

Fracture resistance of simulated immature teeth after apexification with calcium silicate-based materials

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ABSTRACT

Objective: To compare the fracture resistance of simulated immature teeth filled with an apical barrier of mineral trioxide aggregate (MTA), Biodentine, and calcium-enriched mixture (CEM). **Materials and Methods:** Fifty-two single-rooted human maxillary central incisors were used. For standardization, the teeth were sectioned 6 mm above and 9 mm below the cemento-enamel junction to simulate immature apex. Simulations of roots into immature apices were carried out using 1.5 mm diameter drills. The specimens were then randomly divided into three experimental groups ($n = 13$) and one control group ($n = 13$). In experimental groups, MTA, Biodentine, and CEM were placed to apical 4 mm of the simulated immature roots. The samples were stored at 37°C and 100% humidity for 1 week. A load was applied on the crown of all teeth at 135° to their long axis until fracture. The data were analyzed using one-way analysis of variance and Tukey *post-hoc* tests. **Results:** No statistically significant differences were found among MTA, CEM, and Biodentine ($P > 0.05$), and these groups demonstrated higher fracture resistance than control group ($P < 0.05$). **Conclusions:** Using any of the MTA, Biodentine, and CEM as an apical plug and restoring with fiber post and composite resin increases the fracture resistance of immature teeth.

Key words: Biodentine, calcium-enriched mixture, immature teeth, mineral trioxide aggregate, vertical root fracture

INTRODUCTION

Traumatic dental injuries are most frequent in young and adolescent age, and the maxillary central incisors are mostly affected by resulting pulp necrosis.^[1] If the root development of these teeth is incomplete, the clinician should consider apexification treatment.^[2] The treatment of immature teeth is a challenge due to the weak dentinal walls and has a high incidence of root fracture.^[3,4]

Numerous materials have been recommended for the apexification of immature teeth up to date. Calcium hydroxide (CH) has been used for the induction of an apical barrier in immature teeth due to the high pH and antimicrobial activity for years.^[5,6] However, CH has some disadvantages; the CH treatment may extend up to 1 year and this may decrease the fracture

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resistance of immature teeth due to the long-term CH treatment.^[7] In addition, CH changes the organic matrix of the dentin and this may increase susceptibility to root fracture.^[4,8] Mineral trioxide aggregate (MTA) is recommended as an alternative material to CH for the induction of apical barrier of immature teeth.^[9,10] MTA contains tricalcium aluminate, dicalcium silicate, tricalcium silicate, tetracalcium aluminoferrite, and bismuth oxide.^[11] MTA is a biocompatible material and has low solubility capacity, ability to set in a wet environment and presence of blood.^[12,13] However, it has some disadvantages such as difficulty of handling, long setting time,^[14] and has an effect on the fracture resistance of immature teeth after exposure more than 5 weeks.^[15] A variety of new calcium silicate-based materials have been developed recently to overcome the shortcomings of MTA. One of these materials is Biodentine, which contains tricalcium silicate, calcium carbonate, and zirconium oxide. Biodentine is a biocompatible material, has good sealing ability, high compressive strength, short setting time, and biomineralization properties.^[16,17] Another calcium silicate-based material is calcium-enriched mixture (CEM), which is a new material that contains various calcium combinations, including oxide sulfate, phosphate, carbonate, silicate, hydroxide, and chloride compounds. CEM has a shorter setting time, lower viscosity, and less film thickness compared to MTA.^[18,19]

Endodontically treated immature teeth are more susceptible to root fracture than mature teeth because of it has thin dentinal walls.^[20-22] White *et al.* stated that MTA reduced the fracture resistance of the bovine dentin by 33%.^[15] Few studies in the literature have evaluated the fracture resistance of MTA-based materials.^[15,20] MTA is the preferred product on the market, whereas Biodentine and CEM are new materials. No *in vitro* study in literature could be found that evaluated the effect on root fracture of immature teeth after apexification with Biodentine and CEM. The aim of this study was to evaluate and compare the fracture resistance of simulated immature teeth after using MTA, Biodentine, and CEM as an apical plug.

MATERIALS AND METHODS

The study was approved by the Institutional Review Board of Şifa University (Protocol number 211-58), Izmir, Turkey. Fifty-two extracted, intact, human maxillary central incisors with single root and straight root canals were selected and stored in distilled water. For standardization, the teeth were sectioned 6 mm

above and 9 mm below the cemento-enamel junction using a diamond-coated bur under water cooling. The teeth were examined with a stereomicroscope under $\times 10$ magnification (Zeiss, Oberkochen, Germany) to exclude any roots with open apices, root caries, cracks, or fractures. The buccolingual (BL) and mesiodistal (MD) dimensions of the root canals were measured using a digital caliper (Teknikel, Istanbul, Turkey). The weights of the roots were measured with a sensitive precision balance (Kern, Balingen, Germany). We equally splitted the roots to each group in an active sense based on their weights and the homogeneity of the groups. The roots were distributed into three experimental groups and one control group ($n = 13$). Then, the root canals were shaped with ProTaper Universal rotary files (Dentsply, Ballaigues, Switzerland) up to F5 size. Simulation of roots into immature apices was carried out using size 4 green 1.5 mm diameter UniCore[®] postdrills (Ultradent Products, Inc., USA). The smear layer was removed using 3 ml 17% ethylenediaminetetraacetic acid followed by 3 ml 5.25% NaOCl and 5 ml distilled water.

Group 1: The method followed was a modification of the technique described previously by Brito-Júnior *et al.*^[23] White MTA mixed at a powder to liquid ratio of 3:1, MTA (Angelus, Londrina, PR, Brazil-M24929) was placed into the simulated immature roots and condensed with a hand plugger as a 4-mm apical plug. The apical height, homogeneity, and the thickness of apical plug were confirmed with radiograph [Figure 1]. The samples were stored at 37°C and 100% humidity for 1 week. The glass-fiber post UniCore[®] size 4 (Ultradent Products, Inc., USA) was cemented into the root canals with a self-adhesive resin cement (Bifix SE; Voco, Cuxhaven, Germany). The mixed resin

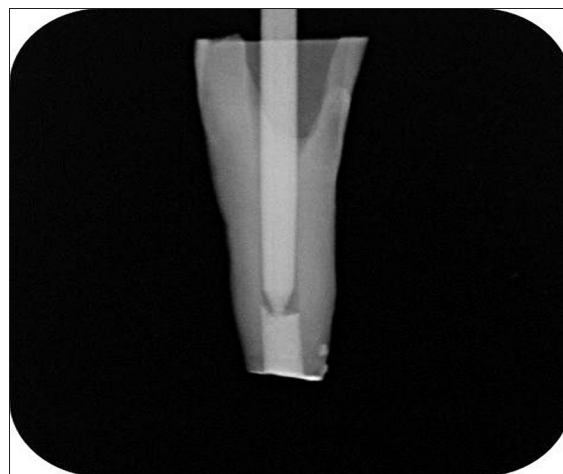


Figure 1: The apical height, homogeneity, and the thickness of mineral trioxide aggregate plug

cement was placed into the root canal, postinserted and cured with light for 20 s [Figure 2]. The fiber post was sectioned 3 mm above the cemento-enamel junction and the remaining space was filled with a Grandio SO (Voco GmbH, Cuxhaven, Germany) composite resin and cured with light for 40 s.

Group 2: Five doses of liquid and powder of Biodentine (Septodont, Saint-Maur-des-Fosses Cedex, France-B08889) was supplied for 30 s. With a mixed amalgamator, a 4-mm apical plug with Biodentine was placed into the simulated immature roots and condensed with hand plugger. And then, the same method of Group 1 was done for this group.

Group 3: The powder with the liquid of CEM (Yektazist Dandan, Tehran, Iran-C100501) was mixed for 15–30 s, and a 4-mm apical plug with CEM was placed into the simulated immature roots and condensed with hand plugger. And then, the same method of Group 1 was done for this group.

Group 4 (control): The apical roots of 4 mm were not filled with any of the MTA, Biodentine, and CEM. And then, the same method for postplacement procedure was applied as in the Group 1 for this group.

Periodontal ligament simulation

Periodontal ligament (PDL) simulation of the teeth was performed by the method described by Soares *et al.*^[24] The teeth were immersed in wax with 0.2–0.3 mm thickness and 2.0 mm below the cemento-enamel junction. Then, the teeth were embedded with 45° angled perpendicularly to the surface of self-cured acrylic resin blocks (Imicryl, Konya, Turkey) with dimensions of 25 mm high and 10 mm in diameter. After polymerization, the teeth

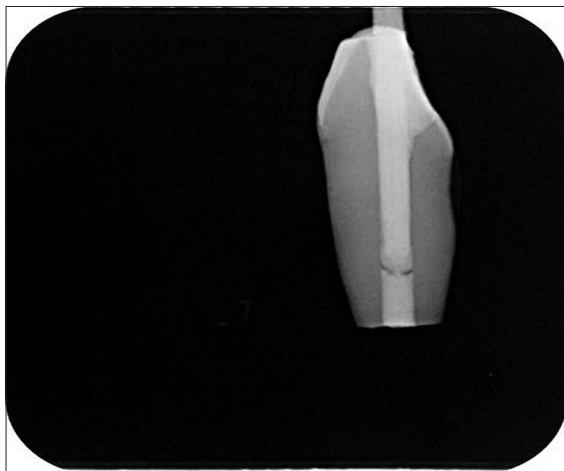


Figure 2: Mineral trioxide aggregate plug and backfilled with fiber post and composite resin

were removed from the resin blocks; the wax was removed from root surface using warm water. The resin cylinders were filled with C-type silicone-based impression material (Zeta Plus, Zhermack, Badia Polesine Rovigo, Italy) and the teeth were inserted again into the resin blocks and excess impression material was removed. The roots were kept wet with a wet towel to prevent dehydration until they were ready for fracture testing.

Fracture strength test

The universal testing machine (Shimadzu Corporation, Kyoto, Japan) was used at a speed of 1 mm/min and a load was applied on the crown of all teeth at 135° to their long axis until fracture [Figure 3]. The values measured at the moment of fracture were recorded in Newton.

Statistical analysis

The SPSS v11.5 (IBM, Chicago, IL, USA) software was used for statistical analysis. The BL and MD dimensions and weights were subjected to Kolmogorov–Smirnov statistical test to test the normality of these continuous variables. One-way analysis of variance test was used to evaluate the difference among the BL and MD dimensions and the weight of the samples. After completing the fracture test, the data were subjected to statistical analysis using one-way analysis of variance with Tukey *post-hoc* test for multiple comparisons. The testing was performed at the 95% level of confidence ($P < 0.05$).

RESULTS

The statistical analysis approved the standardization of roots among the groups according to weight, BL, and MD diameter.

All the roots were fractured vertically that extended along the long axis of the root or fractures occurred



Figure 3: The universal testing machine

in postmaterial conjunction [Table 1]. The mean, standard deviation, minimum, and maximum values of the groups were shown in Table 2. Statistically significant difference was found among the groups. According to the results of the present study, no statistically significant difference was found among MTA, CEM, and Biodentine ($P > 0.05$), and these groups demonstrated higher fracture resistance than control group ($P < 0.05$).

DISCUSSION

Standardization is an important factor in evaluating the fracture resistance of immature teeth. In the present study, BL, MD dimensions, and weights of the teeth were measured and no significant differences were found among groups. PDL is an important factor in the distribution of the stress in the root canals, and the fracture modes might be affected by the type of PDL simulation.^[24] In the present study, the simulation of the PDL was performed using silicone-based impression material.

Immature teeth have a risk for root fracture because of it has weakened dentinal walls in root canals.^[20-22] It has been suggested that using adhesive materials for filling immature root canals could improve the fracture resistance.^[25,26] In addition, in another study, it has been suggested that using MTA for apical plug of the immature root canals and restoring with fiber post increases the fracture resistance of immature teeth^[23] because elastic moduli of the fiber posts are similar with dentin and they can distribute loads in root canals by reducing the stress concentrations in root canals.^[23] In the present study, we used MTA, Biodentine, and CEM for apical plug and fiber posts

and composite resin for the restoration of immature teeth.

It has been reported that MTA increases the fracture resistance of teeth compared with CH.^[20,27] Using MTA as a root canal filling material in immature teeth is an excellent choice due to its mechanical and biological properties.^[2] Bortoluzzi *et al.*^[2] stated in their study when MTA was used as apical plug and teeth restored with metallic posts, the fracture resistance of the teeth was four times higher than that of empty roots. According to the results of the present study, using MTA, Biodentine, or CEM as apical plug and teeth having restored with fiber posts, the fracture resistance of immature teeth was improved compared with control group. Control group had the lowest fracture strength among the groups. Using an apical plug with any of the MTA, Biodentine, and CEM has a major role to improve the fracture resistance of immature teeth.

Brito-Júnior *et al.*^[23] evaluated the fracture resistance and stress distribution of simulated immature teeth after apexification with MTA and found that the teeth restored without fiber posts were more prone to root fracture in the cervical and middle thirds of the roots due to the stress concentration in these areas. They^[23] stated that fiber posts were able to improve fracture resistance and stress distribution of immature teeth after apexification with MTA. In addition, according to the results of the present study, using any of the calcium silicate-based material and restoring immature teeth with fiber posts increased the fracture resistance which is similar to a study by Bortoluzzi *et al.*^[2] and Brito-Júnior *et al.*^[23]

The initial setting time of Biodentine was 9–12 min and final setting time was 45 min.^[28] However, the setting time of MTA was 165 ± 5 min, which is a major drawback for MTA.^[12,29] The initial setting time of CEM was 40 min and final setting time was 140 min,^[30] which is longer than Biodentine. In addition, El-Ma'aïta *et al.*^[31] stated that particles of Biodentine are smaller than MTA and this provides Biodentine a better penetration capacity to dentine tubules. The differences between the setting time of the root and filling materials have a clinical significance.^[30] According to the results of the present study, although there was no statistically significant difference among MTA, CEM, and Biodentine, the setting time and particle size gain an advantage to Biodentine compared with CEM and MTA. We might say that Biodentine is a good material for an apical plug in the apexification treatment of immature teeth due to good physical properties.

Table 1: Fracture modes detected in all groups

Group	Vertical	Postmaterial conjunction	Total
MTA	7	6	13
CEM	6	7	13
Biodentine	9	3	13
Control	13	0	13

CEM: Calcium-enriched mixture, MTA: Mineral trioxide aggregate

Table 2: The mean, standard deviation, minimum, and maximum values of the groups

Group	n	Mean	SD	Minimum	Maximum	Significance*
MTA	13	1238.58	142.16	911.00	1480.00	a
Biodentine	13	1130.61	223.46	867.00	1460.00	a
CEM	13	1309.46	177.65	911.00	1676.00	a
Control	13	459.50	169.23	247.39	790.29	b

CEM: Calcium-enriched mixture, MTA: Mineral trioxide aggregate, SD: Standard deviation

CONCLUSION

Within the limits of this study, it can be concluded that in the treatment of simulated immature teeth with open apices, using any of the MTA, Biodentine, and CEM as an apical plug and restoring with fiber post and composite resin increases the fracture resistance of immature teeth.

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Conflicts of interest

There are no conflicts of interest.

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