JOURNAL OF ENDODONTICS
Copyright © 2004 by The American Association of Endodontists

Printed in U.S.A.
VOL. 30, NO. 9, SEPTEMBER 2004

Sealing Ability of One-Up Bond and MTA With and Without a Secondary Seal as Furcation Perforation Repair Materials

Ike Hardy, DMD, Frederick R. Liewehr, DDS, MS, Anthony P. Joyce, DDS, Kelli Agee, BS, and David H. Pashley, DMD, PhD

This study investigated the ability of One-Up Bond alone and mineral trioxide aggregate (MTA), with and without a secondary seal of One-Up Bond or Super-EBA to seal saucer-shaped perforation defects in human molars. Cusps were removed, roots were amputated, and endodontic therapy completed on 40 extracted teeth. A cylindrical hole was made in each tooth from the furcation area to the chamber, into which a section of steel tubing was cemented. Intracoronal saucer-shaped defects were created over the perforation. The teeth were restored with MTA, One-Up Bond, or MTA with a secondary seal of One-Up Bond or SuperEBA. The integrity of the seal was evaluated by fluid filtration. MTA alone leaked significantly more than One-Up Bond or MTA with either secondary seal at 24 h. At 1 month, MTA, MTA plus One-Up Bond, and One-Up Bond alone were equivalent.

Furcation perforations that occur during endodontic treatment often result in loss of periodontal attachment and ultimately the involved tooth. Difficulties encountered when repairing furcation perforations include inadequate sealing of the defect (1), extrusion of the repair material (2), and inadequate material biocompatibility (3). Various materials and techniques have been tested but have failed to produce a consensus recommendation among researchers (4).

For optimum results, the repair should be made immediately (5, 6), bacterial contamination minimized (3), and a repair material selected that is biocompatible, has good sealing properties, and can be controlled to prevent extrusion into the furcation region (7). A successful repair will result in the reattachment of the periodontal structures (8).

MTA has been recommended for the treatment of furcation perforations. Weldon et al. (9) determined that MTA produces a good seal to fluid flow at a physiologic pressure of 20 cm H_20. Pitt Ford et al. (6) found that it is biocompatible and can be extruded without harmful sequelae. According to Schwartz et al. (10), it is the only restorative material that consistently allows for the overgrowth of cementum, and it may facilitate the regeneration of the periodontal ligament (PDL). Although resin restorative materials have been shown to bond well to pulp chamber dentin (11), their biocompatibility has not been fully evaluated.

The purpose of this in vitro study was to investigate the ability of MTA, One-Up Bond, and MTA with a secondary seal of One-Up Bond or SuperEBA to seal saucer-shaped furcation perforations in human molars using a fluid-filtration model operated at physiologic pressure.

MATERIALS AND METHODS

Fifty, extracted, human molars with nonfused roots were stored in physiologic saline with 0.2% sodium azide (Sigma Chemical Co., St. Louis, MO) until use: 10 teeth to be used as control teeth and 40 for use as experimental teeth. One investigator (I.H.) performed all procedures. Cusps were removed from all teeth perpendicular to their long axes and roots were amputated 3 mm below the furcation using an Isomet saw (Buehler Ltd., Lake Bluff, IL). Access openings were made, canals were prepared with Flexofiles (Dentsply Maillefer, Tulsa, OK), and obturated by lateral condensation with gutta-percha cones and Roth's 801 sealer (Henry Schein Inc., Port Washington, NY).

A 1-mm deep, blind hole was made in the center of the furcation of each of the 40 experimental teeth from the PDL side with a #959 size 014 end-cutting bur (Brasseler USA, Savannah, GA). A short section of 18-gauge stainless steel tubing was forced into the hole and cemented with resin cement (C&B Metabond, Parkell, Farmingdale, NY). A #80 (0.34 mm) drill bit (SME Inc., Shanghai, China) was placed inside the 18-gauge tubing and used to perforate the floor of the chamber using a miniature drill press (Servo Products Co., Pasadena, CA), and a 1-mm deep, saucer-shaped defect was created over this hole in the chamber floor with a #10 round slow-speed bur (Brasseler USA). A 20-mm length of 20-gauge solid wire was temporarily placed into the 18-gauge tubing during the repair procedure to prevent furcation-repair material from flowing into the tubing.

The teeth were soaked in 5.25% NaOCl for 5 min, rinsed with copious amounts of water, dried to simulate the effects of endodontic irrigation during cleaning and shaping, and randomly divided into 4 groups of 10 teeth each. In group 1, MTA (ProRoot,

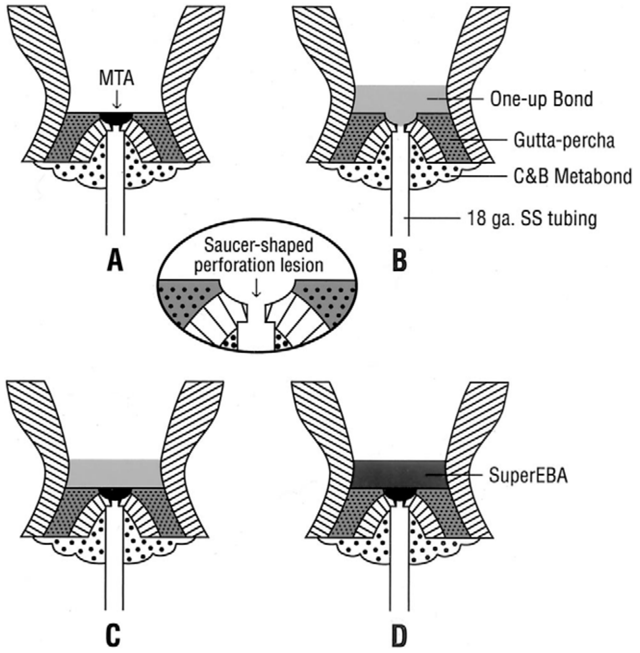

FIG 1. Tooth specimens showing the furcation perforation, the saucer-shaped defect, the attachment of the 18-gauge steel tubing into the furcation hole with C&B Metabond (*spaced speckles*) and the gutta-percha-filled root canals (*tight speckles*). (*A*) Perforation repaired with MTA (*black*). (*B*) Perforation repaired with One-Up Bond (*light gray*). (*C*) Perforation repaired with MTA (*black*) and covered with 2 mm of One-Up Bond (*light gray*) as a secondary seal. (*D*) Perforation repaired with MTA (*black*) and covered with 2 mm of Super-EBA (*lighter black*) as a secondary seal. (*Center*) Close up schematic of the saucer-shaped perforation lesion.

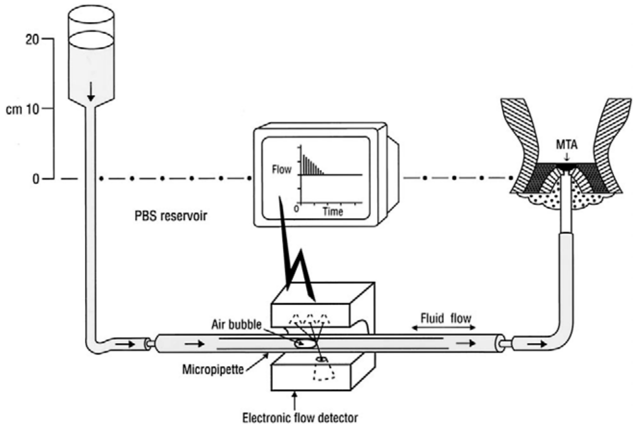

FIG 2. Tooth specimen connected via tubing to a Flodec device used to measure fluid flow in a micropipette under a pressure of 20 cm of H_20.

Dentsply/Tulsa) was mixed according to manufacturer's recommendations, placed into the broad, shallow defect with an Endogun (Medidenta Int. Inc., Woodside, NY), and compacted with Schilder pluggers until the material was flush with the chamber floor (Fig. 1A). A cotton pellet moistened with saline was placed in the pulp chamber against the MTA. In group 2, One-Up Bond (Tokuyama Corp., Tokyo, Japan) was mixed according to the manufacturer's recommendations and placed with the microbrushes included in the kit to a depth of 2 mm across the chamber floor and over the root canal orifices, and light-cured for 20 s (Fig. 1B). The perforations in group 3 were repaired with MTA in the same manner as group 1, after which 2 mm of One-Up Bond were placed over the MTA and light cured (Fig. 1C). The perforations in group 4 were repaired with MTA in the same manner as group 1, after which two mm of SuperEBA (Harry J. Bosworth Co., Skokie, IL) were placed over the MTA and allowed to set (Fig. 1D). Ten teeth were not perforated and served as the negative controls. The same 10 teeth were then perforated and not repaired and served as the positive controls. All teeth were placed in a closed container at 100% relative humidity at 37°C for storage for 1 day and 1 month.

Microleakage assessment was conducted under a pressure of 20-cm H_20 using the fluid-filtration technique described by Derkson et al. (12). The cotton pellets were removed from the pulp chambers of group 1. The 18-gauge tubing connected to the specimen was filled with water using a 27-gauge needle to remove all air bubbles and connected to the Flodec device containing a micropipette system (DeMarco Engineering, Geneva, Switzerland) via polyethylene tubing (Fig. 2). The connected specimen was placed into a beaker of distilled water during the microleakage measurements to avoid evaporative water loss. Fluid filtration pressure was applied to each sample for 4 min, comprising four 1-min measuring intervals. These four values were averaged. The direction of filtration was always from the furcation toward the pulp chamber. The specimens were tested at 24 h and 1 month. After each test period, the samples were returned to their storage container.

Fluid conductance, in microliters per minute per centimeter of H_20 pressure (μl min^{-1} cm H_20^{-1}) was calculated for each specimen at each time period. The data were analyzed by a two-way ANOVA, and significant differences were isolated by the Student-Newman-Keuls method ($p < 0.05$).

After the experiment, two teeth from each group were sectioned through the repaired perforations to permit measurement of the remaining dentin thickness and the thickness of the restorative materials with a videomicrometer system (Micro Enterprises, Inc., Norcross, GA). The data were analyzed by a one-way ANOVA.

RESULTS

All groups leaked significantly less than the positive controls ($p < 0.05$). All materials sealed the perforations well, both initially and during the 1-month duration of the study (Table 1). There was no significant difference between any of the groups and the negative controls. MTA alone leaked significantly more than One-Up Bond alone or when combined with One-Up Bond or SuperEBA at 24 h. ($p < 0.05$). There was no significant difference between MTA with a secondary seal of One-Up Bond or SuperEBA at 24 h. At 1 month, MTA with a secondary seal of SuperEBA leaked more than MTA with One-Up Bond; the other groups were statistically equivalent. With time, the seal of MTA improved, whereas that of One-Up alone or MTA with SuperEBA worsened. There were no significant differences in remaining dentinal thickness or in the thickness of the repair materials among the four groups.

DISCUSSION

To allow periodontal healing, a perforation material must provide a leak-proof seal to ensure that contaminants within the tooth cannot reach the periodontal ligament in which the resultant in-

TABLE 1. Microleakage of perforation repairs with time

Time	Fluid Flow (μl min^{-1} cm H$_2$O^{-1})			
	Material			
	MTA	OneUp Bond	MTA + OneUp Bond	MTA + SuperEBA™
24 h	0.012 ± 0.004 (10)^{a}	0.002 ± 0.002 (10)^{b}	0.004 ± 0.001 (10)^{b}	0.005 ± 0.003 (10)^{b}
1 month	0.006 ± 0.003 (10)^{b}	0.006 ± 0.006 (10)^{b}	0.005 ± 0.002 (10)^{b,c}	0.010 ± 0.005 (10)^{b}

Groups identified by the same superscript letters are not significantly different ($p > 0.05$).
Different letters identify significantly different groups ($p < 0.05$).

flammation would compromise repair. The material also must be biocompatible, so that inflammation does not result as a reaction to the material itself (13). MTA has been shown to leak less than amalgam and Super EBA (14, 15) when used as a perforation repair material, and has been shown to be less cytotoxic (16, 17) and neurotoxic (18) than other repair materials. Bonded resins have the potential to provide a good seal through their intimate adherence to dentin (11), but may not perform well when used to repair perforations because of their exposure to moisture through the perforation site (19). Additionally, some of these materials may be cytotoxic (20). Despite its advantages, MTA may be inconvenient to use clinically because the manufacturer's directions require that it be covered by a wet cotton pellet and left for at least 3 to 4 h to set (21). Thus, repair of a perforation discovered or produced during endodontic therapy requires termination of the procedure and reappointment of the patient after the material has hardened, which is inexpedient for both the patient and the practitioner.

Clinical directions (21) recommend packing MTA into the perforation to give it mechanical support during the hardening process. However, many perforations created while searching for sclerosed canals present as broad, shallow, saucer-shaped lesions with pinpoint perforations that have no confining walls to stabilize the MTA. Therefore, unlike most in vitro perforation studies that use a hole drilled into the furcation area into which the repair material may be easily placed and retained, we designed our experimental perforations to simulate a saucer-shaped preparation without walls.

SuperEBA has good adhesive properties; however, histological studies have shown no PDL/cementum repair when this material is extruded into the PDL space (10, 22). In contrast, MTA has been shown to permit PDL/cementum repair (6), but shows little adhesion to dentin and has a very long setting time. One-Up Bond is a self-etching, self-priming, one-step material that does not require drying of the dentin before application, which avoids air-drying that could dehydrate the MTA and assures that the material will bond despite moisture. It also is extremely easy and fast to use, requiring less than 1 min from the time it is mixed until it is set. Its biocompatibility has not been investigated and will be the subject of future research. Recent reports of excellent sealing of root canals by the application of intracoronal secondary seals (11, 23–25) suggested that they might also stabilize MTA at perforation sites. In our study, we attempted to combine the biocompatibility of MTA with the use of adhesive materials that would stabilize it in saucer-shaped lesions and allow root canal therapy to be continued if desired.

Clinically, the operator would immediately repair the defect with MTA, block out the canals with gutta-percha, place the secondary seal material over the MTA, remove the gutta-percha, and continue the endodontic therapy. Although the material would not be allowed to set under a wet cotton pledget for the recommended 3 to 4 h, this step may be unnecessary, because tissue fluid from the PDL side of the lesion would likely be accessible. Sluyk et al. (26) found that when used as a perforation repair material, there was no difference in the seal produced whether the MTA was covered with a wet or dry cotton pellet and concluded that sufficient moisture may be available from the periodontal tissues to ensure hydration and proper setting. We placed the MTA only in the defect, rather than covering the floor of the chamber, because a clinician would be unable to work through the wet MTA. We covered the floor with the other materials, however, because they could easily be temporarily blocked out of the canals with gutta-percha points.

Fluid filtration was chosen for leakage assessment in this study because it permits quantitative, nondestructive measurements of microleakage during longitudinal time periods. We attempted to simulate in vivo conditions by subjecting the repaired perforations to the physiologic pressures that exist in the marrow spaces of bone. Held and Thron (27) obtained a marrow space pressure of 10 to 20 mmHg (13.5–27 cm H_20), and Christiansen et al. (28) reported a mandibular marrow pressure in dogs of 20 ± 6 mmHg (15 ± 3 cm H_20). Therefore, because the furcation is in direct communication with alveolar marrow spaces via venules passing from the PDL to the marrow, we subjected the furcation repair to a pressure of 20 cm of H_20 during microleakage testing. This is a much lower pressure than that used in previous fluid-filtration experiments measuring microleakage (29).

Filtration results indicated that MTA leaked more at 24 h than One-Up Bond, probably because the resin instantly bonded to the dentin, whereas the unset MTA, particularly without retaining walls against which it could be packed, was not yet stable. The 1-month leakage figures demonstrated that MTA can, if allowed to set undisturbed, provide a leak-proof seal even when used in saucer-shaped defects. The use of either adhesive material, One-Up Bond or SuperEBA, with the MTA provided an immediate seal equivalent to MTA that had been allowed to set, and would allow continuation of endodontic therapy. With time, the seal of the SuperEBA decreased slightly, whereas that of the One-Up Bond remained the same.

Sectioning the restored teeth through the plane of perforation to ensure that One-Up Bond or SuperEBA did not flow down through the MTA, thereby encapsulating or embedding it, revealed that the bottom half of the perforation contained only MTA. Therefore, because only the MTA is in contact with the periapical tissues, the perforations should heal normally, with the production of a cementum seal (6). Further in vivo tests of this procedure are indicated to ensure that MTA still promotes a biocompatible seal of furcation perforations in the presence of these adhesives.

This study is the work of the United States government and may be reprinted without permission. Opinions expressed herein, unless otherwise specifically indicated, are those of the authors. They do not represent the views of the Department of the Army or any other Department or Agency of the United States Government.

Dr. Hardy is former resident, Dr. Liewehr is former program director, and Dr. Joyce is director, U.S. Army Endodontic Residency Program, Fort Gordon, GA. Ms. Kelli Agee is research assistant, and Dr. Pashley is Regents' Professor, Department of Oral Biology and Maxillofacial Pathology, Medical College of Georgia, Augusta, GA.

Address correspondence to Dr. Frederick R. Liewehr, E-mail: doctorendo@comcast.net.

References

1. ElDeeb ME, ElDeeb M, Tabibi A, Jensen JR. An evaluation of the use of amalgam, Cavit, and calcium hydroxide in the repair of furcation perforations. J Endod 1982;8:459–66.
2. Himel VT, Brady J Jr, Weir J. Evaluation of mechanical perforations of the pulp chamber floor using bio-degradable tricalcium phosphate or calcium hydroxide. J Endod 1985;11:161–5.
3. Arens DE, Torabinejad M. Repair of furcal perforations with mineral trioxide aggregate: two case reports. Oral Surg 1996;82:84–8.
4. Bryan EB, Woollard G, Mitchell WC. Nonsurgical repair of furcal perforations: a literature review. Gen Dent 1999:274–8.
5. Seltzer S, Sinai I, August D. Periodontal effects of root perforations before and during endodontic procedures. J Dent Res 1970;49:332–9.
6. Pitt Ford TR, Torabinejad M, McKendry DJ, Hong CU, Kariyawasam SP. Use of mineral trioxide aggregate for repair of furcal perforations. Oral Surg 1995;79:756–63.
7. Lemon RR. Nonsurgical repair of perforations defects. Dent Clin North Am 1992;36:439–57.
8. Himel VT, Alhadainy HA. Effect of dentin preparation and acid etching on the sealing ability of glass ionomer and composite resin when used to repair furcation perforations over plaster of Paris barriers. J Endod 1995;21:142–5.
9. Weldon JK, Pashley DH, Loushine RJ, Weller RN, Kimbrough WF. Sealing ability of mineral trioxide aggregate and Super-EBA when used as furcation repair materials: a longitudinal study. J Endod 2002;28:467–70.
10. Schwartz RS, Mauger M, Clement DJ, Walker WA III. Mineral trioxide aggregate: a new material for endodontics. J Am Dent Assoc 1999;130:967–75.
11. Belli S, Zhang Y, Pereira PNR, Pashley DH. Adhesive sealing of the pulp chamber. J Endod 2001;27:521–6.
12. Derkson GD, Pashley DH, Derkson ME. Microleakage measurement of selected restorative materials: a new in vitro method. J Prosthet Dent 1986;56:435–40.
13. Dazey S, Senia ES. An in vitro comparison of the sealing ability of materials placed in lateral root perforations. J Endod 1990;16:19–23.
14. Torabinejad M, Watson FT, Pitt Ford TR. Sealing ability of a mineral trioxide aggregate when used as a root end filling material. J Endod 1993;19:591–5.
15. 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.
16. Osorio RM, Hefti A, Vertucci FJ, Shawley AL. Cytotoxicity of endodontic materials. J Endod 1998;24:91–6.
17. Keiser K, Hohnson CC, Tipton DA. Cytotoxicity of mineral trioxide aggregate using human periodontal ligament fibroblasts. J Endod 2000;26:288–91.
18. Asrari M, Lobner D. In vitro neurotoxic evaluation of root-end-filling materials. J Endod 2003;29:743–6.
19. Daoudi MF, Saunders WP. In vitro evaluation of furcal perforation repair using mineral trioxide aggregate or resin modified glass ionomer cement with and without the use of the operating microscope. J Endod 2002;28:512–5.
20. Huang F-M, Tai K-W, Chou M-Y, Chang Y-C. Resinous perforation: repair materials inhibit the growth, attachment, and proliferation of human gingival fibroblasts. J Endod 2002;28:291–4.
21. Torabinejad M, Chivian N. Clinical applications of mineral trioxide aggregate. J Endod 1999;25:197–205.
22. Suehara M, Morinaga K, Nakagawa KI. Tissue reactions of furcation perforations in dog teeth after application of mineral trioxide aggregate of reinforced zinc oxide eugenol cement [Abstract]. Jpn J Cons Dent 2001;44:66.
23. Pisano DM, DiFiore PM, McClanahan SB, Lautenschlager EP, Duncan JL. Intraorifice sealing of gutta-percha obturated root canals to prevent coronal microleakage. J Endod 1998;24:659–62.
24. Wolanek GA, Loushine RL, Weller RN, Kimbrough WF, Volkmann KTC. In vitro bacterial penetration of endodontically treated teeth coronally sealed with a dentin-bonding agent. J Endod 2001;27:354–7.
25. Galvan RR, West LA, Liewehr FR, Pashley DH. Coronal microleakage of five materials used to create an intracoronal seal in endodontically treated teeth. J Endod 2002;28:59–61.
26. 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.
27. Held D, Thron HL. Études sur la circulation de l'os. I. La pression tissulaire de la moelle. Arch Sci Physiol (Paris) 1962;16:167–77.
28. Christiansen RL, Meyer MW, Visscher MB. Tonometric measurement of dental pulpal and mandibular marrow blood pressure. J Dent Res 1977;56:635–45.
29. Welch JD, Anderson RW, Pashley DH, Weller RN, Kimbrough WF. An assessment of the ability of various materials to seal furcation canals in molar teeth. J Endod 1996;22:608–11.