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Sealing Ability of Mineral Trioxide Aggregate and Super-EBA When Used as Furcation Repair Materials: A Longitudinal Study

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Immediate sealing of furcation perforations enhances the repair process. The purpose of this study was to longitudinally compare the ability of mineral trioxide aggregate (MTA) and Super-EBA to seal furcation perforations. Fifty-one extracted human maxillary molars were decoronated 3 mm above the CEJ, and the roots were amputated 3 mm below the furcation. A #2 high-speed round bur was used to perforate the center of the furcations. The canals were obturated with gutta-percha, and the root ends were sealed with C&B Metabond. Three experimental groups of 15 teeth each were restored with MTA, Super-EBA, or a combination of MTA in the perforation and a Super-EBA dome on the pulpal floor. Six teeth served as controls. Each tooth was affixed to a fluid filtration device and subjected to a pressure of 20 cm H_2O. The integrity of the perforation seal was evaluated initially at 30 min for the Super-EBA and the combination groups and at 4 h for the MTA group. Additional measurements were then made at 24 h, 1 week, and 1 month. The controls behaved as expected. A two-way ANOVA revealed a significant difference ($p = 0.01$) between materials. Tukey's test isolated the difference to Super EBA as producing a superior seal but only at 24 h. There was no significant effect with time ($p = 0.57$) or the interaction of the materials with time ($p = 0.66$). All materials sealed the perforations very well. The maximum leakage of all materials was $<0.007\ \mu L\ min^{-1}\ cm\ H_2O^{-1}$.

The long-term prognosis of a perforated tooth is dependent upon the size and location of the perforation, the duration of septic exposure, and the ability to seal the defect (1). A furcation perforation may result in an irreversible periodontal lesion of inflammatory origin due to the proximity of the damaged periodontium to the gingival sulcus. Immediate sealing of the defect allows for the best chance of repair (2).

The ideal repair material should provide an adequate seal, be biocompatible, and possess the ability to induce osteogenesis and cementogenesis (3). The ability of repair materials to seal furcation perforations in vitro has been tested using dye (4), bacteria (5), radioisotopes (6), and fluid filtration (7, 8). Mineral trioxide aggregate (MTA) (9) and Super-EBA (10) have been advocated for sealing furcation perforations.

Numerous investigators have utilized fluid filtration to assess the microleakage of MTA and Super-EBA when used as root-end fillings (11–13). Bates et al. (11), using a filtration pressure of 20 psi (1406 cm H_2O), found no significant differences between MTA and Super-EBA over 12 weeks. During a 24-week observation period, Yatsushiro et al. (12) showed that Valiant PhD amalgam had significantly higher fluid filtration microleakage after 4 weeks than MTA at a test pressure of 10 psi (703 cm H_2O). In a fluid filtration model with a pressure of 0.1 atm (103 cm H_2O), Wu et al. (13) noted an increase in microleakage for Super-EBA (from 0% to 55%) and a decrease in microleakage for MTA (from 55% to 0%) from 24 h to 3 months.

Welch et al. (7) used a fluid filtration pressure of 10 psi (703 cm H_2O) to assess the ability of various materials to seal furcation accessory canals. Fuss et al. (8) determined that Chelon Silver sealed significantly better than amalgam in furcation perforations via fluid filtration at 1.2 atm (1240 cm H_2O). To date, no study has ascertained the seal provided by MTA or Super-EBA with fluid filtration in furcation perforations. Therefore, the purpose of this in vitro study was to longitudinally compare the ability of MTA and Super-EBA to seal furcation perforations in human molars by using a fluid filtration method at a physiologic pressure.

MATERIALS AND METHODS

Fifty-one extracted, human maxillary molars were used in this study. The molars had minimal restorations or caries and roots that were not fused. One investigator performed all procedures. The teeth were stored in physiologic saline before initiation of the procedures. The teeth were decoronated 3 mm above the CEJ, and the roots were amputated 3 mm below the furcation using an Isomet saw (Buehler Ltd., Lake Bluff, IL). Endodontic access was

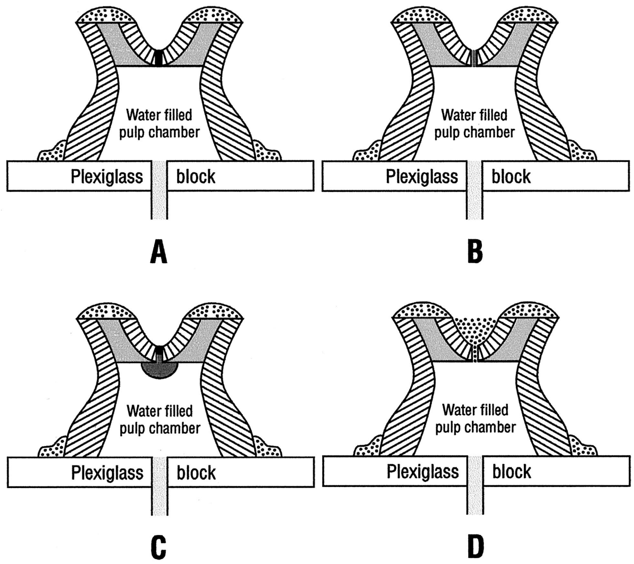

FIG 1. Schematic of the tooth specimens showing the furcal perforation, the attachment of the specimens to plastic blocks perforated by 18-gauge steel tubing, and resin seals on the resected, gutta-percha filled roots. (*A*) Perforation repaired with MTA (*black*). (*B*) Perforation repaired with Super-EBA (*gray*). (*C*) Apical half of perforation filled with MTA (*black*). Coronal half filled with Super-EBA (*gray*) that was formed into a dome. (*D*) Negative control: perforation repaired with C&B Metabond resin cement (*speckled*).

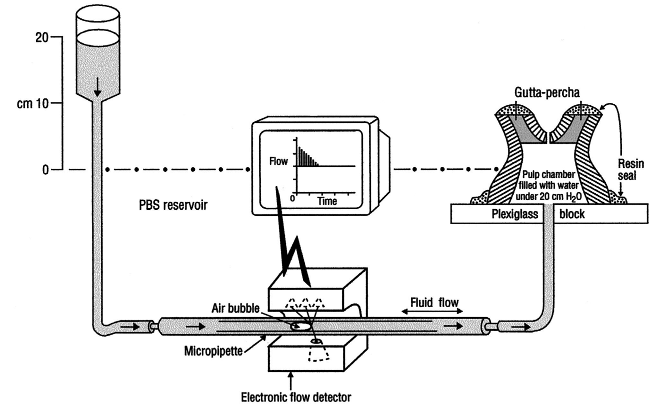

FIG 2. Schematic showing how the tooth specimen was bonded to the plastic block. The root canals were filled with gutta-percha, and the resected root-ends were covered with C&B Metabond resin cement. The fluid filtration chamber was connected via tubing to a Flodec device used to measure fluid flow in a micropipette under a pressure of 20 cm H_2O.

prepared by using a #4 high-speed round bur (Brasseler USA, Savannah, GA) with water coolant. The pulpal tissue was removed from the chamber and canals by using a spoon excavator and Flexofiles (Dentsply/Maillefer, Tulsa, OK). The cleaned root canals were obturated with thermoplasticized injectable gutta-percha (Obtura, II; Obtura Corp., Fenton, MO) without sealer. The root ends were sealed with C&B Metabond (Parkell, Farmingdale, NY). A perforation was made perpendicular to the center of the pulp chamber floor by using a #2 round high-speed bur (Brasseler USA) with water coolant. This created a perforation 1 mm in diameter. Perforation depth varied with the dentin-cementum thickness from the pulp chamber floor to the furcation floor. The chamber and perforation were flushed with water from an air/water syringe and dried with oil-free air. The teeth were stored in physiologic saline containing 0.2% sodium azide (Sigma Chemical Co., St. Louis, MO), an antimicrobial agent, until perforation repair. After removal from the saline storage, the chamber and perforation were dried with oil-free air. A cotton pellet moistened with saline was held in the furcation by orthodontic elastics to simulate the moisture of the periodontal ligament and to provide resistance during compaction of the repair materials. Absorbent points were used to remove excess moisture from the perforation site.

The teeth were randomly divided into 3 groups of 15 teeth each. In group 1, the MTA (ProRoot, Dentsply/Tulsa) was mixed according to manufacturer's recommendations and used to repair the perforations. The MTA was placed with an Endogun (Medidenta Int./Inc., Woodside, NY) and compacted with absorbent points and Schilder pluggers (Fig. 1A). In group 2, Super-EBA cement (Harry J. Bosworth Co., Skokie, IL) was mixed according to manufacturer's recommendations and used to repair the perforations. Super-EBA was placed with a spoon excavator and compacted with Schilder pluggers (Fig. 1B). Both materials in groups 1 and 2 were compacted flush with the chamber floor. The perforations in group 3 were repaired with MTA compacted into the apical half of the perforation. Super-EBA was used to fill the remaining perforation space and formed into a dome on the pulpal floor (Fig. 1C). Three teeth were perforated, but not repaired, and served as the positive controls. Another three teeth were perforated and repaired with C&B Metabond to serve as the negative controls (Fig. 1D). After the MTA repair, a cotton pellet moistened with saline was placed in the pulp chamber against the MTA. A dry cotton pellet was placed against the Super-EBA in groups 2 and 3. All teeth were placed in a closed container at 100% relative humidity at 37°C.

Microleakage assessment was conducted under a pressure of 20 cm H_2O via the fluid filtration technique as described by Derkson et al. (14). Stainless steel tubing (18-gauge) was placed through a hole drilled in the center of $2 \times 2 \times 0.7$-cm Plexiglas squares until flush with the lower surface. The junction of tubing to the Plexiglas was sealed with C&B Metabond. The cotton pellets were then removed from the pulp chambers. The flattened occlusal surfaces were sealed to the lower surface of the Plexiglas over the stainless steel tubing with C&B Metabond. The pulp chambers were filled with water through the 18-gauge tubing with a 27-gauge needle to remove all air bubbles. The transparent Plexiglas allowed visual assurance of air bubble removal. The 18-gauge tubing was connected to a Flodec device (DeMarco Engineering, Geneva, Switzerland) via polyethylene tubing containing a micropipette system (Fig. 2).

The fluid filtration pressure was applied, and four consecutive 2-min measurements of fluid flow were made at each testing interval. The specimens were initially tested at 4 h for group 1 (MTA) and at 30 min for group 2 (Super-EBA) and group 3 (combination). All groups were again tested at 24 h, 1 week, and 1 month. After each test period, the samples were stored in a closed container at 100% relative humidity at 37°C.

Fluid conductance, in microliters per minute per centimeter of H_2O pressure ($\mu L\ min^{-1}\ cm\ H_2O^{-1}$), was calculated using the mean of the four measurements for each specimen at each time period. The overall means of fluid conductance were calculated for each experimental group at each time period. The data were analyzed by a two-way ANOVA by using material as one factor and time as the other. When differences were found, Tukey's multiple comparison test was used to isolate the statistically significant subgroup ($p < 0.05$).

TABLE 1. Microleakage of perforation repair materials over time

Group	Fluid Flow (μL min^{-1}cm H_2O^{-1}) Time			
	30 min	24 h	1 week	1 month
1†	0.005 ± 0.003 (15)[a]	0.006 ± 0.002 (15)[a]	0.006 ± 0.003 (15)[a]	0.006 ± 0.002 (15)[a]
2	0.005 ± 0.003 (15)[a]	0.004 ± 0.002 (15)[b]	0.005 ± 0.002 (15)[a]	0.006 ± 0.002 (15)[a]
3	0.006 ± 0.002 (15)[a]	0.006 ± 0.002 (15)[a]	0.006 ± 0.002 (15)[a]	0.006 ± 0.002 (15)[a]

† Group 1 (MTA) initial measurement was made at 4 h rather than 30 min. Groups identified by the same superscript letter are not significantly different ($p > 0.05$). Different letters identify significantly different groups ($p < 0.05$).

TABLE 2. Comparison of perforation depths

Group	Perforation Depths (mm)
1	2.79 ± 0.70 (15)[a]
2	2.78 ± 0.55 (15)[a]
3	2.78 ± 0.69 (15)[a]

Groups identified by the same superscript letter are not significantly different ($p > 0.05$).

At the end of the experiment, the teeth were sectioned through the repaired perforations to permit measurement of the perforation depth by using a videomicrometer system (Micro Enterprises, Inc., Norcross, GA). The means and standard deviations of the perforation depths in each group were calculated.

RESULTS

No leakage was detected in the negative controls at any time period. The positive controls allowed a mean leakage of 52.7 μL min^{-1} cm H_2O^{-1}. The results of the two-way ANOVA revealed a statistically significant difference between materials ($p = 0.01$). Multiple comparisons of the materials isolated the significant difference to Super-EBA as producing a superior seal ($p < 0.05$), but only at 24 h. There were no significant differences among the groups as a function of time ($p = 0.57$) and no significant interaction between materials and time ($p = 0.66$). All materials sealed the perforations very well (Table 1), both initially and over the 1-month duration of the study. The maximum leakage of any of the materials was <0.007 μL min^{-1} cm H_2O^{-1}. The mean perforation depth in each group is shown in Table 2. There was no significant difference in perforation depths among the three groups ($p > 0.05$).

DISCUSSION

This in vitro study attempted to simulate in vivo conditions by subjecting the repaired perforations to 20 cm of water pressure. This pressure was selected because of reports that such pressures exist in the marrow spaces of bone. Held and Thron (15) obtained a marrow space pressure of 10 to 20 mmHg (13.5–27 cm H_2O). Using a tonometric technique, Christiansen et al. (16) reported a mandibular marrow pressure in dogs of 20 ± 6 mmHg (15 ± 3 cm H_2O). Because the furcation is in direct communication with alveolar marrow spaces via venules passing from the PDL to the marrow, we elected to subject the furcation repair to a physiologic pressure of 20 cm H_2O during microleakage testing. This is a much lower pressure than had been used in previous fluid filtration experiments measuring microleakage (7, 8, 11–13). The fluid filtration technique was chosen for leakage assessment, because it permits a quantitative measurement of microleakage over a longitudinal time period without destruction of the experimental specimens.

The slow setting reaction of MTA required a 4 h delay in measuring the initial microleakage. Because of the slow set of MTA, a pilot project was conducted using a combination of MTA and Super-EBA. In this test, the apical portion of the perforation was filled with MTA and the more occlusal portion was filled flush with the chamber floor with Super-EBA. Significantly more leakage with this repair combination was encountered than when either material was used alone. Alhadainy and Himel (17) reported a similar phenomenon when using plaster of Paris as a barrier beneath light-cured glass ionomer repair materials in furcation repairs. They speculated that residual plaster of Paris on the walls of the perforation negatively affected the seal of the glass ionomer. To overcome the problem of MTA debris on the perforation walls and its interference with the adhesion of the Super-EBA, the MTA-repaired perforation was covered with a dome of Super-EBA. This dome extended at least 1-mm peripherally from the margins of the perforation. Leakage assessment with this combination of MTA and a Super-EBA dome could then be initially conducted at 30 min with minimal leakage differences from the 30 min Super-EBA and 4 h MTA samples.

The biocompatibility of MTA (9) and Super-EBA (10) are well known; in contrast, the biocompatibility of newer resin restorative materials has not been fully evaluated. Some authors have advocated using dentin-bonding agents and other adhesive agents to seal the floor of the pulp chamber after root canal therapy (18, 19). The combination of MTA and Super-EBA sealed very well but did allow some microleakage. Further studies are warranted to ascertain whether C&B Metabond or other dentin-bonding agents placed directly over MTA or Super-EBA, as a secondary seal, would negate all microleakage. These combinations, if compatible, would also allow placement of a permanent restoration at the completion of the appointment, provided obturation had been accomplished. Wolanek et al. (18) reported that Clearfil Liner 2V, a self-etching adhesive system, when used as a coronal barrier, provided a leak-proof seal against oral streptococci. Also, the use of a eugenol-containing sealer had no effect on the sealing ability of this dentin-bonding agent.

Although some perforations seen clinically are created as narrow, deep defects as represented in this study, others are produced as broad, shallow, saucer-like defects. These defects may have a smaller perforation diameter and thinner remaining dentin thickness. It may be difficult to stabilize MTA long enough for the material to set. Super-EBA might be a better choice in such situations because of its intrinsic adhesive properties.

Within the constraints of this study it can be concluded that (a) Super-EBA allowed significantly less microleakage than MTA or the combination of materials only at 24 h; (b) the MTA required 4 h to obtain a satisfactory seal; (c) the combination of MTA and Super-EBA provided a more rapid seal than MTA alone; and (d) C&B Metabond prevented microleakage throughout each experimental time period.

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