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SCIENTIFIC ARTICLES

Longitudinal Sealing Ability of Mineral Trioxide Aggregate as a Root-End Filling Material

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This study evaluated the ability of mineral trioxide aggregate (MTA) to seal the root end effectively. Seventy-six single-rooted, extracted human teeth were cleaned and shaped using a step-back technique. After root-end resection and ultrasonic preparation, 72 root sections were randomly allocated to three groups and filled with dental amalgam and cavity liner, Super-EBA, or MTA. Microleakage was assessed at 24 h, 72 h, 2 wk, 4 wk, 8 wk, and 12 wk, using a fluid filtration measurement system. MTA demonstrated excellent sealing ability throughout 12 wk of fluid immersion, comparable with that observed for Super-EBA. Microleakage in the MTA group, as well as the Super-EBA group, was significantly less ($p < 0.05$) than in the amalgam group at 24 h, 72 h, and 2 wk. At the subsequent periods, there were no significant differences among the three materials. In this study, MTA was determined to be superior to amalgam, and comparable with Super-EBA in preventing microleakage when used as a root-end filling.

A relatively new material, mineral trioxide aggregate (MTA), has demonstrated promise as a suitable root-end filling material (1–3). MTA is a proprietary material, and its compositional analysis is unpublished. MTA consists of several principle compounds: (a) tricalcium silicate, (b) tricalcium aluminate, (c) tricalcium oxide, (d) silicate oxide, and (e) other unknown mineral oxides (1). Reports indicate that the material sets by hydration of hydrophilic particles, resulting in a colloidal gel that solidifies as a hard structure in <4 h (1). The developers of the material have reported that MTA outperformed both amalgam and Super-EBA in short-term dye leakage comparisons, either when placed under dry conditions or in the presence of contamination with blood (1, 2). Similarly, the developers reported that, in a bacterial leakage study, MTA leaked significantly less than amalgam, Super-EBA, and Intermediate Restorative Material (IRM) for up to 90 days (3). When evaluated histologically in beagle dogs, MTA elicited less extensive inflammation and more bone apposition than amalgam root-end fillings (4). Although these reports suggest MTA to be a promising root-end filling material, the amount of existing data concerning MTA is very limited, particularly in comparison with standard root-end filling materials.

Research into the long-term sealing ability of MTA should greatly clarify the potential of this material for future use. If MTA is to be accepted as a root-end filling material, its longitudinal sealing ability needs to be known. To date, quantitative measurement of interface microleakage is the best means available to assess the ability of a filling material to adapt to the canal walls and reduce the space available for bacterial transport and colonization. The specific aim of this study was to determine if MTA can effectively seal the root end. Therefore, this study examined the longitudinal sealing ability of MTA, in comparison with amalgam with cavity liner and Super-EBA, using the fluid filtration method (5).

MATERIALS AND METHODS

Seventy-six freshly extracted, single-rooted human teeth with mature apices were used in this study. All teeth were immediately fixed in 10% formalin after extraction. Only maxillary anterior or mandibular premolar teeth were studied, because of the size and shape requirements of the testing methods. Teeth with root fractures, root caries, deep root concavities, or evidence of periradicular resorptive processes were excluded from the study. Additionally, teeth were not accepted if they radiographically demonstrated multiple canals, lateral radicular canals, or significant apical curvatures. Accepted teeth were then transferred to 0.9% sterile saline, supplemented with 0.1% thymol (Sigma Chemical Co., St. Louis, MO) for antibacterial activity and stored 30 days before use. Throughout the experiment, samples remained immersed in this solution and were maintained at 37°C. The storage solution was changed weekly.

The clinical crowns were resected at the cementoenamel junction using a #701 fissure bur in a high-speed handpiece and water spray. The root canals were cleaned and shaped using Flex-R files (Union Broach, New York, NY) and Gates Glidden drills (L. D. Caulk Division, Dentsply Int., Inc., Milford, DE) with 5.25%

sodium hypochlorite as an irrigant. Working lengths were determined by placing a #10 file in the canal until it was visible at the apical foramen and subtracting 1 mm. The canals were then enlarged to a #45 apical canal size using a step-back filing technique.

All canals were dried using paper points and obturated with laterally condensed gutta-percha, with no sealer. The purpose of the gutta-percha was to provide a solid base to support condensation of the root-end filling material. Teeth were radiographed to ensure an adequate apical obturation had been performed. Any that did not demonstrate proper obturation qualities were reobturated until satisfactory form, fill, and density were obtained. Two root samples were randomly selected to serve as negative controls. These were completely sealed with sticky wax at the canal orifice and apical foramen. Two layers of nail polish were applied to the external surface of all root sections and allowed to dry.

The apical 3 mm of each root was resected using a low-speed diamond saw (Isomet; Buehler Ltd., Lake Bluff, IL) and water coolant. A resection angle of 90 degrees to the long axis of the root was developed to minimize the number of exposed-cut dentinal tubules and possible leakage through these (6). Further elimination of filtration through any exposed tubules in the root face was accomplished by sealing the cut dentin with a layer of Scotchbond 2 light-cure, multipurpose dental adhesive (3M Co., St. Paul, MN). This adhesive system was used according to the manufacturer's instructions.

Root-end preparations were performed on all apices in an identical fashion, using telescopic (×2.0) magnification (Orascoptic Research, Inc., Madison, WI). A Neosonic Piezo-Electric ultrasonic unit (Amadent Co., Cherry Hill, NJ) with a universal retropreparation tip (CT-1; Excellence in Endodontics, San Diego, CA) was used with water coolant to create circular preparations 1 mm in diameter and 3 mm in depth. A single periodontal probe served as the measuring device for preparation depth, and a stainless steel template ensured standardization of the preparation diameter. Two prepared root sections were randomly selected to serve as positive controls. The gutta-percha in these samples was withdrawn, and the roots remained unfilled in both the main canal and at the root end.

The remaining 72 prepared roots were randomly divided into three test groups of 24 each. Group 1 samples were apically filled using two air-dried coats of cavity liner (Plastodent; Plastodent, Inc., Bronx, NY) and dental amalgam (Tytin capsules, slowset; Kerr, Romulus, MI), which was mixed according to the manufacturer's instructions. Roots in group 2 were filled with Super-EBA cement (Harry J. Bosworth Co., Skokie, IL), which was also mixed according to the manufacturer's instructions; group 3 received the MTA (Loma Linda University, Loma Linda, CA), which was mixed and handled according to instructions provided by the developers. A 3:1 MTA powder to ultrafiltered (0.2 μm pore size) water weight ratio was used. All preparations were sprayed with a water stream for 5 s and then dried with sterile paper points before placement of fillings. Placement of restorative materials began immediately following mixing, and the condensation process was complete within 1 min from the start of the mix. Each of the materials was condensed into the preparations using one modified condenser. The materials were allowed to set for 30 s and then were carefully carved to the cavosurface margin, after which they were lightly burnished. All procedures were accomplished by one operator (C.F.B.). Immediately after burnishing, all restored roots were placed into vials containing the saline storage solution.

After the restorative materials had set for 24 h, all gutta-percha was extracted using only a hemostat. Rotary instruments, irrigants, or files did not pass into the canal space. Periapical radiographs were taken to verify that filling materials did not bypass the gutta-percha or demonstrate radiographic voids. Filling dimensions were measured from the radiographs to ensure a uniform depth of 3 ± 0.5 mm and width of 1 ± 0.25 mm. Any samples that did not meet these acceptance criteria were discarded and replaced. Twenty-two samples from each group were used in the filtration study.

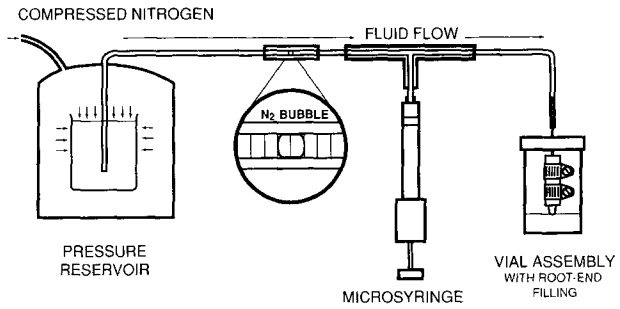

FIG 1. Fluid filtration measurement system. Schematic diagram of the apparatus used to quantitate microleakage. Microleakage was calculated from the linear distance that the nitrogen bubble traveled in the micropipette.

Individual vial-tube assemblies were specially constructed for each root segment. Each vial cap was penetrated with a modified 18-gauge, 1½-inch stainless steel needle (Becton Dickinson & Co., Rutherford, NJ) placed through its center to exit on the outside surface. Modification of the needle consisted of resecting the needle bevel and removing the lip from the plastic hub. Polyethylene tubing was used to connect this needle end of the vial-tube assembly to the fluid filtration device. A 10-mm length of 3/16 inch inside diameter Nalgene Premium tubing (Nalge Co., Rochester, NY) bridged the connection between the modified needle hub and the root segment. The hub and root were inserted into the tubing until contacting one another and then tightly secured with two adjustable hose clamps. All root sections remained attached to their respective vial-tube assemblies throughout this study. The roots were attached to allow for flow of fluid from the coronal aspect of the root toward the root end. Each 20-ml vial (Baxter Diagnostics, Inc., Deerfield, IL) was partly filled with sterile 0.9% saline, in which the root segments remained immersed throughout the study. A second hole was prepared in the vial cap to allow for possible venting during filtration.

The fluid filtration apparatus (5) consisted of a pressurized tank of nitrogen gas, a fluid dye reservoir, polyethylene tubing containing an in-line 25-μl micropipette, a microsyringe assembly, and the root segment attached to the vial-tube assembly (Fig. 1). Microleakage measurements were made by delivering nitrogen gas at a constant pressure of 20 psi to the fluid reservoir, which contained a beaker of FD & C red dye #40 (Adams Extract Co., Austin, TX) in 0.9% sterile saline (1:500 dilution). Dye was added to aid in visualizing movement of the nitrogen bubble. Before use, fresh dye solution was syringe-filtered through a micropore (0.45 μm) cellulose-acetate membrane. Polyethylene tubing connected the pressurized dye solution to the micropipette, which was subsequently connected to the vial-tube assembly. A 5-min pressurization preload of the system was completed before taking readings, to allow for relaxation of the tubing. A 1-mm nitrogen bubble was introduced into the tubing with the microsyringe, until it reached the micropipette. Linear movement of the bubble was viewed against an endodontic ruler that was graduated in 0.5-mm increments.

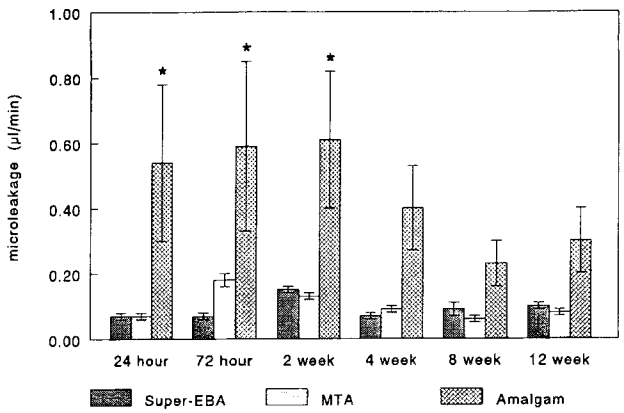

FIG 2. Microleakage of root-end filling materials determined using fluid filtration. Microleakage measurements were obtained using the fluid filtration apparatus described in Materials and Methods. Linear measurements were converted to microliters/minute · 20 psi. Data are expressed as the mean ± SE. *Asterisks* indicate that microleakage in the amalgam group at 24 h, 72 h, and 2 wk is significantly greater than all the other groups ($p < 0.05$).

Telescopic magnification and a digital electronic timing device (Fisher Scientific Co., Pittsburgh, PA) were used for all readings.

The order of sample measurements was completely randomized by a computer software package (Statgraphics Plus, version 6, Manugistics, Inc., 1992). A sampling sequence printout was obtained and followed. Microleakage measurements were obtained at the following time intervals: 24 h, 72 h, 2 wk, 4 wk, 8 wk, and 12 wk after placement of the root-end fillings. The leakage of each sample was measured for 1 min, three times in succession at each test period. Linear measurements were converted to microliters/minute · 20 psi. Variation between readings was insignificant, and only the final 1-min microleakage reading was analyzed for each sample. Positive and negative control samples were examined at the beginning of each experimental session. These data were pooled and examined using the Statgraphics Plus statistical analysis program. The main effects of material type and time were analyzed individually and in interaction using a repeated measures analysis of variance to determine the presence of significant differences in microleakage ($p < 0.05$). One-way analysis of variance was subsequently used to evaluate for the presence of significant differences between material groups at the six experimental periods. Duncan's multiple range analysis at the 95% confidence level served as the post-hoc test.

RESULTS

Mean microleakage measurements and standard errors, in microliters/minute · 20 psi, are shown in Fig. 2 for all materials at each time period. MTA demonstrated the least amount of microleakage among the tested materials during four of the six experimental periods, including the 8- and 12-wk observations. The amalgam samples demonstrated the greatest amount of microleakage, as well as the greatest variability of individual readings at all experimental time periods. Maximum amalgam microleakage was evident at 24 h. Microleakage remained at maximum through 2 wk, after which microleakage began to decrease. Mean microleakage measurements for the amalgam group ranged from 0.23 to 0.61 µl/min · 20 psi. Microleakage was similar in the MTA and Super-EBA groups throughout the entire experiment. Mean microleakage measurements for MTA ranged between 0.06 and 0.18 µl/min · 20 psi, whereas those for Super-EBA ranged from 0.07 to 0.15 µl/min · 20 psi.

Statistical analysis of the data indicated that microleakage in the MTA group, as well as the Super-EBA group, was significantly less ($p < 0.05$) than in the amalgam with cavity liner group at 24 h, 72 h, and 2 wk. At the subsequent 4-, 8-, and 12-wk experimental periods, there were no statistically significant differences among the amalgam with cavity liner, Super-EBA, and MTA groups.

The positive controls demonstrated extreme amounts of leakage at all time periods. No significant difference was detected over the experimental period. The unobstructed flow of dye solution was too rapid to permit measurement of bubble movement in the usual manner. Instead, solution was collected in a graduated cylinder for 60 s, and the leakage was converted to microliters/minute. Mean leakage for the positive controls was observed to be 8000 µl/min · 20 psi. The negative controls registered no detectable bubble movement at 20 psi, for a minimum of 5 min before each data collection period began. A single sample root section was lost (group 1) early in the study because of a root fracture. Samples were routinely examined outside the vial, for any evidence of leakage away from the tooth-restoration interface.

DISCUSSION

In this study, we chose to compare MTA to the two most common root-end filling materials in use today. MTA demonstrated excellent sealing ability throughout 12 wk of fluid immersion, comparable with that observed for Super-EBA. Both MTA and Super-EBA demonstrated remarkable stability in sealing ability throughout the study. Neither showed evidence of deterioration in the ability to restrict fluid movement along the walls of the canal preparation. Amalgam showed much less consistency in sealing ability. Variation was quite high, typically in the direction of increased microleakage. In spite of consistent material handling, several amalgam specimens leaked considerably, enough to develop visible liquid droplets at the root ends within 10 s. The ability of these restorations to seal bacteria adequately or their endotoxins within a root canal system would certainly be doubtful. Amalgam microleakage was particularly evident during the early (24 h to 2 wk) portion of the study, when it was significantly ($p < 0.05$) elevated compared with the MTA and Super-EBA groups. During this interval, the average amalgam root-end filling allowed up to eight times the amount of fluid transport as these other materials. Clinically, such early, extreme leakage could adversely affect the developing osseous and soft tissue healing processes. Although there was no statistically significant difference in the microleakage observed during the later section of the study, the mean amalgam microleakage remained three times that of MTA and Super-EBA at 12 wk. A 3-fold increase in the degree of periradicular contamination might be of clinical significance, particularly in cases of a poor coronal seal, and/or an incompletely debrided canal.

The findings of this study support previous studies that reported the excellent sealing properties of MTA (1–3). It was shown that MTA could withstand fluid immersion and filtration with no loss of sealing ability, for a period of 12 wk. This study has also demonstrated that the ability of MTA to prevent microleakage was comparable with that of Super-EBA. In some previous studies (1–3), MTA was reported to be significantly superior to amalgam, Super-EBA, and IRM in preventing microleakage. Methodological

differences may explain this discrepancy. Passive dye and/or bacterial solution penetration methods used in the earlier studies require that the liquid reach the material. By contrast, the high-pressure (20 psi) fluid filtration method used in this study should have eliminated air entrapment as a variable.

Validity of the many techniques used to measure microleakage has been undergoing considerable scientific examination. Historically, investigators have evaluated quality of the apical seal by the degree of dye, radioisotope, or bacterial penetration; electrochemical means; scanning electron microscopy; or fluid filtration. The most frequently used method is undoubtedly dye penetration. This technique has the main disadvantage of being semiquantitative in design, often involving only one plane of view. Dye penetration techniques do not provide any information concerning the volume of tracer that actually penetrates the interface void (7). By contrast, the fluid filtration technique used in the present study is a relatively new method, first described by Pashley et al. (8). Modified by Derkson et al. (5), fluid filtration allows evaluation of the longitudinal ability of a material to resist microleakage, when challenged with a fluid under pressure. Most importantly, measurements reflect the cumulative leakage of the entire tooth-restoration interface and are therefore quantitative. Several investigators have successfully used the fluid filtration methodology to study the sealing ability of root-end fillings (6, 9–11). Fluid filtration is the most clinically relevant method currently available to measure the ability of a root-end filling to create a fluid-tight seal.

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