Comparative Study of White and Gray Mineral Trioxide Aggregate (MTA) Simulating a One- or Two-Step Apical Barrier Technique

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This study investigated the use of Mineral Trioxide Aggregate (MTA) as an apical barrier by comparing the sealing ability and set hardness of white and gray MTA. Forty-four root segments were prepared to simulate an open apex. Apical barriers of white and gray MTA were placed to a thickness of 2 mm or 5 mm. The samples were obturated immediately (one-step) or after the MTA set for 24 h (two-steps). After placement in methylene blue dye for 48 h, the samples were sectioned for leakage analysis and microhardness testing of the barrier. Gray MTA demonstrated significantly less leakage than white MTA ($p < 0.001$), and the two-step technique showed significantly less leakage than one-step ($p < 0.006$). The 5-mm thick barrier was significantly harder than the 2 mm barrier, regardless of the type of MTA or number of steps ($p < 0.01$). Results suggested that a 5 mm apical barrier of gray MTA, using two-steps, provided the best apical barrier.

One of the principal objectives of nonsurgical root canal therapy is to seal the canal system from apical and coronal leakage after cleaning and shaping. Preparation of an apical seat or stop during root canal instrumentation is critical to achieving an apical seal. If an apical stop cannot be developed, it is difficult to prevent extrusion of filling material from the confines of the root canal space during obturation. The absence of an adequate apical constriction is often found in cases of apical root resorption, apical perforations and immature, necrotic teeth. In these cases, it is critical that either a stop be developed or an apical barrier be placed to limit extrusion of obturation materials.

Previous investigations have focused on the management of teeth with open apices. Long-term calcium hydroxide [$Ca(OH)_2$] therapy has been advocated for treatment of nonvital immature teeth to induce an apical barrier formation (1), but recent research has shown that long-term $Ca(OH)_2$ may decrease the fracture resistance of teeth (2). An alternative approach is the placement of an apical barrier to prevent extrusion of root-filling materials. Materials previously considered for barriers include dentin chips, freeze-dried cortical bone/dentin, calcium phosphate, and $Ca(OH)_2$ (3–7). The main advantage with this technique is the efficiency of creating a barrier and obturation in one appointment, but these materials do not provide a well-sealed apical environment.

Mineral Trioxide Aggregate (MTA) has been advocated for use as an apical barrier (8). This material holds promise because of its sealing capabilities, ability to set-up in the presence of blood, and biocompatibility (9–12). Additionally, the material has demonstrated long-term success when used as a perforation repair material, which may be a result of its capabilities to induce hard tissue formation (13, 14).

A previous investigation of perforation defects repaired with MTA showed that periradicular moisture was advantageous in adapting the material to the walls of the perforation. This moisture may have allowed the MTA to set properly, as its retention characteristics were not altered by placement of either a moist or dry cotton pellet over the material (15). Thus, it is reasonable to question whether a moist cotton pellet is needed over the MTA when used as an apical barrier. With an open apex, MTA may set in the presence of periapical moisture; and if this is true, the material could be used in a one-visit procedure.

There is limited research evaluating MTA as an apical barrier material. According to case reports, MTA has been successfully used in this capacity, but required two appointments to allow for setting of the material (8, 16, 17). A more recent article suggested the use of this cement in a one-visit apexification procedure (18). The purpose of this study was to investigate the use of MTA as an apical barrier by comparing the sealing ability and microhardess of white and gray MTA when used in a one- or two-step method.

MATERIALS AND METHODS

Forty-four extracted, single canal human incisor teeth were stored in 0.2% sodium azide. The teeth were decoronated and standardized 10-mm root lengths were prepared to simulate the clinical situation of an open apex.

The canals were instrumented with Gates Glidden burs #5-#1 (Dentsply Maillefer, Tulsa, OK) in a crown-down manner until the #1 size bur could pass through the apical foramen. The specimens were then prepared with Flexofiles (Dentsply Maillefer, Johnson City, TN) until an ISO size 90 file could be visualized 1 mm past

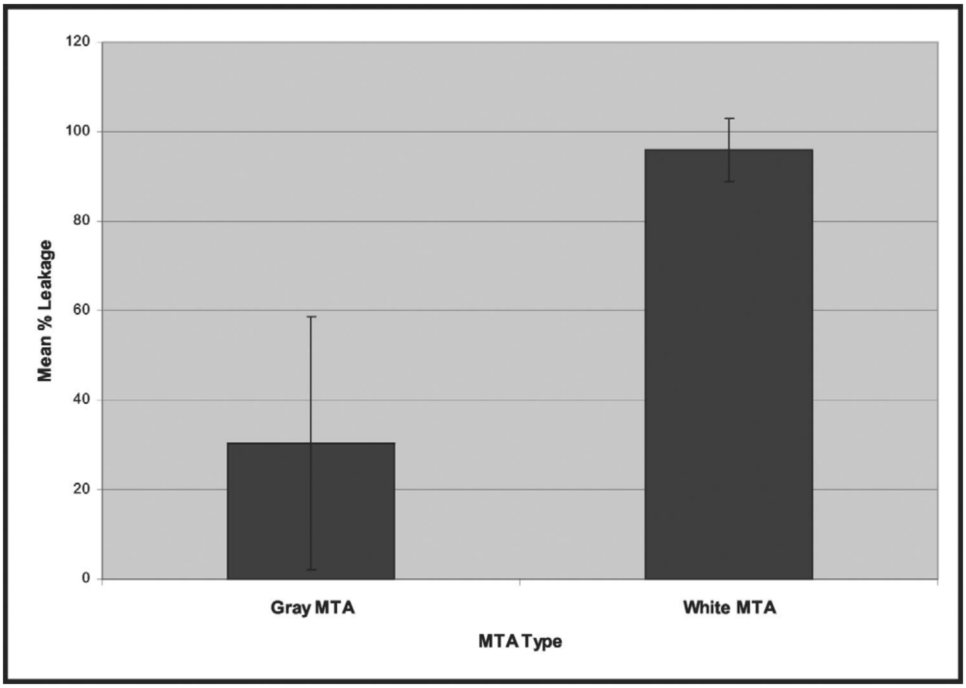

FIG 1. Leakage results: gray versus white MTA ($p < 0.001$).

the apex. Irrigation with 5 ml of 6% sodium hypochlorite (Ultra Clorox—Clorox Co., Oakland, CA) was used throughout instrumentation, and was followed by a final 5-ml flush.

The root segments were randomly placed into eight groups of five samples each and four root segments were used as controls. To provide a simulated periapical environment, the root segments were placed into saline-soaked Oasis, as previously described by Lee et al. (19). White (lot number 02021303) and gray (lot number 00721) MTA (ProRoot, Dentsply Tulsa Dental, Tulsa, OK) were mixed according to manufacturers' recommendation and used as an apical barrier. The MTA was delivered to the canal space with a messing gun and compacted with prefit pluggers. After the initial compaction, the plugger was then placed passively on the barrier and ultrasonic energy (lowest power setting) was transmitted to the shaft of the plugger via an ultrasonic handpiece (SybronEndo, Orange, CA). In the one-step groups, the samples were obturated immediately with Roth Root Canal Cement 801 Type (Roth International Ltd., Chicago, IL) and thermoplasticized gutta-percha using the Obtura II (Obtura Spartan, Fenton, MO). For the two-step groups, a moist cotton pellet was placed over the MTA and the teeth were sealed with Cavit (3M ESPE, St. Paul, MN). The MTA was allowed to set at 37°C and 100% humidity for 24 h and then the remaining canal space was obturated as in the one-step groups. Four control root segments were obturated completely with Roth 801 sealer and thermoplasticized gutta-percha.

The experimental groups were divided as follows: group 1, 2 mm gray MTA barriers and obturated after 24 h setting; group 2, 2 mm gray MTA barriers and obturated immediately; group 3, 5 mm gray MTA barriers and obturated after 24 h setting; group 4, 5 mm gray MTA barriers and obturated immediately. Groups 5 through 8 were identical to groups 1 through 4 but white MTA was substituted for the gray material.

The coronal portion of all samples was sealed with glass ionomer (Fuji IX GP, GC America Inc., Alsip, IL). All samples were stored in Oasis for 4 wk at 37°C and 100% humidity. After 4 wk, the samples were removed and double coated with nail varnish except for the apical 1 mm. Negative controls were entirely coated in two layers of nail varnish and the positive controls were coated as the experimental groups. The root segments from all groups were placed in methylene blue dye for 48 h. To determine the depth of dye penetration, each specimen was embedded in orthodontic resin and sectioned longitudinally with a diamond saw.

All sections were evaluated under a dental operating microscope (Global Surgical Co., St. Louis, MO) at 6.4X magnification, and digital images were captured and imported into Photo Shop Pro version 5.01 (Jasc Software, Inc., Minneapolis, MN). After randomization of the samples, linear dye penetration was measured independently by two observers from the apical root surface to the most coronal extent of dye penetration using a grid and ruler-measuring device. This linear dye measurement was then converted to a percentage of dye penetration through the entire length of the barrier. A three-way ANOVA was used to determine the statistical difference regarding technique, barrier thickness, and type of MTA.

The Micromet II (Buehler Ltd., Lake Bluff, IL) was utilized for a microhardness test. The resin embedded samples were placed in a vise and then the Vickers-type indenter was positioned in the center of the MTA barriers. The indenter placed 100 g of pressure for 15 s on the material and microhardness was evaluated by measuring (in microns) the indentation into the MTA. A three-way ANOVA was used to determine the statistical difference regarding technique, barrier thickness, and type of MTA.

RESULTS

Dye penetrated the entire length of the positive controls, and there was no dye penetration in negative controls.

The thickness of the MTA barrier demonstrated no significant statistical difference in dye penetration ($p < 0.283$). However, the type of MTA and the one- or two-step technique yielded significant

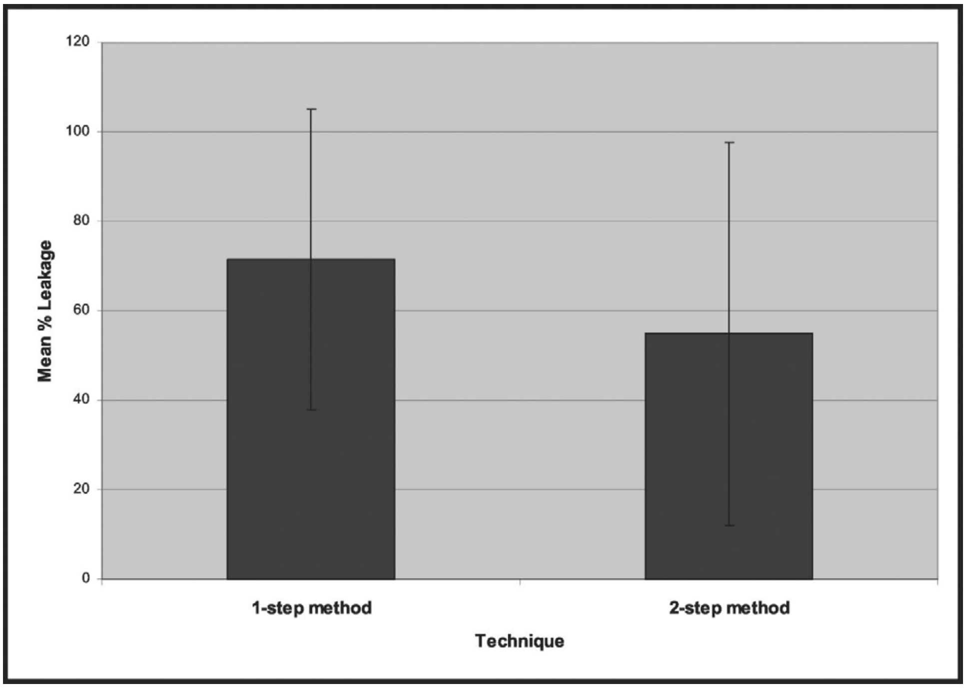

FIG 2. Leakage results: one-step versus two-step technique ($p < 0.006$).

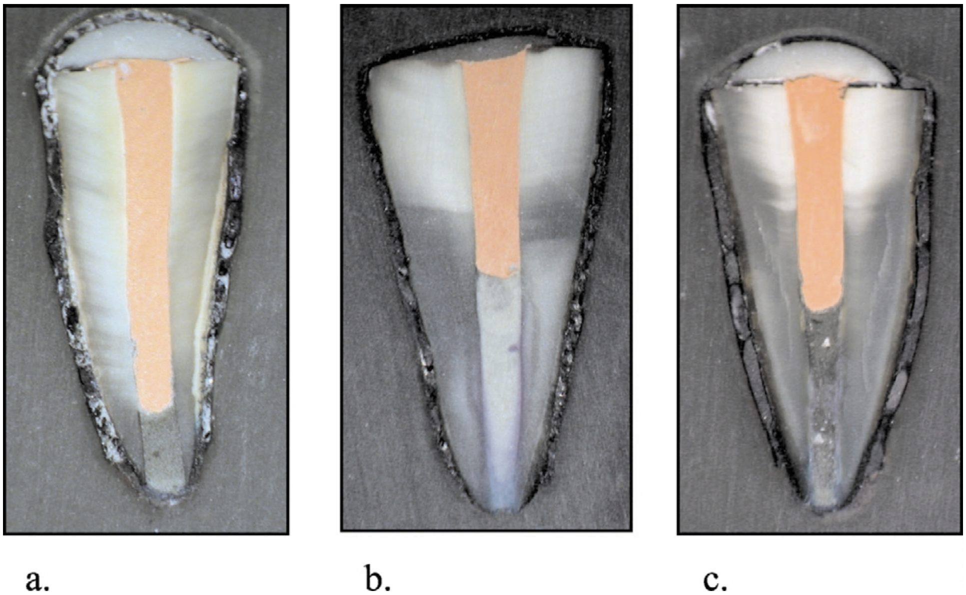

FIG 3. (*a*) Minimal dye penetration with two-step, 2 mm gray MTA. (*b*) Almost complete dye penetration with two-step, 5 mm white MTA. (*c*) Increased dye penetration with one-step, 5 mm gray MTA.

results. Gray MTA demonstrated significantly less dye leakage as compared to white MTA ($p < 0.001$) (Fig. 1). None of the gray MTA barriers showed complete dye penetration after 48 h, whereas 14 of 20 samples of white MTA revealed complete dye penetration through the barrier (Fig. 3 *a*, *b*). The two-step technique demonstrated significantly less leakage than the one-step technique of barrier placement ($p < 0.006$) (Fig. 2 and 3*c*).

Statistical analysis of the MTA microhardness test revealed that the 5 mm thick barrier was significantly harder than the 2 mm barrier, regardless of the type of MTA or technique utilized ($p < 0.01$).

DISCUSSION

There is little research investigating the properties and clinical applications of white MTA and none have shown a comparative analysis between the white and gray products. The principal components of gray MTA are tricalcium silicate, dicalcium silicate, tricalcium aluminate, tetracalcium aluminoferrite, and calcium sulfate dihydrate. In addition to these components, mineral oxides have been added that are responsible for the chemical and physical properties of this aggregate (19). Tetracalcium aluminoferrite is reportedly removed in the white formulation. It is speculated that the elimination of this component may be responsible for the altered properties of the material noted in this investigation. Because both materials appeared clinically set and showed no differences in hardness, it is hypothesized that perhaps slight volumetric shrinkage occurred with the white product that accounts for the increased leakage seen between the MTA and root dentin. The only other research at this time evaluating white MTA, showed orifice plugs of the white cement where of no benefit to inhibiting the development of apical periodontitis in dog's teeth (20). Further research is needed to verify these findings and account for the differences in the two products.

Although the methods for mixing and placing the cement were well standardized in this study, there is evidence that increased water-to-powder mixing ratios could account for increased solubility and porosity of the material (21). Because of the handling properties of MTA, it is likely that clinicians vary in the way they mix and place the cement. It is advised that manufacturer's recommendations for mixing be strictly followed to avoid decreasing the optimum properties of the material.

The benefit to using ultrasonics for placement of MTA apical barriers is still in question. When orthograde MTA is placed in teeth with open apices, it has been shown that a good seal and adequate retention is difficult to achieve (22). Other research has shown that ultrasonic energy applied while placing the barrier may improve the seal of the set cement (23). In our pilot study, barriers placed with ultrasonic activation, as described by Witherspoon et al. (18), demonstrated fewer voids than barriers placed without ultrasonic energy. The ultrasonic energy helped move the MTA apically and more completely condense the material without dislodgement. The increased hardness noted in the 5 mm barrier as compared to the 2 mm barrier was an interesting finding of the study. The central region of the barrier was tested to determine whether the MTA had set completely through the material. Perhaps the 5 mm barriers demonstrated an increased hardness because they were condensed more thoroughly. Once the barrier reached approximately 3 to 5 mm in depth, placement became easier because of increased resistance to dislodgement through the open apex. Our findings, although contradictory to a previous investigation (24), suggest that an ultrasonically compacted gray MTA apical barrier of 3 to 5 mm provided the hardest, most impervious apical barrier.

Clinically, a barrier of 5 mm may be considered if root-end surgery is a treatment option. Recent evidence has shown that teeth obturated with orthograde MTA and followed by root-end resection showed periradicular healing similar to teeth with fresh MTA placed as a root-end filling material (25). If a 3 mm root-end resection had to be performed after the placement of a 5 mm MTA apical barrier, then no root-end filling would have to be placed at the time of surgery.

Although a one-visit apexification procedure with MTA has been suggested (18), findings of this experiment clearly support the two-step technique over the one-step procedure. MTA powder consists of fine, hydrophilic particles that set in the presence of water. It is possible that moisture from the periapical environment could be sufficient for MTA to set, but it seems clear that additional moisture from a cotton pellet is crucial for the material to establish its optimum properties. These findings concur with the manufacturers' recommendation of placing a moist cotton pellet in the canal, temporizing, and allowing the material to set for a minimum of 4 h.

Under the parameters of this study, the following conclusions can be drawn regarding the best apical barrier:

1. Gray MTA demonstrated significantly less apical dye leakage than white MTA.
2. A two-step MTA placement technique showed significantly less apical dye leakage than a one-step procedure.
3. A 5 mm barrier demonstrated significantly greater microhardness than the 2 mm barrier.

The opinions or assertions expressed in this article are those of the authors and are not to be construed as official policy or position of the Department of the Navy, Department of Defense or the U.S. Government.

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References

1. Frank AL. Therapy for the divergent pulpless tooth by continued apical formation. J Am Dent Assoc 1966;72:87–93.
2. Andreasen JO, Farik B, Munksgaard EC. Long-term calcium hydroxide as a root canal dressing may increase risk of root fracture. Dent Traumatol 2002;18:134–7.
3. Brady JE, Himel VT, Weir JC. Periapical response to an apical plug of dentin filings intentionally placed after root canal overinstrumentation. J Endod 1985;11:323–9.
4. Rossmeisl R, Reader A, Melfi R, Marquard J. A study of freeze-dried (lyophilized) cortical bone used as an apical barrier in adult monkey teeth. J Endod 1982;8:219–26.
5. Rossmeisl R, Reader A, Melfi R, Marquard J. A study of freeze-dried (lyophilized) dentin used as an apical barrier in adult monkey teeth. Oral Surg Oral Med Oral Pathol 1982;53:303–10.
6. Coviello J, Brilliant JD. A preliminary clinical study on the use of tricalcium phosphate as an apical barrier. J Endod 1979;5:6–13.
7. Weisenseel JA, Jr., Hicks ML, Pelleu GB, Jr. Calcium hydroxide as an apical barrier. J Endod 1987;13:1–5.
8. Torabinejad M, Chivian N. Clinical applications of mineral trioxide aggregate. J Endod 1999;25:197–205.
9. Nakata TT, Bae KS, Baumgartner JC. Perforation repair comparing mineral trioxide aggregate and amalgam using an anaerobic bacterial leakage model. J Endod 1998;24:184–6.
10. Torabinejad M, Higa RK, McKendry DJ, Pitt Ford TR. Dye leakage of four root end filling materials: effects of blood contamination. J Endod 1994;20:159–63.
11. Torabinejad M, Hong CU, Pitt Ford TR, Kettering JD. Cytotoxicity of four root end filling materials. J Endod 1995;21:489–92.
12. Mitchell PJ, Pitt Ford TR, Torabinejad M, McDonald F. Osteoblast biocompatibility of mineral trioxide aggregate. Biomaterials 1999;20:167–73.
13. Main C, Mirzayan N, Shabahang S, Torabinejad M. Repair of root perforations using mineral trioxide aggregate: a long-term study. J Endod 2004;30:80–3.
14. Yaltirik M, Ozbas H, Bilgic B, Issever H. Reactions of connective tissue to mineral trioxide aggregate and amalgam. J Endod 2004;30:95–9.
15. Sluyk SR, Moon PC, Hartwell GR. Evaluation of setting properties and retention characteristics of mineral trioxide aggregate when used as a furcation perforation repair material. J Endod 1998;24:768–71.
16. Shabahang S, Torabinejad M. Treatment of teeth with open apices using mineral trioxide aggregate. Pract Periodontics Aesthet Dent 2000;12:315–20.
17. Hayashi M, Shimizu A, Ebisu S. MTA for obturation of mandibular central incisors with open apices: case report. J Endod 2004;30:120–2.
18. Witherspoon DE, Ham K. One-visit apexification: technique for inducing root-end barrier formation in apical closures. Pract Proceed Aesthet Dent 2001;13:455–60.
19. Lee SJ, Monsef M, Torabinejad M. Sealing ability of a mineral trioxide aggregate for repair of lateral root perforations. J Endod 1993;19:541–4.
20. Mah T, Basrani B, Santos JM, et al. Periapical inflammation affecting coronally-inoculated dog teeth with root fillings augmented by white MTA orifice plugs. J Endod 2003;29:442–6.
21. Fridland M, Rosado R. Mineral trioxide aggregate (MTA) solubility and porosity with different water-to-powder ratios. J Endodo 2003;29:814–7.
22. Hachmeister DR, Schindler WG, Walker WA, III, Thomas DD. The sealing ability and retention characteristics of mineral trioxide aggregate in a model of apexification. J Endod 2002;28:386–90.
23. Lawley GR, Schindler WG, Walker WA, III, Kolodrubetz D. Evaluation of ultrasonically placed MTA and fracture resistance with intracanal composite resin in a model of apexification. J Endod 2004;30:167–72.
24. Aminoshariae A, Hartwell GR, Moon PC. Placement of mineral trioxide aggregate using two different techniques. J Endod 2003;29:679–82.
25. Apaydin ES, Shabahang S, Torabinejad M. Hard-tissue healing after application of fresh or set MTA as root-end-filling material. J Endod 2004;30:21–4.