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Comparison of the fracture resistance of simulated immature permanent teeth using various canal filling materials and fiber posts

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Abstract – *Background*: The purpose of this study was to compare the fracture resistances of immature teeth treated with MTA along with root canal obturation methods using AH Plus, MetaSEAL, MTA Fillapex sealers + lateral compaction technique, and Unicore quartz fiber posts. *Materials and methods*: Fifty single-rooted maxillary anterior teeth were divided into five groups. The crowns were dissected and root canals were enlarged. #6 Peeso reamers were allowed to protrude 1 mm. beyond the apex to simulate immature teeth. The apical 4–5 mm of each tooth was filled using Angelus white MTA. The remaining portions of canals were obturated as follows: Group 1: No backfilling (control), Group 2: AH Plus + gutta-percha, lateral compaction, Group 3: MetaSEAL + gutta-percha, lateral compaction, Group 4: MTA Fillapex + gutta-percha, lateral compaction, Group 5: UniCore Fiber posts luted using PermaFlo DC. The specimens were embedded into self-curing acrylic poured into identical cylinders which were mounted on a jig providing a 45° angle. A compressive load increasing at 1 mm min^{-1} was applied and the maximum load at which fracture occurred was recorded. Statistical analysis was performed using Kruskal–Wallis and Dunn's multiple tests. *Results*: The highest fracture resistance was obtained with Group 5 (Fiber posts) whereas Group 4 (MTA Fillapex) yielded the lowest values. The mean fracture resistance value of Group 2 (AH Plus) was significantly higher than Group 4 (MTA Fillapex) ($P = 0.001$). The mean fracture value of Group 5 (Fiber posts) was significantly higher than Group 2 (AH Plus), Group 3 (MetaSEAL), and Group 4 (MTA Fillapex) ($P = 0.02$, 0.004, and 0.0001, respectively). *Conclusion*: Within the limitations of this study, UniCore quartz fiber posts provided the highest resistance. This methodology may specifically be advantageous for teeth with arrest of development at early stages, as these teeth are more susceptible to fracture owing to their excessively weak dentinal walls.

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Preservation of teeth whose apical development has been arrested owing to certain situations is a very important issue in dentistry. In earlier years of life, extraction and implant supported crowns and fixed prosthesis may not be feasible treatment options owing to the ongoing craniofacial growth process (1). Meanwhile, it has been indicated that missing, fractured, and esthetically poor anterior teeth or restorations may exert adverse effects on nutrition and may even compromise the individual's psychology and personality development (1). Thus, the practitioner must spend utmost effort to preserve teeth with interrupted root development and keep them as esthetic and functional integrities of the masticatory system.

In case the pulps of immature teeth are non-vital, the necessity of an endodontic intervention arises. On the other hand, endodontic treatment of immature teeth frequently poses a significant challenge for the practitioner owing to open apices and thin remaining dentinal walls which predispose teeth to fracture easily (2, 3). Application of calcium hydroxide to the root canal system to promote the formation of an apical barrier is the conventional treatment in these clinical situations. This procedure may extend to a period as long as 18 months with the requirement of regular change of intracanal calcium hydroxide medication until the formation of the apical hard tissue is confirmed (4). On the other hand, the necessity of continuing this process for a prolonged period may have some drawbacks. It has been shown that long-term exposure of root dentine to calcium hydroxide may adversely affect the dentinal collagen, resulting in a decrease in fracture resistance (4). Moreover, it may be difficult to provide regular patient attendance in the prolonged treatment period, during which the dislodgement of the temporary filling material and subsequent recontamination are quite likely. It has also been emphasized that it is rather common for the patient to sustain another injury and fracture the root before the hard tissue barrier is formed owing to the already compromised hard tissue structure (5). Cvek (6) has reported that cervical fracture is most common among immature teeth with long-term calcium treatment with an incidence of 28–77% depending on the stage of root development.

Recently, a new methodology which comprises the apical placement of mineral trioxide aggregate (MTA) and completion of the procedure in a single appointment has been advocated as an alternative treatment option. There are some studies in which this technique has been selected for the apexification process (7–9). Owing to its fast application, MTA has specifically gained attention among clinicians and started to be a popular methodology in the treatment of these clinically challenging cases which may otherwise require a long period to be thoroughly completed. MTA is a recently developed promising material consisting of tricalcium oxide and other mineral oxides such as tricalcium silicate, silicate oxide, and tricalcium oxide. The pH of the material has been determined as 12.5 when set, which is comparable to that of calcium hydroxide (10). MTA's biocompatibility and low cytotoxicity, antimicrobial properties (11) and low microleakage (12), ability to set in the presence of blood or moisture are among the material's additional advantages.

In spite of mineral trioxide aggregate's favorable characteristics, there still exists the necessity of obturating the remaining canal space and provide a reinforcement of the weak structure. It has been stated that studies focusing on the reinforcing effect of different root canal obturation methodologies differ in terms of teeth selection, simulation of open apices, preparation of experimental models, and the direction of force applied during fracture testing (1). Furthermore, there is limited information on the strengthening capacity of novel root canal filling methodologies. Also, although fiber posts have been evaluated in terms of various properties so far, their reinforcing capacity on immature teeth has not been widely elucidated. This implies the necessity to further investigate and highlight this clinically significant issue.

The purpose of this *in vitro* study was to test and compare the fracture resistance of teeth with immature apices treated with apical MTA placement along with various root canal obturation methodologies.

Materials and methods

Ninety-eight freshly extracted maxillary anterior teeth were selected to be utilized in the study. Prior to experimentation, the teeth were observed carefully under magnification to confirm that they were devoid of resorptions, extensive caries, cracks, or deformities. The selected teeth were measured with a digital caliper (Mitutoyo, Hampshire, UK) in the faciolingual and mesiodistal dimensions 2 mm coronal to the cemento-enamel junction and mean values were obtained. After excluding those teeth that showed major deviations from these mean values (approximately more than 20% deviation), 50 teeth were selected for the experimentation. The teeth were assigned into five groups, 10 in each. The first group served as the control.

Preparation of the specimens

Standardization was made with respect to the length of each root by removing the crowns approximately 2 mm coronal to the cemento-enamel junction as well as apical portion with disks to obtain a final length of 13 ± 1 mm for each sample (Fig. 1). Measurements of the samples were made using a digital caliper (Mitutoyo). Then, dental pulps and remnant tissues were removed using barbed broaches. Root canal instrumentation was initiated and the canals were enlarged using K3 rotary files (Sybron Endo, Orange, CA, USA) mounted on a torque-controlled reduction handpiece.

For the simulation of teeth with immature apices, Peeso reamers between #1 and #6 were introduced in the root canals and a #6 Peeso reamer was allowed to protrude 1 mm beyond the apex. The root canals were irrigated using 2 ml of 5.25% sodium hypochlorite after each file and a final flush with 5 ml of 17% EDTA was made to remove the smear layer. Finally, the root canals were flushed with distilled water and dried using paper points (Diadent; Diadent Group, International, Burnaby, BC, Canada). During all the procedures, teeth were kept in moistened gauze.

To simulate clinical conditions, a calcium hydroxide paste (Pulpdent, Watertown, MA, USA) was introduced in the root canals. Then, the root canal accesses were filled using a temporary filling material (Cavit; 3M ESPE, St Paul, MN, USA) and the samples were kept for 7 days at 37°C under 100% humidity.

Following the 7-day incubation period, the temporary filling material was removed from the access cavities, and the previously placed calcium hydroxide paste was removed from the root canals using 5.25% sodium hypochlorite and a final flush with 17% EDTA. A final irrigation was made using distilled water and the root canals were dried with paper points (Diadent; Diadent Group, International).

The method used by Bortoluzzi et al. (13) was chosen for the placement of MTA. White ProRoot MTA (Angelus) was prepared according to the manufacturer's instructions and placed in the root canal using a lentulo

Fig. 1. Standardization of the samples by removing with discs from the coronal and apical portions.

spiral until 2 mm short of the apex. A cotton pellet moistened with distilled water was wrapped around a file and the MTA was condensed until a 4- to 5-mm apical thickness was achieved. The thickness and homogeneity of the MTA plug were radiographically confirmed. The apices of the experimental teeth were covered with a wet cotton pellet and the samples were kept for 12 h at 37°C under 100% humidity for allowing MTA to set completely.

The remaining portions of the root canals were treated in the following manners by the same operator after the placement of MTA:

Group 1 (Control): The remaining portions of the root canals were left unfilled. The orifice of the root canal space was filled with a composite filling material (Filtek Z250; 3M ESPE).

Group 2 (AH Plus + gutta-percha lateral compaction): The remaining root canal space was backfilled using AH Plus sealer (Dentsply, DeTrey, Konstanz, Germany) + gutta-percha (Diadent; Diadent Group International) by the lateral compaction technique. A master cone was dipped in the sealer and introduced in the root canal until the working length. Then, accessory cones were inserted in the same manner and condensed using finger spreaders. Excess material was seared off and condensation was made using a plugger 1 mm below the orifice of the root canal. The orifice of the root canal space was filled with a composite filling material (Filtek Z250; 3M ESPE).

Group 3 (MetaSEAL + gutta-percha lateral compaction): The remaining root canal space was filled using MetaSEAL (Parkell, Farmington, NY, USA) a methacrylate-based obturation system according to the manufacturer's instructions. Initially, a master cone was selected that fits the root canal space. Three drops of liquid and one scoop of powder of the MetaSEAL material were mixed and applied to the root canal. A master cone was dipped in the sealer and introduced in the root canal until the working length. Then, accessory cones were inserted in the same manner and condensed using finger spreaders. Excess material was seared off and condensation was made using a plugger 1 mm below the orifice of the root canal. The orifice of the root canal space was filled with a composite filling material (Filtek Z 250; 3M ESPE).

Group 4 (MTA Fillapex + gutta-percha lateral compaction): Initially, a master cone was selected that fits the root canal space. A self-mixing tip was attached to the syringe of MTA Fillapex (Angelus) sealer. MTA Fillapex was applied to the remaining root canal space using an applicator adapted to the self-mixing tip. A master cone was dipped in the sealer and introduced in the root canal until the working length. Then, accessory cones were inserted in the same manner and condensed using finger spreaders. Excess material was seared off and condensation was made using a plugger 1 mm below the orifice of the root canal. The orifice of the root canal space was filled with a composite filling material (Filtek Z250; 3M ESPE).

Group 5 (Unicore fiber posts): Post spaces were created using #4 Unicore drills (Ultradent, Salt Lake City, CA, USA) in the remaining unfilled portion of the root canal. Surfaces of the posts were cleaned with alcohol and dried with air. The prepared spaces were rinsed using distilled water and dried using paper points. An etching agent containing 35% orthophosphoric acid was applied within the post space for 15 s. Then, a puddle coat of Primer A of PermaFlo® DC (Ultradent) was applied for 10 s as per manufacturer's instructions without drying followed by the application of 2–4 drops of Primer B for 10 s. The entire post space was dried for 10 s using air/water syringe. The intraoral tip was attached to PermaFlo® DC mixing tip, and using even pressure, PermaFlo® DC was delivered from the base of the post space, coronally. A #4 UniCore fiber post (Ultradent) was inserted until the termination of the post space by using finger pressure and excess material was immediately removed. The light curing was performed for 10 s through the post. The protruding coronal portion of the fiber post was trimmed using high-speed handpiece.

The names, manufacturers, and composition of the materials used in the study are summarized in Table 1. Figures 2 and 3 show the radiographic appearances of a representative sample after simulation of an immature tooth and following apical MTA placement and total obturation of the root canal, respectively.

Fracture testing

The specimens were stored in 100% humidity at 37°C until fracture testing. Then, the specimens were perpendicularly embedded in self-curing acrylic resin poured in identically shaped cylinders, leaving a gap of 2 mm between the top of the acrylic and the cemento-enamel

Table 1. Compositions of the filling materials and fiber posts used in the study

Materials	Company	Composition
MTA Angelus	Angelus, Londrina, Brazil	Tricalcium silicate, dicalcium silicate, tricalcium aluminate, tetracalcium aluminoferrite, bismuth oxide
AH Plus	Dentsply, DeTrey, Konstanz, Germany	Paste A: Bisphenol-A epoxy resin, Bisphenol-F epoxy resin, calcium tungstate, zirconium oxide, silica, iron oxide pigments Paste B: Dibenzyldiamine, aminoadamantane, tricyclodecane-diamine, calcium tungstate, zirconium oxide, silica, silicone oil
MetaSEAL	Parkell Inc., Farmington, NY, USA	Liquid: HEMA, 4-META, dimethacrylate Powder: zirconium oxide, silica amorphous, water soluble polymerization initiator
Fillapex	Angelus, Londrina, Brazil	Mineral trioxide aggregate and salicylate resin, bismuth trioxide, natural resin
Permaflo DC	Ultradent, Salt Lake City, UT, USA	Resin: Bis-GMA, benzoyl peroxide, tertiary amine, 92% isopropanol as silane solution
Unicore fiber posts	Ultradent, Salt Lake City, UT, USA	Prestressed quartz fibers embedded in a composite matrix

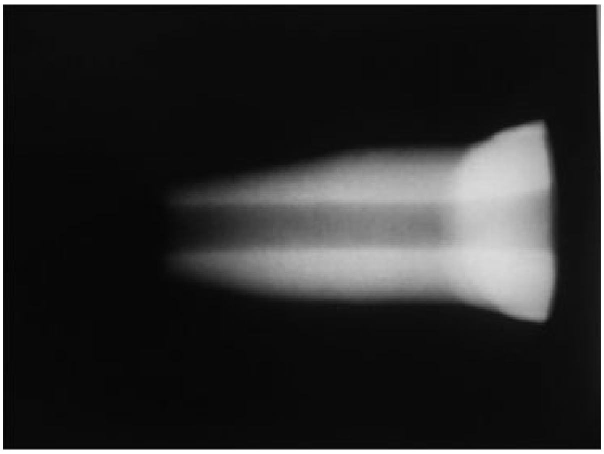

Fig. 2. The radiographic appearance of a representative sample after simulation of an immature tooth.

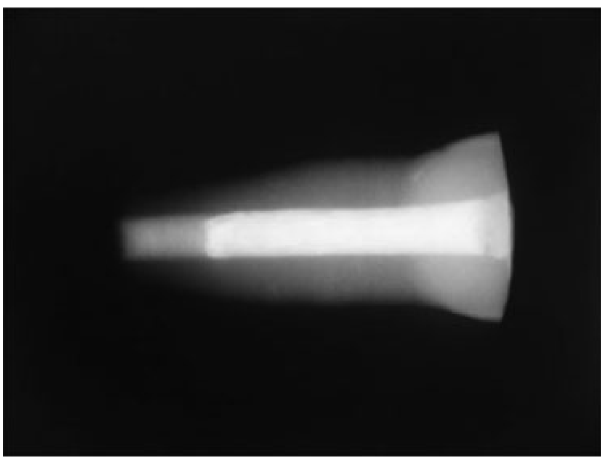

Fig. 3. The radiographic appearance of a representative sample following apical MTA placement and total obturation of the root canal.

junction. This was performed to simulate the relationship between the bone and the tooth. For the fracture testing, a jig as described by de Melo et al. (14) was prepared that allowed the fixation of the cylinders at an angle of 45° (Fig. 4).

A compressive load was applied at a crosshead speed of 1 mm min^{-1} until fracture. Loading was adjusted so that the force was applied from the palatal surface at a point corresponding to the middle of the mesiodistal length of the sectioned surface. The maximum load at which the specimens fractured was recorded in Newtons. Figure 5 schematically represents the setup for the assessment of fracture resistance.

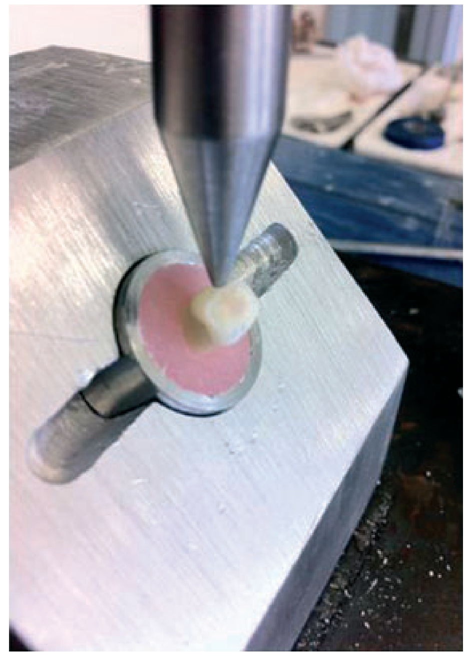

Fig. 4. The specially designed jig allowed the specimens to be fixed with an angle of 45°.

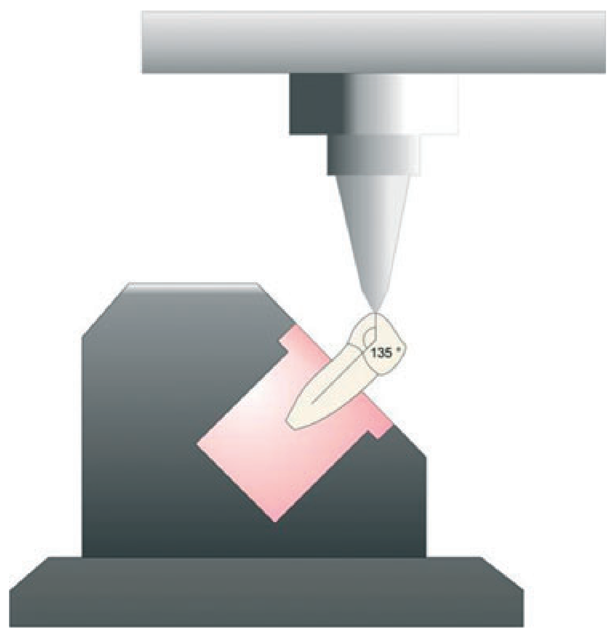

Fig. 5. Schematic representation of the set-up for the assessment of fracture resistance.

Statistical analysis

Statistical analysis was made using the NCSS 2007 pocket program. Apart from definitive statistical methods (mean, standard deviation), Kruskal–Wallis test followed by Dunn's multiple comparison test was used for statistical analysis. The results were evaluated at a 5% significance level.

Results

The mean fracture resistance values and standard deviations obtained for each group and the results of Kruskal–Wallis test are presented in Table 2. The mean fracture strength for the control, AH Plus, MetaSEAL, Fillapex, and fiber post groups were 512.36, 866.38, 763.90, 664.77, and 1091.51 Newtons, respectively.

Table 2. The mean fracture resistance values in Newtons and standard deviations of all groups tested and results of Kruskal–Wallis test

Groups	Mean (SD)	Median
Group 1 (Control)	512.36 (153.45)	550.65
Group 2 (AH Plus)	866.38 (79.17)	892.35
Group 3 (MetaSEAL)	763.90 (144.15)	794.65
Group 4 (Fillapex)	664.77 (73.89)	633.00
Group 5 (Fiber post)	1091.51 (235.35)	1070.5
KW		33.55
P		0.0001

Table 3. The result of *post hoc Dunn's* multiple comparison test

Dunn's multiple comparison test	*P*
Control/AH Plus	0.0001*
Control/MetaSEAL	0.005*
Control/Fillapex	0.019*
Control/Fiber post	0.0001*
AH Plus/MetaSEAL	0.700
AH Plus/Fillapex	0.001*
AH Plus/Fiber post	0.023*
MetaSEAL/Fillapex	0.130
MetaSEAL/Fiber post	0.004*
Fillapex/Fiber post	0.0001*

*$P < 0.05$.

Table 3 and Fig. 6 show the comparison between each group in terms of fracture resistance. Among the experimental groups, the highest mean fracture resistance value was obtained with Group 5 (Fiber posts luted with PermaFlo DC) whereas Group 4 (MTA Fillapex) yielded the lowest values. A statistically significant difference was determined between Group 1 (control) and the experimental groups, with the control group exhibiting the lowest resistance to fracture ($P < 0.05$). The mean fracture resistance value of Group 2 (AH Plus) was found to be significantly higher than Group 4 (MTA Fillapex) ($P = 0.001$). The mean fracture value of Group 5 (Fiber posts) was significantly higher compared to Group 2 (AH Plus), Group 3 (MetaSEAL), and Group 4 (MTA Fillapex) ($P = 0.02$, 0.004, and 0.0001, respectively).

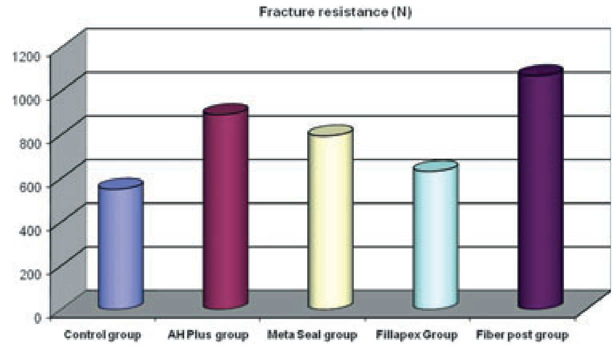

Fig. 6. Graphical representations of fracture resistance of the control and experimental groups.

Discussion

Reinforcement of endodontically treated immature teeth is a very important task for the dental practitioner as these teeth are more susceptible to external and masticatory forces. Therefore, it is essential to select a material that would substantially exert a reinforcing effect. Moreover, the selected material must be applied easily in clinical practice, readily be removed in case an additional restorative procedure is rendered necessary, bond successfully to dentine, and serve as a good barrier against microleakage that could lead to eventual failure (15). The results of the present study indicate that the control group with no backfilling exhibited a significantly lower fracture resistance value compared to the experimental groups. This implies that MTA placed apically does not exert a reinforcing effect and ways should be sought to prefer a methodology that would substantially increase the physical resistance of the remaining tooth structure to external impacts. On the other hand, the results of the experimental groups show that all the materials and techniques tested had a reinforcing effect to the weakened structure to some degree.

Maxillary anterior teeth were selected for experimentation in the present study as they are more susceptible to trauma and external impacts owing to their localizations. The validity of the samples evaluated in these types of studies has been questioned. It has been indicated that in pulpless immature teeth, as root dentinogenesis is halted, depending upon the stage of root development, the thin root wall has incompletely developed peritubular and intertubular dentine with higher tubular density toward the cementum. When mature teeth are enlarged to resemble immature teeth, the outer part of their roots would demonstrate lower tubular density and more intertubular dentine (1). It has therefore been concluded that although teeth used in these studies may morphologically mimic immature teeth, they are unable to do so in terms of tissue composition or physical characteristics. Nevertheless, all the experimental teeth went through the same procedures for the simulation of immature teeth, while in reality they are mature teeth extracted for various reasons. Therefore, it can be assumed that they still allow making a relative comparison between materials' reinforcing effect on physically weak dentinal structures. Bovine teeth could also be an alternative for experimental models as they show similarity to human teeth, and reproducible. However, the use of human teeth was preferred in the present investigation to mimic clinical conditions more precisely. Although individual differences are always likely among different teeth, extreme care was taken during the selection and distribution of the experimental teeth. Another option could be selection of immature premolars that are sometimes extracted for orthodontic purposes. Although these teeth would display the true histological characteristics of teeth with immature apices, this approach was not selected because of the difficulty of obtaining adequate number of such teeth and collecting them all with similar dimensions.

Another shortcoming of these types of studies is that there might be variations among natural teeth in terms of dentin, enamel, and cementum thicknesses. Although extreme care was taken in the selection of experimental teeth's dimensions, it is not possible to make a definite standardization with respect to the aforementioned properties. Meanwhile, the length of the supported part of the root within the acrylic block and the length of the canal preparation and the filling coronal to the MTA are difficult to be unified. This factor was attempted to be minimized by one operator performing these experimental procedures and careful mounting in the acrylic blocks.

Several loading angles have been used in studies aiming to assess fracture strength of immature teeth. A jig that allowed the placement of the samples to the Instron testing device at an angle of 45° was preferred in the present study to simulate a load occurring at the lingual area of an anterior tooth. Similar study designs were used by Stuart et al. (15) and Carvalho et al. (16).

Prior to placement of MTA for apexification, the manufacturer recommends that the canal be medicated with calcium hydroxide for 1 week, with subsequent removal using sodium hypochlorite and instruments as needed. It has been indicated that this may enhance the difficult task of debriding the canal system with an open apex (17). Therefore, calcium hydroxide medication was applied to the experimental teeth in the present study for 1 week to simulate clinical conditions. Extreme care was taken during the removal of calcium hydroxide in order not to leave residual material that might hamper the provision of a successful final obturation.

Composites have specifically been the focus of attention in terms of their reinforcing capacity (17, 18). However, they bring along the disadvantage of difficulty in removal in case a retreatment is indicated. Meanwhile, extending the access composite several millimeters apical to the cemento-enamel junction has been advocated by some to provide additional reinforcement (15). In the present study, only root canal accesses were filled with a composite resin not to include composite's reinforcing effect and to be able to compare the tested materials only. However, in case an additional retention is desired without jeopardizing the removal of the obturating material in a possible retreatment, such an approach can be selected.

With the recent advancement of dentine bonding technology, several brands of methacrylate resin-based root canal sealers have been developed. These sealers use the beneficial properties of methacrylate to reduce leakage and provide a reinforcement to the tooth (19, 20). Epiphany SE and MetaSEAL are two recent generations of methacrylate materials which are called self-adhesive dual-curable sealers eliminating the necessity of a separate priming step (19, 20).

MetaSEAL has been evaluated in terms of physicochemical properties. It has been proposed that Hybrid Root SEAL (MetaSEAL) had less fluid movement with cold lateral and vertical condensation techniques when compared with Thermafil and Ultrafil techniques (21). Furthermore, the material showed favorable push-out values when used in combination with Resilon (22). On the other hand, Lawson et al. (23) determined that the push-out strength of AH Plus was significantly higher than MetaSEAL with the lateral compaction and single cone techniques. The authors regarded this result as an unexpected finding for a sealer that theoretically forms hybrid layers to dentin and gutta-percha. They explained this finding with the thin, incomplete or nonexistent hybrid layer formation with self-adhesive MetaSEAL during SEM evaluation. The results of the present study are consistent with their findings, because MetaSEAL provided significantly lower fracture resistance compared to the AH Plus group. However, different combinations such as the utilization of the material with Resilon also need to be assessed to make a more valid statement. A recent study (22) determined favorable push-out values for Resilon/MetaSEAL combination; therefore, it is appropriate that this methodology is evaluated for physically weakened immature teeth to make a further recommendation. Meanwhile, strengthening capacity is one aspect of a material, and factors such as good sealing ability and biocompatibility are also properties expected from a permanent obturating material. In a recent study, MetaSEAL has shown similar sealing performances with RealSeal and AH Plus when used either with gutta-percha or Resilon (24). Furthermore, in an immunohistochemical analysis of subcutaneous tissue reactions to methacrylate resin-based root canal sealers, all sealers tested including MetaSEAL exhibited similar immunological reactions (19). These results reconfirm the necessity of the evaluation of multiple factors in the selection of a filling material in the permanent obturation of root canals.

Another methacrylate sealer evaluated so far in the reinforcement of immature roots is Epiphany, a methacrylate-based sealer used in combination with Resilon, over which specific attention has been directed in recent years. Many aspects of this filling methodology have been assessed in quite a number of investigations. A study on the reinforcing effect of the material on immature roots showed no difference between Resilon/Epiphany and a self-curing composite resin (15). This may indicate that methacrylate-based sealers may provide as much reinforcement as composites and may be feasible options instead of composite materials, taking into consideration the benefit of allowing a retreatment.

MTA Fillapex has been developed very recently by the manufacturers of MTA, to be used as a permanent root canal filling material, presumably in an attempt to integrate the beneficial properties of mineral trioxide aggregate in a permanent sealing material. The possible advantages of this system are the utilization of the material with the desired gutta-percha techniques and the chance of removal. On the other hand, whether it exerts the same beneficial effects as the original MTA, such as calcium release and induction of cementogenesis, is a topic of discussion and needs to be supported by future studies. Although the MTA-based sealer used in the present study was not evaluated in terms of these properties, another MTA-based sealer has been shown to release calcium ions in solution that encouraged the deposition of calcium phosphate crystals (25). For the time being, MTA Fillapex can be considered as an alternative root filling material and its usage in combination with an apical plug of MTA may provide the advantage of using materials of the same characteristics in the root canal system.

Attention has also been directed toward intraradicular posts to be used in immature teeth. Specifically, metallic posts have been tried as an option for their reinforcing capacity within roots with incomplete development. Bramante et al. (8) in a clinical case described the use of MTA in association with an intracanal post to reinforce a maxillary central incisor with horizontal root fracture in its cervical third. Bortoluzzi et al. (13) used bovine incisors to evaluate the reinforcing effect of a metallic post inserted within the non-set MTA. They stated that this methodology resembles the metallic frames embedded in Portland cement in civil engineering and attempted to find out whether a similar approach would have any strengthening on the overall root structure. They determined that roots reinforced with MTA and metallic posts had fracture strengths that were four times higher than the control roots. However, they added that a metallic post with high resistance to oxidation must be selected as corrosion problems are likely to develop at the post/MTA interface eventually. Another shortcoming of such an approach may be that there is no possibility of a retreatment procedure in case it is indicated. On the other hand, fiber posts have started to become more popular in clinical usage in recent years owing to beneficial properties such as good esthetics, easy application, modulus of elasticity which is similar to that of dentin, chance of removal using their own special drills in case of retreatment, and the possibility of building a core during the same appointment the post is inserted. Although various aspects of fiber posts have been evaluated in considerable number of investigations, their reinforcing capacity in underdeveloped teeth remains to be further highlighted. A study by Huang and Wang (26) investigated the influence of different cements on the fracture of immature teeth and proposed to use composite resin cement as a bonding material when immature teeth are restored with fiber posts. In another study by Carvalho et al. (16), it was concluded that the use of zirconium fiber post or composite resin can increase significantly the structural resistance of the weakened tooth. Quartz fiber post group in combination with a composite/luting resin was selected in the present study to compare its efficacy with other backfilling methodologies. PermaFlo DC is a flowable composite material recommended by the manufacturer to be used when UniCore fiber posts are to be luted. It can be speculated that the methodology used in the present study combines the beneficial effect of composite resins with that of fiber posts, yielding higher resistance values compared to other methodologies tested. Cvek (6) has reported that reinforcement of the remaining tooth structure is specifically important in earlier stages of development as dentinal deposition on root canal walls is not satisfactory in these teeth, predisposing them to fracture easily. Therefore, this methodology can be recommended specifically in teeth whose apical development has been halted in earlier stages of development and cases where additional retention to the restorative material is required owing to severe loss in the coronal structure.

The present study as well as others of the same nature focuses on the reinforcing capabilities of materials over teeth with a specific dimension. Stuart et al. (15) used a similar methodology with the present study in the preparation of root canals, making the initial root canal preparation with K3 files and passing a #5 Peeso reamer beyond the apex. The authors discussed that using a #5 Peeso reamer may not have been sufficient to create an adequate weakened structure. In the present study, a combination of enlargement with K3 files and #6 Peeso reamers were used. However, it is true that by future studies that focus on the reinforcing effect of materials on teeth with different stages of underdevelopment, guidelines can be developed on the material of choice depending on the specific case. Similar comments were made by Stuart et al. (15).

Another note to be mentioned is that the present study evaluates the resistance of immature teeth shortly after root canal obturation. A recent study attempted to assess fracture resistance over 1-year elapse, during which some changes in the tooth structure as well as the filling material are likely (27). Thus, fracture resistance of teeth with the tested materials in the present study after a specific time lapse may give rise to different results.

Usage of MTA in a single appointment is one way of handling underdeveloped necrotic teeth. Recently, there is a new concept in the management of immature necrotic teeth called 'regenerative endodontics' which brings a totally new insight into the discipline. The generation of a new matrix into which vital tissue can proliferate by the use of a triantibiotic paste and MTA is the basic principle behind this treatment approach (28). There are successful cases and reports favoring the clinical application of this promising technique (28, 29). By this methodology, continuation of root formation by dentinal deposition is targeted, which can substantially contribute to the reinforcement of these compromised teeth. On the other hand, future prospective trials are mandatory to firmly establish this innovative method into routine clinical use. Until then, the practitioner's aim must be not only to induce the apexification process but also to build a resistant and durable structure that will serve the patient for a prolonged period. Future studies focusing on this issue performed with different materials are warranted to further highlight this challenging task.

Conclusions

Within the limitations of this study, it can be concluded that all the materials tested exerted some degree of reinforcement and physical enhancement to simulated immature teeth with an apical MTA plug. UniCore quartz fiber posts luted using PermaFlo® DC flowable composite material seemed to provide higher resistance compared to the other materials tested. This methodology may specifically be recommended for those teeth with early arrest of root development as these teeth require a higher degree of reinforcement owing to their excessively thin and weakened dentinal walls.

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