Case Report

Maturogenesis of Two Maxillary Central Incisors: A Case Report with 10 Years of Follow Up

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Abstract

This case report describes the treatment of two immature maxillary central incisors in a 7-year-old female patient. She suffered complicated crown fracture because of trauma, and the root formation was incomplete. White mineral trioxide aggregate (MTA) was selected as the pulp-capping material after cervical pulpotomy to preserve the pulp tissue vitality and achieve maturogenesis. Follow-up evaluations showed successful treatment in terms of preservation of pulp vitality and demonstrated marked continuous physiological root development. During 10 years of follow-up, both teeth were clinically asymptomatic, and radiographic evaluations showed apparent root regeneration with apical root-end closure without pulp or periapical pathosis.

Key words: Tooth Crown; Immature; Traumatized; Mineral Trioxide Aggregate; Pulpotomy

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INTRODUCTION

In endodontics, we sometimes encounter complexities in the treatment of traumatized immature permanent teeth, particularly when the vital pulp exposure occurs in cases with incomplete root formation. Traumatic injuries are the most common threats to the vitality and integrity of developing teeth since trauma may jeopardize the pulp vitality. Irreversible pulpal damage and eventual necrosis of the pulp tissue may occur [1]. Pulp necrosis and apical periodontitis can interrupt normal root development [2]. An important component responsible for root development is Hertwig's epithelial root sheath (HERS) [3,4]. In addition, complex cellular and molecular activities are involved in natural tooth development. These processes are controlled by specific basement membrane-mediated epithelial-mesenchymal interactions together with various enzymatic and biomolecular activities [3-5]. Pulpal infection and inflammation can impair the differentiation and proliferation of cells between HERS and dental pulp, or dental papilla. This impairment can hinder development of root, particularly in the developmental stages of root formation. Such events can adversely affect the long-term prognosis and tooth survival [6]. Hence, the primary aim of treatment in immature traumatized teeth should be maintaining the pulp vitality to allow natural root development or maturogenesis to occur [7]. The term "maturogenesis" was first introduced by Weisleder and Benitez [8].

It describes a vital pulp therapy procedure that triggers continuous deposition of dentin all along the root length and culminates complete

physiological root formation together with natural root end closure. According to the glossary of American Association of Endodontists (AAE) [9], unlike apexogenesis, the definition of root development is not limited to the induction of apical end closure because dentinogenesis occurs throughout the root as well [8]. At present, this procedure is the preferred treatment for immature and traumatized vital teeth because it induces healing via regeneration instead of repair. Furthermore, it results in increased tooth thickness, root length, and fracture resistance [10-13]. Recently, several materials have been introduced for maturogenesis, including calcium hydroxide, MTA, adhesive resins, Biodentine, and bioaggregate (BA) [14-17]. On the basis of findings of several in vitro and in vivo studies, MTA has demonstrated several advantages over calcium hydroxide and adhesive resins. It induces minimal inflammation in the pulp tissue and significantly increases the secretion of IL-1β in the pulp; thus, providing favorable conditions for pulp regeneration [14-16]. It seems that MTA utilizes complex mechanisms to provide an appropriate surface (scaffold) for the adhesion of progenitor cells. It also activates cell interaction functions, ultimately stimulates continuous reparative dentinogenesis throughout the length of the root, and induces physiological root development [18]. One important challenge of using gray and white MTA in the anterior teeth is preventing the development of crown discoloration [19-21]. Some authors have elucidated that discoloration occurs due to a chemical reaction between the pulp and blood products [20,22]. There are several techniques available to improve this esthetic problem; for example, bleaching, laminate veneers and porcelain crowns. Removal of discolored white MTA using a high-speed bur with a water-cooling system under an operative microscope may cause considerable improvement in tooth color. However, internal bleaching of the crown has been recommended as the best procedure to attain desirable results [23]. The aim of this case report was to describe the treatment of two immature traumatized permanent central maxillary incisors with complicated crown fracture using white MTA. We discussed the biological basis of maturogenesis in this case, which was managed appropriately and followed-up for 10 years.

CASE REPORT

A 7-year-old girl was referred to my private practice with complicated crown fracture in two permanent maxillary central incisors. Her medical history was unremarkable. In the patient's dental history, she reported a traumatic accident in school as a result of falling down and hitting her front teeth on the table. Her two maxillary central incisors had been broken 20 days prior to presentation. There was no apparent trauma to the soft tissues during extra- and intraoral examination. Inspection of the intraoral hard tissues revealed that both teeth had horizontal crown fractures and pulp exposure. Periapical radiography showed incomplete root development without root or alveolar bone fractures (Fig.1-a). We performed additional diagnostic tests on the upper and lower anterior teeth.

The injured teeth responded to percussion with mild pain, and there was no pain in palpation. There was a severe but not lingering pain response to a cold thermal test. Both teeth responded normally to the electric pulp tester. The periodontal evaluations and mobility tests were normal in all teeth and had results comparable to those of the control teeth. We considered vital pulp therapy as the treatment of choice to preserve pulp vitality. We explained the treatment plan to the parents and they consented to the treatment. We administered local infiltration anesthesia using 2% lidocaine and 1:80000 epinephrine (Darupakhsh, Tehran, Iran).

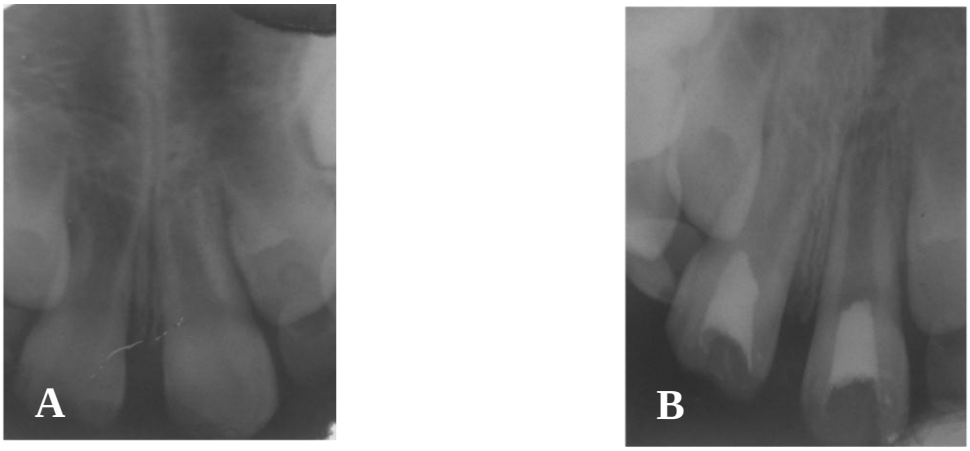

Fig 1. (A) Seven-year old patient with two immature maxillary central incisors. **(B)** Cervical pulpotomy was performed and white MTA was placed as a conservative treatment procedure for inducing physiological continuous root development.

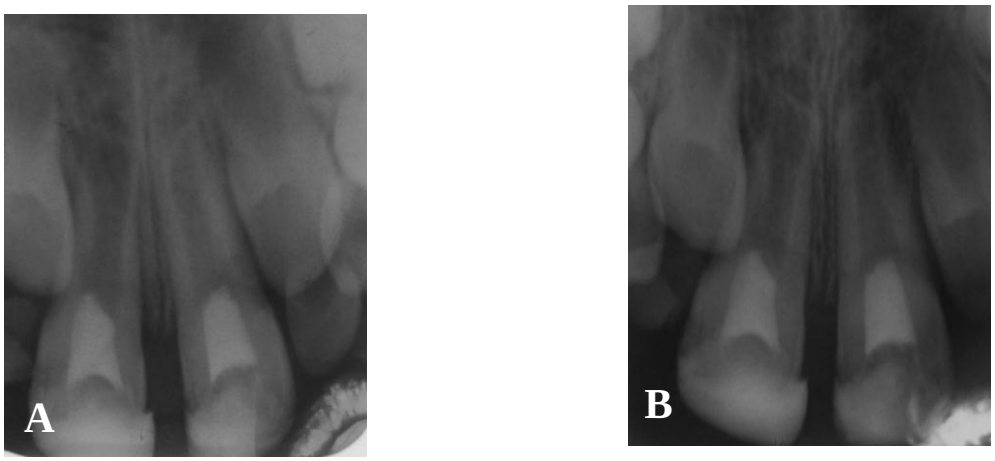

Fig. 2. (A) Forty-eight hours later, crown restoration is complete with translucence self-cure GI cement and light cure composit resin. **(B)** Radioghraphic appearance at one month follow-up.

On the basis of findings from a histological study by Cvek et al, [24] we performed cervical pulpotomy under a rubber dam using a high-speed size 2 round diamond bur (Diatech, Heerbrugg, Switzerland) with copious water as a coolant.

We removed the coronal pulp tissue to a level at which we could achieve adequate hemostasis.

Then, we rinsed the access cavity with 3 mL of 5.25% sodium hypochlorite (NaOCl) solution (Golrange, Tehran, Iran) for up to three minutes to provide hemostasis.Once hemostasis was achieved, we placed an approximately three millimeter-thick layer of ProRoot white MTA (Dentsply Tulsa Dental, Tulsa, OK, USA), mixed according to the manufacturer's instructions, over the remaining pulp tissues. In order to set the MTA, we placed a moist cotton pellet over the MTA and covered it with Coltosol (Coltene/Whaledent AG, Altstätten, Switzerland) as a temporary filling material and then took a final periapical radiograph (Fig. 1-b). After 24 hours, we evaluated the hardening of MTA with an endodontic explorer. Finally, we restored the teeth with self-setting glass ionomer (Fuji, Tokyo, Japan) and light-cure composite resin (3M ESPE, St. Paul, MN, USA) (Fig. 2).

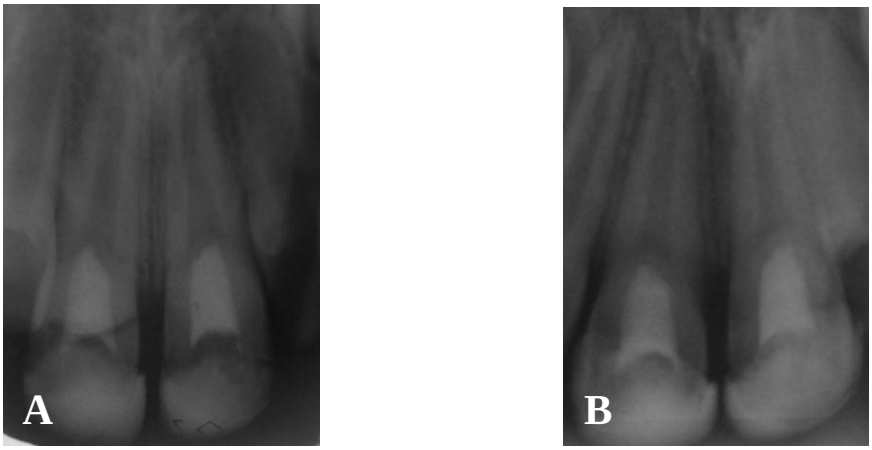

Fig. 3. (A) Twelve months later, radiograph demonstrated complete root formation and apical closure. A longer root, greater crown-root ratio, smaller pulp space and thicker convergent dentinal walls are seen. **(B)** Replaced crown restoration can be seen.

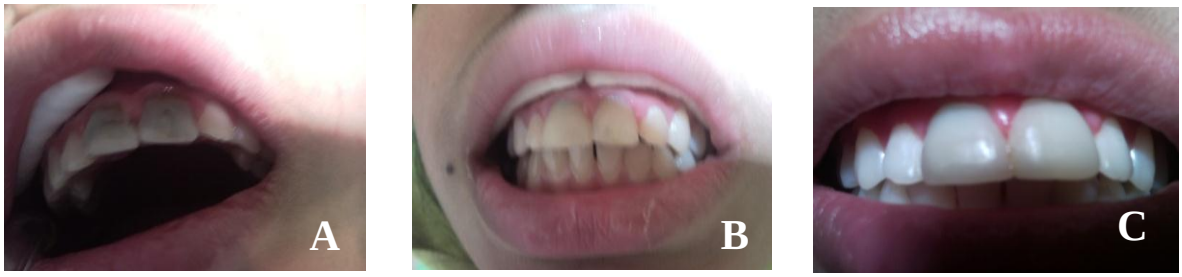

Fig. 4. (A) Discoloration as a result of white MTA application. **(B)** After four appointments of walking bleaching the teeth regained their original shade. **(C)** Placement of a new well-sealed light–cure composite resin restored esthetics after 12 months of follow- up.

We re-evaluated the patient at one, three, six and 18 months, and then after 10 years. The patient returned on the ninth day with a slight gray discoloration of the teeth that was limited to the cervical area of the crowns. There was further evidence of crown discoloration at the fourth month. The crown discoloration extended to the incisal edge at the eighth month (Fig. 4-a). However, the teeth were asymptomatic, and there was radiographic evidence of hard tissue bridge formation and continuous root maturation. These findings were followed and finally we observed promising, successful, normal root development after one year (Fig. 3). After we were confident that there was successful maturogenesis, we discussed the necessity of internal bleaching with the patient and her parents to improve tooth discoloration. They agreed to this treatment plan.

Walking bleaching is considered to improve this type of esthetic problems. Thus, after the administration of local anesthesia, we isolated the teeth with a rubber dam and accessed the pulp chamber again. We irrigated the pulp chamber with 5.25% NaOCl and dried it with a cotton pellet. Considerable improvement in the color of the teeth was seen immediately after the removal of the discolored white MTA. At the same session, we applied 10% carbamide peroxide gel (pH 6.62; Nite White, Beverly Hills, CA, USA) as a bleaching agent in the cavity over the white MTA. We placed a cotton pellet over the bleaching agent and finally sealed the cavity with Coltosol. According to the manufacturer's instructions, we refreshed the bleaching material every three days. After four sessions, the color of the teeth had returned to normal and both teeth were clinically asymptomatic (Fig. 4-b).

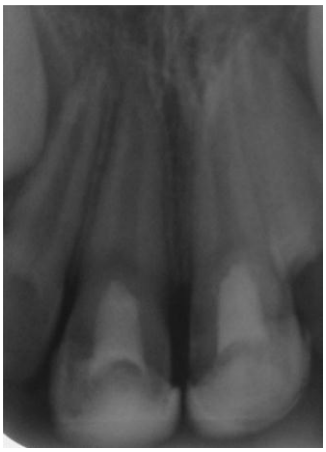

Fig. 5. Follow-up radiograph five years after treatment showing hard-tissue barrier formation along the interface of white MTA and pulp tissue. Successful continued root development is also seen.

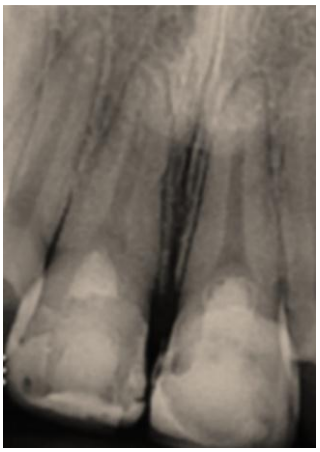

Fig. 6. After 10 years, digital radiograph shows hard–tissue barrier formation along the interface of white MTA-pulp and root development is complete without pathological changes in pulp or periradicular tissue.

Under rubber dam isolation, we accessed the teeth again and irrigated them with sterile normal saline and then sealed them with Coltosol for one week.

After one week, we restored the access cavity with a layer of self-curing glass ionomer cement (Fuji, Tokyo, Japan) as an orifice plug. We then restored the teeth and their crowns with light-cured composite resin (3M ESPE, St. Paul, MN, USA). We also replaced the labial composite with translucent composite resin restoration to match the patient's improved esthetics (Fig. 4-c). After a five-year follow-up period, both teeth were clinically and radiographically asymptomatic, and the color of the crowns was normal (Fig. 5). After 10 years, radiographic findings showed that the teeth had developed satisfactorily and there was no evidence of internal or external resorption or other pathological changes (Fig. 6). Photographs show that the esthetic problem is successfully resolved (Fig. 7).

DISCUSSION

Preserving the pulp vitality of traumatized teeth with incomplete root formation is the most important criterion for tooth survival because a vital pulp can provide nutrition for metabolic and dentinogenesis activities and biosensory, and defense functions against noxious irritants and finally encourage continuous normal root development. In comparison with conventional root canal treatments, maintaining pulpal vitality in teeth with incomplete root formation requires preservation of the coronal cell-rich zone and radicular pulp tissues.

These induce continuous physiological deposition of dentin in the coronal region and all along the length of the root canal with greater quality and structural integrity [8]. This procedure results in increased resistance to vertical/horizontal root/crown fractures [10,11,13]. Additional advantages of pulp vitality preservation are: the prevention of the probable discoloration of tooth crown [25] and apical periodontitis after current endodontic procedures [26] and maintenance of a viable HERS as a critical component in the induction of continuous physiological root formation with natural root end closure for obturation, if necessary [3-5].

The two vital pulp therapy procedures (defined as apexogenesis and maturogenesis) considered necessary to achieve these requirements include direct pulp capping and partial or cervical pulpotomy.

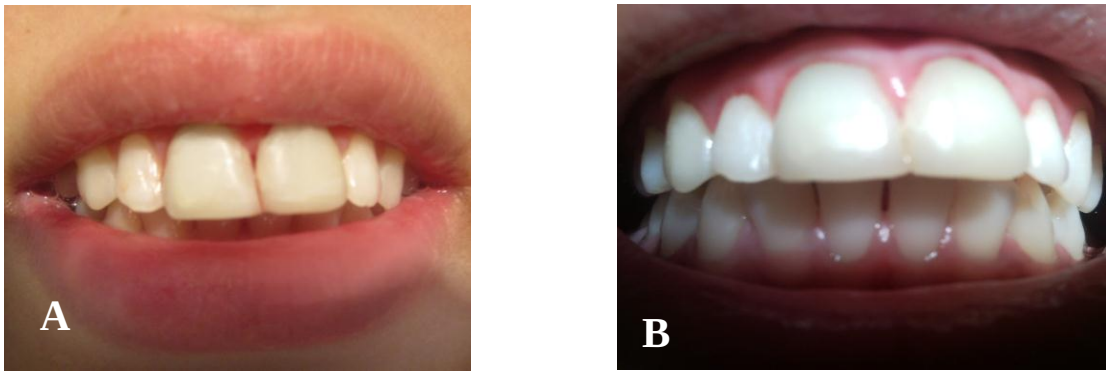

Fig. 7. Clinical appearance at 10 years follow-up. **(A)** Note that the teeth have preserved esthetics and original shade. **(B)** Mandibular and maxillary incisors are control teeth to illustrate marked harmonic color change.

Pulp capping and partial pulpotomy are believed to have more favorable prognoses and many advantages as compared with cervical pulpotomy [27,28]. However, in special situations as in our current cases, extensive crown fractures may not allow sufficient space for partial pulpotomy and coronal restoration materials.

In addition, cervical pulpotomy is advocated in these cases due to the long interval between the accident and treatment. An additional important criterion is selection of a vital pulp therapy material that can initiate biologic responses in the pulp tissue.

The preferred material must stimulate the production of biomolecules and markers of mineralization, while satisfactorily managing the various cellular regulatory and protective mechanisms. In other words, these materials must be biocompatible.

Ultimately, it triggers complete root formation with higher strength and resistance to fracture and no pathological lesions. In order to achieve normal physiological activities of pulp cells, vital pulpal therapy materials should cause minimal inflammation and hyperemia, without pulpal necrosis or high alkalinity, and possess an optimal ability to seal the dental pulp tissue against bacterial invasion (i.e., microleakage). Moreover, these materials should elevate extracellular Ca^{2+} concentration and enzymatic activities as dominant factors in bone metabolism.

It is clear that pulp regeneration after injury is a complex process and its mechanisms remain to be fully elucidated. Some studies have found a direct relationship between high pH and Ca^{2+} concentration in extracellular fluid and chemotactic, proliferative, and differentiation activities of hard tissue forming cells and alkaline phosphatase (ALP) activity at mineralization foci [29].

A high pH can increase levels of some specific calcification enzymes, such as ALP [31]; enhance collagen synthesis by dental pulp cells and stimulate gene expression of bone-related proteins [30,32]. Also, the high concentrations of Ca^{2+} and the continuous release of Ca^{2+} from MTA play important roles in reducing the permeability of newly formed capillaries in the healing tissue, intravascular fluid leakage, and the volume of intercellular fluid, as well as increasing the concentration of Ca^{2+} derived from the blood supply. These processes result in decreased inflammation in the pulp due to MTA [33]. Also, high intracellular Ca^{2+} increases the activity of calcium-dependent pyrophosphatase and reduces the level of mineralization-inhibiting pyrophosphate ions within the tissues that also result in continuous mineralization process [33].

These events can ultimately provide an appropriate scaffold for the migration, adhesion, differentiation, and proliferation of stem/ progenitor pulp cells.

Several other materials have been advocated for these purposes with success rates of 75–100% in incisor teeth [34,35]. The most common materials used are $Ca(OH)_2$, MTA, adhesive systems, Biodentine and BioAggregate (BA). Many in vivo and in vitro studies have confirmed the superior physical and biological properties of MTA [36-38]. However, the mechanisms by which MTA induces mineralization and manages cellular and molecular activities are unclear. There are several theories regarding how MTA accomplishes these functions. It has been shown that MTA may cause the secretion of proinflammatory cytokines in the pulp and may manage the activities of other biomolecules that induce several active markers of mineralization and growth factors in dentinogenesis [39-46]. These findings elucidate how MTA could play a protective role in dental pulp tissue just after tissue injury. In healthy pulp tissue, biomolecules and basement membrane act as natural scaffolds for the migration and adhesion of progenitor cells, differentiation of cells, and subsequent events. Conversely, when the pulp is exposed after trauma and the basement membrane or dental epithelium (i.e., the natural scaffold) is absent, the hard-tissue-forming cells in the pulp need a suitable surface (scaffold) for adhesion and differentiation to commence dentinogenesis. We know that MTA can act as a pulp-capping material in vital pulp therapy, and it has optimal interaction with pulp tissue; therefore, it may be able to provide a suitable scaffold for reparative dentinogenesis [39]. In addition, dental pulp has natural repair/regeneration capacity; for example, pulp tissue fluid is rich in phosphate ions. When MTA is placed on the exposed pulp tissue, a chemical reaction between the pulp tissue fluid and tricalcium oxide in MTA results in the production of calcium hydroxide [47]. Calcium hydroxide releases a lot of Ca^{2+} ions, and both Ca^{2+} and phosphate ions are critical for bone metabolism. A continued reaction occurs between these two types of ions, which leads to the precipitation of hydroxyapatite crystals (HAP). At first, there is probably continuous precipitation of HAP crystals in the MTA due to its porous structure. Over time, with gradual dissolution of MTA, HAP crystals nucleate, grow, and deposit on the surface of MTA [48]. Ultimately, a thick layer of dystrophic calcification with integrated structures (i.e., a dentinal bridge) is formed along the MTA and pulp tissue according to the aforementioned mechanisms. This dentinal bridge is observable as a radiopaque zone on radiographs, as seen in this case report. Subsequently, the pulp cells migrate, attach to HAP crystals, and enable continuation of dentinogenesis with other biomolecules. In this article, two maxillary central incisors in a seven-year-old female patient with immature roots and complicated crown fracture were treated successfully using white MTA after cervical vital pulpotomy. One of the complicating factors in the treatment of immature teeth is how to predict the depth of the inflammatory reaction in the traumatized pulp. Of course, this depends on several factors, the most critical of which is the time interval between the accident and treatment. According to the study by Cvek et al, the inflammatory reaction usually does not extend more than two millimeters from the exposed surface within 48 hours, but after seven days it can go deeper [24].

Therefore, cervical pulpotomy was the most suitable treatment choice in this case with a long interval between the accident and treatment. Recheck examinations at all periodic follow-ups revealed that the treatment was successful in preserving pulpal vitality and continuation of root development in teeth. However, both teeth showed crown discoloration as reported in some other studies [20,22]. This was likely due to a probable chemical reaction between the white MTA and blood products or pulp tissue fluid [19-22].

In this case, bleaching was postponed until the formation of a hard tissue bridge and confidence of successful maturogenesis. Ultimately, after one year and complete maturogenesis, the teeth color was returned to normal with four bleaching sessions, and was maintained during the long-term follow-up. In the literature, there is controversy concerning whether root canal treatment is necessary after successful maturogenesis. Some authors believe that severe calcification probably occurs over a long time; thus, they advocate that it would be better to perform conventional root canal therapy after complete root formation and natural apical constriction [49]. Conversely, other studies report that there are no histological data based on pathological changes; thus, they emphasize that root canal treatment in traumatized cases should be based on specific findings such as necrosis, infection, apical periodontitis and internal/external pathological root changes, not just pulp canal obliteration [50]. In the current case, the teeth did not show any radiographic or clinical pathological changes; therefore, we did not perform root canal therapy. In conclusion, this case report showed that successful maturogenesis can occur with long-term treatment of fractured crowns complicated with vital pulp exposure and incomplete root formation using white MTA in the absence of pathological changes in the pulp and periapical tissues. In addition, endodontic treatment can be postponed until evidence of pathological changes is observed.

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