation.

Therefore, the present clinical study was designed to evaluate the clinical and radiographic outcomes of vital pulpotomy using Trioxident (VladMiVa) and ProRoot MTA in immature permanent teeth with incomplete root development.

The study assessed postoperative clinical findings, the occurrence of periapical complications, changes in crown color, and radiographic evidence of continued root formation and apical maturation during follow-up. The findings were intended to provide clinical evidence regarding the potential use of Trioxident as an accessible alternative calcium silicate-based material for vital pulp therapy in developing permanent teeth.

Aim: The aim of this study was to present the clinical results of the use of Trioxident and MTA in the treatment of pulpitis in young permanent teeth with incomplete roots, based on clinical and radiological findings.

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MATERIALS AND METHODS

In two dental clinics of YSMU, permanent molars at various stages of formation with a confirmed diagnosis of pulpitis were treated in 20 patients (13 males [65%] and 7 females [35%]) aged 7–13 years, followed by clinical and radiological examination. A total of 27 teeth were treated, of which 10 (37.03%) were located in the upper jaw and 17 (62.97%) in the lower jaw. Following pulpotomy, Trioxident (VladMiVa) was used in 14 teeth (51.9%), while ProRoot MTA (Dentsply) was used in the remaining teeth. The main characteristics of the study population are presented in Table 1.

Table 1. Baseline demographic and clinical characteristics

Characteristic	Value
Study population	
Patients, n	20
Age range, years	7–13
Male patients, n (%)	13 (65%)
Female patients, n (%)	7 (35%)
Mean age, years	9.5 ± 1.59
Treated teeth, n	27
Maxillary teeth, n (%)	10 (37.03%)
Mandibular teeth, n (%)	17 (62.97%)
Clinical diagnosis	Pulpitis
Root development	Incomplete
Trioxident-treated teeth, n (%)	14 (51.9%)
ProRoot MTA-treated teeth, n (%)	13 (48.1%)

ProRoot MTA (Mineral Trioxide Aggregate) is a powder consisting of small hydrophilic particles that harden after being mixed with water. The powder turns into a gel after hydration.

Composition:tricalcium aluminate, tricalcium silicate, calcium oxide, silicon oxide, and bismuth oxide.

Trioxident consists of calcium oxide, silicon oxide, aluminum oxide, and copper-calcium hydroxide. It is an easy-to-use material that does not lose its plasticity within 10–15 minutes. It is prepared by mixing a finely ground hydrophilic powder with distilled water at a 3:1 weight ratio.

All patients underwent standard diagnostic and treatment procedures:

1. Diagnostic radiograph.
2. Administration of anesthesia.
3. Isolation of the tooth with a rubber dam.
4. Preparation of the cavity according to the topography of the tooth, with removal of all carious dentin.
5. Opening of the pulp chamber.
6. Pulpotomy of the coronal pulp using a sharp excavator or a round bur.
7. Assessment and control of bleeding. The tooth cavity was thoroughly rinsed with distilled water and dried with sterile cotton pellets. Sterile cotton pellets slightly moistened with distilled water were applied to the root canal orifices, and dry pellets were placed over them and pressed gently. After 2–3 minutes, the pellets were removed. The subsequent stage of pulpotomy was performed after hemostasis had been achieved.
8. The root canal orifices were closed with MTA or Trioxident after bleeding had been controlled. The tooth was then finally restored with glass-ionomer cement, compomer, or composite materials.

Long-term results were assessed by clinical and radiographic examinations.

The criteria for successful treatment in the immediate postoperative period were:

- absence of pain (spontaneous pain, night pain, pain from thermal stimuli, or pain while biting);
- painless percussion;
- gingival mucosa without visible pathological changes.

The criteria for long-term successful treatment were:

- absence of pain;
- absence of discoloration of the tooth crown;
- gingival mucosa without visible pathological changes.

Continued root formation, including growth in length, closure of the apical foramen, and narrowing of the root canals, was considered the radiological indicator of treatment effectiveness.

Control examinations were carried out at different periods after treatment, including 3 months, 6 months, and 2 years, depending on the stage of root formation before treatment, but always until complete root formation, to establish the effectiveness of the pulpotomy performed.

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Statistical Analysis

Statistical data processing was performed using SPSS version 16.0. The analysis included calculation of percentages, mean values, and standard deviations, as well as Student's *t*-test.

RESULTS

The mean age of the children at the time of treatment was 9.5 ± 1.59 years. During history taking, it was found that 9 children (45%) had no complaints at the first visit, 6 children (30%) complained of the presence of a deep carious cavity, and 11 children (55%) reported prolonged pain after eating.

Clinical examination of the treated molars revealed deep carious cavities containing softened, pigmented dentin. The lesions were localized on the proximal surfaces in 9 teeth (33.3%), on the occlusal surfaces in 14 teeth (51.85%), and on both the occlusal and proximal surfaces in 4 molars (14.81%). Sharp localized pain was elicited during probing of the cavity floor in all teeth, whereas percussion was negative. Pain following removal of the cold stimulus subsided slowly. The mucous membrane in the region of the examined teeth was pink, clean, and painless on palpation. Radiographic examination did not reveal internal or external root resorption or destruction of bone tissue in the furcation or periapical regions.

During dental follow-up examinations, changes in crown color were observed in 8 teeth (57.1%) among the children treated with Trioxident. Percussion of the treated teeth and palpation of the mucogingival junction in the projection of the roots were painless, and no signs of inflammation of the oral mucosa were observed. Overall, complications in the periapical tissues during the follow-up period were detected in 4 teeth (14.81%). Among the 13 teeth treated with ProRoot MTA, one tooth (7.69%) developed a complication in the form of periodontitis. Among the 14 teeth treated with Trioxident, complications were observed in 3 cases (21.4%). The difference between the groups was statistically insignificant ($p > 0.1$).

In the remaining cases, radiographic examination demonstrated positive dynamics, including the absence of internal or external root resorption, absence of destruction of the cortical plate and periapical bone tissue, and continued root development. Continued root formation was manifested by an increase in root length, narrowing of the root canals, and closure of the apical foramen. Complete root formation was observed in 13 cases (57%). The clinical and radiographic findings are summarized in Table 2.

Table 2. Clinical and radiographic findings during follow-up

Outcome	n (%)
Total treated teeth	27 (100%)
Maxillary teeth	10 (37.03%)
Mandibular teeth	17 (62.97%)
Deep carious lesions on proximal surfaces	9 (33.3%)
Deep carious lesions on occlusal surfaces	14 (51.85%)
Combined occlusal and proximal lesions	4 (14.81%)
Internal/external root resorption at baseline	0
Furcation/periapical bone destruction at baseline	0
Periapical complications during follow-up	4 (14.81%)
ProRoot MTA: periapical complications	1/13 (7.69%)
Trioxident: periapical complications	3/14 (21.4%)
Statistical significance of group difference	*p* > 0.1
Crown discoloration after Trioxident treatment	8/14 (57.1%)
Continued root development	Reported in remaining cases
Complete root formation	13 (57%)

The findings demonstrate that the treated immature permanent teeth showed generally favorable clinical and radiographic responses during follow-up. The absence of internal or external root resorption and the absence of furcation or periapical bone destruction indicate that no radiographic progression of destructive pathology was observed in the examined teeth.

The occurrence of periapical complications was relatively limited in the overall study population. Although complications were more frequent in the Trioxident group than in the ProRoot MTA group (21.4% vs 7.69%), the difference did not reach statistical significance ($p > 0.1$). Therefore, the present results do not demonstrate a statistically significant difference between the two materials with respect to periapical complications.

An important clinical observation was crown discoloration in 8 of the 14 teeth treated with Trioxident (57.1%). This finding represents a relevant clinical outcome of the present investigation and should be considered when assessing the overall clinical performance of the material.

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The radiographic findings were characterized by continued root development in the remaining cases, including root elongation, narrowing of the root canals, and closure of the apical foramen. These findings are consistent with continued maturation of immature permanent teeth following vital pulpotomy. Complete root formation was reported in 13 cases (57%), indicating that root development continued in a substantial proportion of the treated teeth during follow-up.

Clinical Case

A representative clinical case demonstrating continued root development after vital pulpotomy with ProRoot MTA is presented below. *(Doctor: Badeyan E.)*

A patient, A.A., born on 05.11.2009, presented with complaints of nocturnal pain for two days. An objective examination of tooth 46 revealed a deep carious cavity filled with softened dentin and food debris. Probing was very painful throughout the entire floor of the cavity, but there was no communication between the carious cavity and the pulp chamber. X-ray examination showed root development corresponding to the age of the child. Based on the clinical and radiological findings, irreversible pulpitis of tooth 46 was diagnosed, and a decision was made to perform vital pulpotomy with MTA to achieve apexogenesis (**Figure 1a,b and Figure 2**).

The pulpotomy procedure and hemostasis followed by application of MTA are shown in **Figure 1a,b**. **Figure 2** demonstrates the packing of MTA into the pulp chamber. There were no signs of complications two weeks after treatment. Control X-ray examinations revealed signs of apexogenesis, and complete formation of the roots was observed two years after treatment (**Figure 3a,b,c,d**).

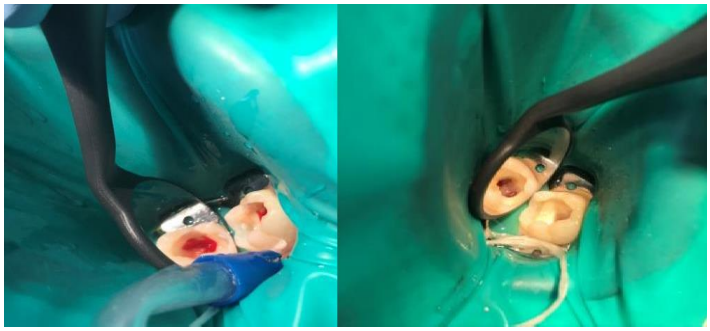

Figure 1. Pulpotomy of tooth 46. **(a)** Pulpotomy; **(b)** hemostasis and application of MTA.

Figure 2. Packing of MTA in the pulp chamber.

Figure 3. Serial X-ray examinations demonstrating root development after vital pulpotomy with MTA. **(a)** X-ray 1 (31.01.2018); **(b)** X-ray 3 (29.06.2019); **(c)** X-ray 4 (20.02.2020); **(d)** X-ray examination demonstrating complete root formation.

Thereby, the use of MTA in the treatment of pulpitis among children by the method of vital pulpotomy allowed positive results to be obtained in 44.4% of cases, while the use of Trioxident resulted in positive outcomes in 40.7% of cases.

DISCUSSION

The present study evaluated the clinical and radiographic outcomes of vital pulpotomy using Trioxident and ProRoot MTA in young permanent teeth with incomplete root development. The principal finding was that both materials were associated with continued root development during follow-up, while the frequency of periapical complications differed numerically between the treatment groups but did not reach statistical significance. These findings are clinically relevant because the primary objective of vital pulp therapy in an immature permanent tooth is preservation of viable radicular pulp and maintenance of the biological potential for continued physiological root maturation [1–4].

The absence of pathological internal or external root resorption and the lack of furcation or periapical bone destruction in the radiographic assessments provide evidence of a favorable response in the treated teeth. In

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addition, the absence of percussion sensitivity and clinically detectable inflammatory changes during follow-up supports the clinical stability observed in most cases. Contemporary evidence emphasizes that successful vital pulp therapy should be assessed using both clinical and radiographic outcomes rather than symptom resolution alone, particularly in immature permanent teeth in which continued root maturation represents an important treatment objective [2,3].

In the present study, periapical complications were detected in 4 of the 27 treated teeth (14.81%). One of the 13 teeth treated with ProRoot MTA (7.69%) developed periodontitis, whereas complications occurred in 3 of the 14 teeth treated with Trioxident (21.4%). Although the complication rate was numerically higher in the Trioxident group, the difference was statistically insignificant ($p > 0.1$). Accordingly, these findings do not demonstrate a statistically significant difference between the two materials. The numerical difference should be interpreted cautiously because of the small sample size and the limited statistical power of the study.

The absence of a statistically significant difference between the materials is consistent with recent evidence indicating that the clinical performance of contemporary calcium silicate-based materials is generally favorable and that clear superiority of one material over another has not been consistently demonstrated. Sabeti et al. reported a high overall prognosis for vital pulp therapy in permanent dentition, although differences between treatment modalities and materials varied according to follow-up and clinical circumstances [1]. A systematic review and meta-analysis by Xavier et al. similarly reported generally favorable clinical, radiographic, and histological outcomes for calcium silicate-based cements, while highlighting substantial heterogeneity among studies and materials [4].

The findings are also supported by the systematic review and meta-analyses of Coll et al., which evaluated vital pulp therapy in permanent teeth using evidence available through June 2024. Their analysis demonstrated high success rates across indirect pulp treatment, direct pulp capping, partial pulpotomy, and full pulpotomy in appropriately selected permanent teeth. Importantly, in teeth diagnosed with symptomatic irreversible pulpitis, partial or full pulpotomy also showed favorable outcomes, and the authors emphasized the importance of adequate pulpal bleeding control in achieving successful treatment [3]. This is relevant to the present study because hemostasis was an integral part of the pulpotomy protocol.

Recent evidence specifically addressing calcium silicate materials also supports the present observations. Immich et al. evaluated premixed calcium silicate-based materials in a 2025 systematic review and meta-analysis and reported clinical success rates ranging from 76.6% to 97.1%, with no significant overall differences between premixed calcium silicate materials and comparator materials. The authors concluded that larger clinical studies with longer follow-up were still needed, particularly for permanent teeth, where the certainty of evidence remained low[7]. This supports a cautious interpretation of the present comparison between Trioxident and ProRoot MTA.

The radiographic findings of the present study are particularly important because the treated teeth had incomplete root development before intervention. Continued root formation was manifested by an increase in root length, narrowing of the root canals, and closure of the apical foramen, while complete root formation was reported in 13 cases (57%). These findings are consistent with the biological rationale for vital pulpotomy in immature permanent teeth. Ageel et al., in their systematic review of MTA-assisted apexogenesis, found that different pulpotomy agents generally produced comparable clinical outcomes to MTA in carious or traumatized immature permanent teeth. However, the authors emphasized that the available evidence was insufficient to establish a definitive advantage of one material over another [5].

The findings of the present study are also consistent with the most recent evidence comparing vital pulp therapy with root canal treatment in immature permanent teeth. Gu and Yang reported in a 2026 meta-analysis that vital pulp therapy was associated with higher odds of clinical and radiographic success than root canal treatment in immature permanent teeth with pulpal involvement. Their analysis further suggested favorable outcomes for complete or coronal pulpotomy and for follow-up of at least 24 months [6].

The two-year follow-up included in the present study therefore provides clinically meaningful evidence of the potential for continued root maturation after vital pulpotomy.

The clinical case of tooth 46 provides an illustrative example of this biological response. The patient presented with nocturnal pain and a deep carious lesion, and the tooth was diagnosed clinically and radiographically with irreversible pulpitis. Following vital pulpotomy with ProRoot MTA, no signs of complications were observed at the two-week follow-up. Subsequent radiographs demonstrated signs of apexogenesis, and complete root formation was observed after two years. Although this individual case cannot be considered comparative

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evidence, the sequential radiographic findings provide a clinically clear example of continued root maturation following preservation of the remaining pulp.

The management of symptomatic irreversible pulpitis has undergone a substantial conceptual change in recent years. Historically, irreversible pulpitis was generally considered an indication for complete pulpectomy and root canal treatment. Current evidence, however, suggests that the clinical designation of irreversible pulpitis does not necessarily imply complete loss of the biological capacity for pulp healing. Asgary and Eghbal highlighted this changing concept and argued that contemporary vital pulp therapy may preserve viable pulp tissue in selected cases that would previously have been managed exclusively by root canal treatment [13]. Similarly, Kahler et al. reviewed the biological basis for VPT in permanent teeth diagnosed with irreversible pulpitis and emphasized that appropriate case selection, aseptic treatment, calcium silicate-based materials, and an effective coronal seal are essential to treatment success [14].

The systematic review by Bafail further supports this emerging clinical approach. In teeth with symptomatic irreversible pulpitis treated with hydraulic calcium silicate cements, reported clinical success generally ranged from 78% to 90% at one to five years, while radiographic success ranged from 81% to 90%. Importantly, some studies reported outcomes comparable with nonsurgical root canal treatment[10]. Although most of the evidence summarized by Bafail concerns mature permanent posterior teeth, the underlying biological concept is relevant to the present study because the current investigation also treated teeth with clinical features of advanced pulpal inflammation while attempting to preserve viable radicular pulp in immature teeth.

The present findings should also be interpreted in relation to broader evidence regarding pulpotomy. Wang et al. reported in a 2024 systematic review and meta-analysis that pulpotomy using hydraulic calcium silicate cements achieved success rates comparable with root canal treatment in mature permanent teeth with carious pulp exposure. Their analysis also found lower postoperative pain during the first postoperative week following pulpotomy [11]. Bastos et al. similarly reported favorable clinical and radiographic outcomes for pulpotomy across primary and permanent teeth in their 2024 systematic review and meta-analysis [12]. Although these studies predominantly involve mature teeth or mixed dentitions and therefore are not directly equivalent to the present population, they provide additional support for the broader biological and clinical role of contemporary pulpotomy.

A 2025 systematic review and meta-analysis focused specifically on vital pulp treatment in children and adolescents also supports the present therapeutic concept. Asgary et al. analyzed randomized clinical trials involving vital permanent teeth and found that contemporary pulp-preserving approaches, including MTA-based therapy, provided effective outcomes, although uncertainty remained regarding the relative performance of individual treatment protocols and materials [15]. The consistency between this evidence and the present clinical observations supports continued investigation of conservative pulp therapy in young permanent teeth.

Another relevant consideration is crown discoloration. In the present study, crown discoloration was observed in 8 of the 14 teeth treated with Trioxident (57.1%). This finding is clinically important because the assessment of treatment success should consider not only pulpal and periapical healing but also clinically relevant changes in tooth appearance. Recent systematic evidence has identified discoloration as a recognized limitation of some calcium silicate-based materials. Coll et al. reported greater discoloration with MTA than with Biodentine in their evidence synthesis, while Immich et al. similarly found a greater discoloration tendency associated with MTA compared with premixed calcium silicate-based materials [3,7]. However, the present study cannot establish a causal relationship between Trioxident and the observed discoloration because an objective colorimetric assessment was not performed.

The 2026 network meta-analysis by Elmsmari et al. further emphasizes the complexity of comparing bioactive materials. In mature permanent teeth, MTA remained an important reference material, but several newer calcium silicate-based materials demonstrated outcomes that were not significantly different from MTA in the analyzed comparisons [8]. The significance of this evidence for the present study is methodological rather than direct, because the present investigation concerns immature teeth. Nevertheless, it reinforces the need to avoid interpreting numerical differences between individual calcium silicate materials as evidence of superiority without appropriately powered comparative studies.

The 2025 systematic review by Pusa et al. likewise demonstrated favorable overall outcomes for vital pulp therapy in pulp-exposed permanent teeth, although the magnitude of success varied according to treatment modality, follow-up duration, and clinical circumstances [9]. These observations are consistent with the present findings, in which favorable clinical and radiographic responses were observed over follow-up but a statistically significant difference between Trioxident and MTA could not be demonstrated.

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A further strength of the present study is the inclusion of longer-term radiographic assessment rather than restricting evaluation to the immediate postoperative period. Continued root elongation, canal narrowing, and apical closure represent clinically meaningful outcomes in immature permanent teeth because they indicate that the tooth retained the capacity for further maturation. The evidence summarized in recent systematic reviews indicates that longer follow-up is particularly important in evaluating VPT, since early clinical success does not necessarily predict long-term biological stability [3,6,7].

At the same time, the findings should not be interpreted as establishing equivalence between Trioxident and ProRoot MTA. Trioxident is considerably less extensively studied in the contemporary clinical literature than established MTA-based materials. Most recent evidence syntheses focus on MTA, Biodentine, premixed calcium silicate materials, or other widely investigated hydraulic cements [4,7–9]. The present study therefore contributes preliminary clinical evidence concerning Trioxident in a specific population of immature permanent teeth, but it does not provide sufficient evidence to establish non-inferiority, equivalence, or superiority. The difference in periapical complication rates observed in the present study may nonetheless be clinically relevant as a hypothesis-generating observation. Complications occurred in 21.4% of Trioxident-treated teeth compared with 7.69% of MTA-treated teeth, but the difference was not statistically significant. Possible explanations for such numerical variation may include the small sample size, differences in the severity of pulpal inflammation, anatomical characteristics of individual teeth, technical factors, and the biological variability of immature pulp tissue. Because these factors were not independently controlled in the present study, attribution of the difference to the material itself would be inappropriate.

The principal scientific contribution of the study is therefore the direct clinical comparison of Trioxident and ProRoot MTA in immature permanent teeth with incomplete root development, with emphasis on both clinical findings and continued physiological root maturation. The study suggests that vital pulpotomy can preserve the developmental potential of immature permanent teeth and provides preliminary evidence supporting further clinical evaluation of Trioxident as a potentially accessible calcium-containing material.

Several limitations should be acknowledged. The sample size was small, comprising 20 patients and 27 treated teeth, which limits statistical power and makes detection of modest between-group differences difficult. The available study description does not indicate randomized treatment allocation or blinded clinical and radiographic outcome assessment. The follow-up intervals varied according to the stage of root development, and quantitative measurements of root length, dentinal wall thickness, and apical diameter were not reported. Crown discoloration was assessed clinically without standardized colorimetric measurements. These limitations reduce the strength of causal and comparative conclusions.

Future research should therefore include larger prospective multicenter studies and, where ethically and clinically feasible, randomized controlled trials comparing Trioxident with ProRoot MTA and other contemporary calcium silicate-based materials. Standardized diagnostic criteria, predefined treatment protocols, objective radiographic measurements, quantitative assessment of tooth color, and long-term follow-up should be incorporated. Particular attention should be given to immature permanent teeth because the preservation of pulp vitality and continued root development may provide benefits that cannot be captured by conventional short-term measures of endodontic success. Overall, the present findings are in agreement with the growing body of evidence supporting vital pulp therapy as a biologically conservative approach to selected permanent teeth. Within the limitations of the present study, both Trioxident and ProRoot MTA were associated with favorable clinical and radiographic findings, including continued root development. The higher numerical frequency of periapical complications in the Trioxident group was not statistically significant, while crown discoloration occurred in 57.1% of Trioxident-treated teeth. These findings support continued investigation of Trioxident but do not justify a conclusion of superiority or equivalence relative to ProRoot MTA.

DECLARATIONS

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The work was not funded.

Data Sharing
Not applicable

Ethical Approval
"Not applicable"

Ethics approval
This study was conducted in accordance with the ethical principles of the World Medical Association Declaration of Helsinki, as revised in 2024. The study protocol was reviewed and approved by the Ethics Committee of Yerevan State Medical University after Mkhitar Heratsi (YSMU).

Consent for publication
Written informed consent for publication of the clinical case and accompanying clinical and radiographic images

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Authors' contributions

All authors contributed to the conception and design of the study, clinical treatment, data collection, interpretation of the findings, and preparation and revision of the manuscript. All authors approved the final version of the manuscript.

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