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Fracture resistance of immature teeth filled with BioAggregate, mineral trioxide aggregate and calcium hydroxide

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Abstract – *Background*: The aim of this *in vitro* study was to assess the long-term fracture resistance of human immature permanent teeth filled with BioAggregate (BA), mineral trioxide aggregate (MTA) and calcium hydroxide (CH). *Materials and methods*: The study consisted of single rooted premolar teeth with immature root formation extracted for orthodontic reasons. A total of 28 immature premolars with average root length of 10.7 mm and apical diameter of 3 mm were included in the study. The pulps were extirpated and the canals were prepared using an apical approach. The teeth were randomly assigned to four groups: Group I: DiaRoot® BA (DiaDent, Burnaby, BC, Canada), Group II: Angelus MTA (MTA-A; Angelus, Londrina, Brazil), Group III: ProRoot® MTA (MTA-PR; Dentsply, Tulsa, OK, USA), Group IV: CH (Sultan Chemists Inc., Englewood, NJ, USA). The teeth were placed in saline solution at 4°C for 1 year. The root of each tooth was then embedded in an acrylic resin block. All specimens were loaded at a crosshead speed of 1 mm min^{-1} in an Instron testing machine and the peak loads up to fracture were recorded. Data were analysed statistically by Kruskal–Wallis and Mann–Whitney *U*-tests. *Results*: Mean ($\pm$SD) failure loads (MPa) were: 37.69 $\pm$ 14.43 for BA group, 32.94 $\pm$ 8.15 for MTA-A group, 28.74 $\pm$ 9.49 for MTA-PR group and 23.18 $\pm$ 8.48 for CH group. The BA group exhibited the highest fracture resistance and the CH group showed the lowest resistance to fracture. Significant differences ($P < 0.05$) in fracture resistance were found between the DiaRoot-BA and CH groups, and also between the MTA-A and CH groups. *Conclusion*: Within the limitations of this study, data suggest that DiaRoot-BA-filled immature teeth demonstrate higher fracture resistance than other groups at 1 year. Considering the long-term risk of cervical root fracture associated with immature teeth, the use of DiaRoot-BA as a root canal filling material appears to be the most advantageous of the materials tested.

Traumatic dental injuries in young and adolescent age groups result from falls, accidents, violent acts and varied sport activities (1). Previous studies indicate that the most common site of dental impact injuries in the developing dentition is the maxillary anterior teeth (1–3). These injuries often result in pulpal necrosis, which might cause the termination of root formation in developing teeth (3–5). It has been stated that the endodontically treated immature teeth have a relatively high incidence (>60%) of cervical root fracture, either spontaneously or due to minor impacts (6).

The endodontic treatment of teeth with immature root formation has been a challenge due to wide, open apices and thin dentinal walls (3, 7). Numerous procedures and materials have been recommended to induce apexification in teeth with immature apexes (8). Calcium hydroxide (CH) treatment has shown adequate apical healing by means of the induction of an apical barrier and the agent's antibacterial capability, caused by a high pH (7, 9, 10). Management of open apexes in immature teeth has been accomplished using long-term CH therapy, with success rates ranging from 79% to 96% (11, 12). However, these teeth showed a 50% reduction in strength vs the controls over 1 year (7), and were compromised by cervical root fractures (6, 13) because of changes in the organic matrix of the dentin.

Mineral trioxide aggregate (MTA), which has a good root sealing ability and a high degree of biocompatibility, has been demonstrated to have good potential as an aid in the formation of apical hard tissue (14). This material consists of tricalcium oxide and other mineral oxides (15) and shows an alkaline reaction in aqueous slurries (pH >11). It has been highly recommended for the apical retrograde root filling (16), apexification (17, 18) and pulp capping (18). MTA's suitability as a

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material for use in immature teeth in which root development was interrupted due to pulp necrosis has been investigated, and it has been reported that MTA promotes apical closure at a rate equal to that seen with CH (14). The studies have exhibited, however, that tooth strength is weakened after exposure to MTA for more than 5 weeks (19).

Structural strengthening of non-vital immature teeth has received a great deal of attention for many years, and different materials and techniques have been examined in this respect (13, 20, 21). Wilkinson et al. (3) reported that the incidence of cervical root fracture might decrease when immature teeth are reinforced by means of procedures that require less time. Hemalatha et al. (1) showed that gutta-percha and resilon reinforcement exhibited increased resistance to root fracture in simulated immature teeth. Furthermore, several studies recommend the use of posts and light-curing composite resin systems (4, 20) or resin glass ionomer systems (22) to reinforce immature teeth.

Recently, BioAggregate (BA) materials have been introduced and used for retrograde root filling, perforation repair, vital pulp therapy and induction of apical closure in incompletely developed teeth. Most of the constituents are similar to those in MTA (23). Despite achieving relative success when using materials such as MTA and CH to treat teeth with immature apexes, the high incidence rate of cervical root fracture drives a continuing search for materials with even safer and more effective biological and mechanical properties.

MTA and CH are still widely used for apexification in immature teeth for long-term treatment in clinics. As there is limited information in the dental literature concerning the evaluation of the effect of root filling materials on fracture strength of immature teeth, the present study compares the long-term fracture resistance of immature teeth filled with BA and with CH.

Materials and methods

Tooth selection

The study consisted of single rooted premolar teeth with immature root formation, which had been extracted for orthodontic reasons in children approximately 11 years of age. All teeth were radiographed for the lateral and facial views and measured for root length and diameter. Teeth were selected according to the Cvek's root development stage III (6). A total of 28 immature teeth with average root length of 10.7 mm, as measured from the facial cemento-enamel junction (CEJ), and apex diameter of 3 mm were involved in the study.

Treatment procedures

The pulps of all teeth were extirpated with broaches, using an apical approach. The root canals were prepared by a #45 Hedström file (Maillefer, Detroit, MI, USA) and irrigated with a 6% solution of sodium hypochlorite (Tulsa Dentsply, Tulsa, OK, USA). The canals of the teeth were filled with the root canal filling materials according to the manufacturers' instructions.

The teeth were randomly assigned to four groups of seven teeth each (Table 1).

Group I (DiaRoot-BA): The canals were filled with DiaRoot® BA system (DiaDent Group International, Canada). 0.5 g of BA powder was mixed with liquid included in the package according to the manufacturer's instructions. The teeth were filled from the apical foramen using lentulo and pluggers.

Group II [Angelus MTA (MTA-A)]: The gray MTA Angelus™ (Angelus, Londrina, Brazil) was inserted into the root canal from the apex, using a lentulo spiral (Dentsply Mailifer, Ballaigues, Switzerland) and then condensed using pluggers.

Group III [ProRoot MTA (MTA-PR)]: The root canal was filled with ProRoot® MTA tooth-colored formula (White MTA; Dentsply, USA). The paste was carried to the coronal part of the pulp cavity using a lentulo spiral (Dentsply Mailifer) and condensed using pluggers.

Group IV (CH): The canals of the teeth were filled with a CH paste which was prepared by mixing $Ca(OH)_2$ (Sultan Chemists Inc., Englewood, NJ, USA) powder with normal saline. The paste was placed from the apical foramen into the root canal with a lentulo spiral. The CH group was used as a control.

In all teeth, apical access was sealed with 2 mm of zinc oxide eugenol cement (IRM; Dentsply, Konstanz, Germany). All teeth were radiographed (Fig. 1a and b) after the treatments. The teeth were placed in saline solution for 12 months and stored in a deep freezer (4°C) until tested for fracture resistance. The saline was exchanged for a fresh solution every 2 weeks.

Table 1. Composition of the root canal filling materials used in the study

Material	Company	Major chemical compounds
BioAggregate	DiaDent Group International, Canada	Tricalcium silicate, Dicalcium silicate, Tantalum pentoxide, Calcium phosphate monobasic, Amorphous silicon oxide
MTA Angelus	Angelus, Londrina, Brazil	Tricalcium silicate, Dicalcium Silicate, Tricalcium Aluminate, Tetracalcium Aluminoferrite, Bismuth Oxide
ProRoot® MTA	Dentsply, USA	Tricalcium silicate, Bismuth oxide, Dicalcium silicate, Tricalcium aluminate, Calcium sulfate dehydrate or Gypsum.
Calcium hydroxide	Sultan Chemists Inc., Englewood, NJ, USA	100% Calcium hydroxide

MTA, mineral trioxide aggregate.

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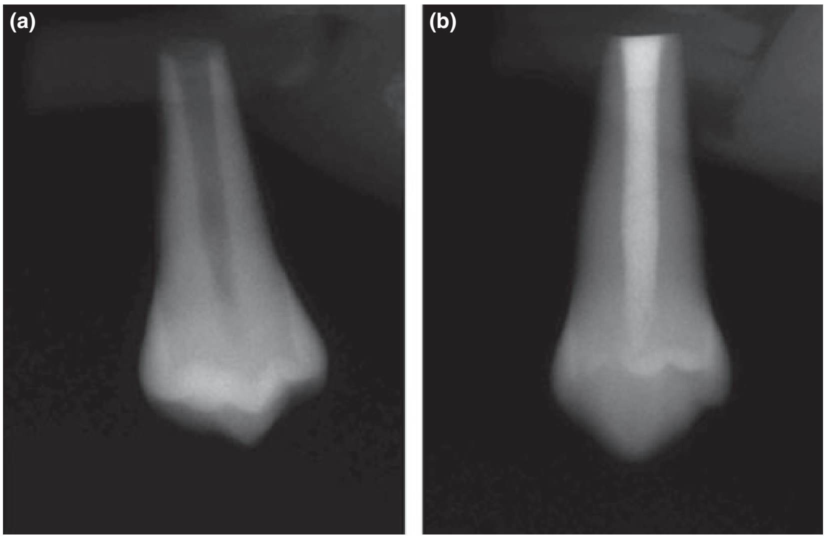

Fig. 1. Frontal views of the immature premolar teeth before (a) and after (b) root filling.

Fracture testing

The root of each tooth was embedded in self-curing orthodontic resin blocks (Dentsply, USA) with dimensions 27 × 15 × 13 mm. The long axis of each tooth was aligned with the central axis of the acrylic resin block. The roots were submerged in acrylic resin until there was a 2 mm gap between the CEJ and the top of resin. This gap, as suggested by Wilkinson et al. (3), simulates the spacing found between the bone crest and the CEJ.

Each specimen was mounted in an Instron universal testing machine (Instron, AG-IS, Shimadzu, Japan). The spade was placed on the facial surface of the teeth, perpendicularly to the long axis of the tooth and parallel to the incisal edge at a point 3 mm above the CEJ (Fig. 2). The samples were loaded at a crosshead speed of 1 mm min^{-1}. Peak shear fracture loads were recorded in *N* and the fracture strength (force/area) was calculated in MPa.

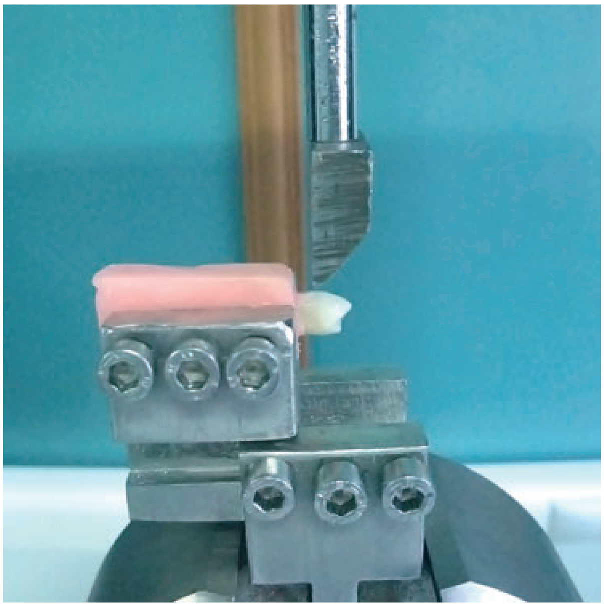

Fig. 2. An Instron universal testing machine applied compression force at a point 3 mm from the CEJ and parallel to the long axis.

Statistical analysis

The mean and standard deviation (SD) for each group were calculated. The findings were analysed statistically using a Kruskal–Wallis test to detect any intergroup differences, and by means of the Mann–Whitney *U*-test to evaluate comparisons at a 5% level of significance.

Results

Table 2 shows the mean fracture strengths and SD obtained in the groups. The mean fracture strength for groups of BA, MTA-A, MTA-PR and CH was measured as 37.69, 32.94, 28.74 and 23.18 MPa respectively. All specimens showed either oblique or horizontal fractures through the cervical area of the root.

The results of the Kruskal–Wallis analysis of variance test exhibited a significant difference ($P = 0.042$) in failure loads among all tested groups. The BA group exhibited the highest fracture resistance, followed by MTA-A, MTA-PR and CH in descending orders. Significant differences ($P < 0.05$) in fracture strength were found between the groups of BA and CH and groups of MTA-A and CH. The Mann–Whitney *U*-test revealed no other significant differences ($P > 0.05$) between the other groups (Table 2).

Discussion

Although endodontic treatment of the immature apex is manageable, the thin dentinal walls, particularly in the cervical area, are susceptible to fracture (4, 20). The frequency of cervical root fracture in immature teeth has been stated to range from 2% in a 11-year-old to 77% in a 6-year old (6). It has been reported that root canal fillings with CH will lead to the weakening of endodontically treated teeth, and this finding can contribute to the change in the organic matrix of dentin (7, 24, 25).

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Table 2. Mean fracture strengths (MPa) at 1-year period of teeth treated with BA, MTA-A, MTA-PR or CH, and intergroup comparison of difference in fracture strength

Groups	Fracture strength Mean ± SD	Median	$P^{\dagger}$
1BA	37.69 ± 14.43	30.9	0.042*
2MTA-A	32.94 ± 8.15	28.5	
3MTA-PR	28.74 ± 9.49	28.4	
4CH	23.18 ± 8.4	21.6	
1–2‡*P*	0.480		
1–3‡*P*	0.225		
1–4‡*P*	0.018*		
2–3‡*P*	0.482		
2–4‡*P*	0.013*		
3–4‡*P*	0.180		

*$P < 0.05$.
BA, BioAggregate; MTA-A, Angelus mineral trioxide aggregate; MTA-PR, ProRoot MTA; CH, calcium hydroxide.
†Kruskal–Wallis test.
‡Mann–Whitney *U*-test.

While short-term CH use is acceptable for disinfecting necrotic root canals, its long-term use (>60 days) has been shown to have a negative impact on the fracture resistance of immature teeth (26).

Many previous studies analysing the fracture resistance of teeth and the long-term effect of endodontic materials have utilized bovine or sheep teeth (26, 27), or simulated human teeth and bovine femur samples (13). Due to the large differences in shape and structure of teeth, the standardization is not possible and these variabilities in the study designs do not provide consistent results (13). Furthermore, it was observed that the effects of the endodontic materials on fracture resistance of human immature teeth have thus far not been studied. For these reasons, in this study, the long-term effects of the root canal filling materials – BA, two different MTA materials and CH – on root fracture resistance were assessed in human immature premolars with similar diameters and length.

BA is a relatively new product and its clinical applications include apexification, repair of root perforation and resorption, and vital pulp therapy (23). BA contains several mixed synthetic components: calcium silicate hydrate, CH, hydroxyapatite, tantalum oxide and amorphous silicon oxide. The manufacturing company claims that BA is free of aluminum (23) and therefore its toxic effect on human body is minimized. This remains to be evaluated by further research. Cheuk et al. stated that study findings showed the biomineralizing ability of BA to be high. Furthermore, BA and MTA-PR have shown similar biomineralizing characteristics and Ca release concentration data. The precipitates from the materials were similar in that they containe Ca, P, and O, and carbonated hydroxyapatite (28). Since BA has been only recently been made available, the clinical use has not been studied.

The results of this *in-vitro* study showed that CH placed in the root canal had significantly more negative long-term effects on the fracture susceptibility of the root than did BA and MTA-A. This finding is consistent with the results of some other studies (9, 14, 20). Andreasen et al. reported that CH may increase the risk of fracture over the long-term and indicated that pH changes in dentin were observed after CH treatment. The reduced root strength seen in CH-treated root canals over time might be explained by weakened dentin, which could be caused by denaturation and hydrolysis taking place in the organic matrix (7). Dentinal strength is determined by the link between hydroxyapatite and collagenous fibrils. Due to its strong alkalinity, CH may denature the carboxylate and phosphate groups, leading to a collapse in the dentin structure (13, 25). This proteolytic reaction may influence the mechanical properties of dentin (7).

MTA is an alternative material that should be considered when planning treatment for teeth that have immature apexes. MTA provides a seal against microleakage, and creates an apical barrier in the treatment of teeth that have an immature apex. White et al. reported that MTA and sodium hypochlorite reduce the fracture susceptibility of bovine dentin by 33% and 59% respectively compared to the control group. These results show the possible reduction in the number of fractures of bovine dentin filled with MTA (19). Andreasen et al. (26) reported that MTA strengthens the cervical fracture resistance of immature sheep incisors more effectively than CH. Recently, Kofman et al. also compared the influence of MTA and CH on fracture resistance in sheep teeth, and stated that over a 1-year period, MTA and CH have showed a 2% and 26% decrease in fracture resistance respectively. Authors reported that after the initial decrease in the fracture resistance of MTA-treated teeth, the process is reversed, and fracture resistance increases for a period between 2 months and 1 year. It was thought that this inhibition of destruction in dentin could be related to a change in the organic matrix of dentin as a result of a biological interaction between MTA and dentin over the period of a year (27).

Endodontically treated teeth with incomplete root formation are susceptible to root fractures. This present *in vitro* study provides evidence that BA-filled immature teeth showed the highest fracture resistance at 1 year, and that BA can be considered a promising material. Also, MTA-A and MTA-PR systems have an important strengthening effect on fracture resistance when compared with CH. Both MTA groups showed more resistance to fracture after long-term treatment than CH in immature human teeth. As MTA-A and MTA-PR are compositionally slightly different, significantly higher fracture resistance between MTA and CH groups has been observed only with MTA-A. The findings of this study confirm that both BA and MTA perform better than CH when considering the long-term risk of cervical root fractures in immature teeth. Therefore, traditional use of CH in long-term apexification treatment is to be re-evaluated. Furthermore, long-term studies in immature human teeth are needed to clinically assess the BA material.

Conclusion

The present study demonstrated that the BA-filled immature teeth showed the highest fracture resistance

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at 1 year. In addition, it was shown that long-term use of CH dressing in the root canal weakened root structure more than did BA and MTA; a MTA-A-treated immature teeth exhibited higher fracture resistance than MTA-PR. Concerning the long-term risk of cervical root fracture, it seems that DiaRoot-BA could be a promising material for the endodontic treatment of teeth with immature apexes.

Conflict of interest

The authors have no financial interest in any manner with the products, materials, or suppliers used in this article.

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