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SCIENTIFIC ARTICLES

Comparative Investigation of Marginal Adaptation of Mineral Trioxide Aggregate and Other Commonly Used Root-End Filling Materials

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This study investigated the marginal adaptation of mineral trioxide aggregate (MTA) as a root-end filling material, compared with commonly used root-end filling materials by scanning electron microscopy (SEM). Eighty-eight single-rooted freshly extracted human teeth were cleaned, shaped, and obturated with gutta-percha and root canal sealer. Following root-end resection and cavity preparation, the root-end cavities were filled with amalgam, Super-EBA, Intermediate Restorative Material (IRM), or MTA. Using a slow-speed diamond saw, 40 roots were longitudinally sectioned into two halves. Resin replicas of resected root ends of the remaining nonsectioned roots were also prepared. After mounting longitudinal sections of roots and resin replicas of resected roots on aluminum stubs, the distance between the test root-end filling materials and surrounding dentin was measured at four points under SEM. Examination of the original samples showed numerous artifacts in the longitudinal sections of the specimens. In contrast, the resin replicas of resected and filled root ends had no artifacts. Statistical analysis of data comparing gap sizes between the root-end filling materials and their surrounding dentin shows that MTA had better adaptation compared with amalgam, Super-EBA, and IRM.

When nonsurgical root canal treatment fails to resolve periradicular lesions of endodontic origin or retreatment is contraindicated, surgical endodontic treatment may be needed. This treatment consists of exposing the involved apex, resecting the root end, preparing a class I cavity, and filling this cavity with a root-end filling material. Investigators have reported that insufficient apical seal is a major cause of surgical endodontic failures (1, 2); root-end cavities should be filled with biocompatible substances that prevent egress of potential contaminants into the periradicular tissues.

The quality of apical seal obtained by root-end filling materials has been assessed by the degrees of dye penetration (3–5), radioisotope penetration (6–8), bacterial penetration (9), electrochemical means (10), and fluid filtration technique (11, 12). In an in vitro dye leakage study using methylene blue dye, Torabinejad et al. (5) evaluated the sealing ability of amalgam, Super-EBA, Intermediate Restorative Material (IRM), and mineral trioxide aggregate (MTA) as root-end filling materials, and showed that MTA leaked significantly less than all the other materials. In another study, they determined the time needed for *Staphylococcus epidermidis* to penetrate around 3-mm-thick root-end fillings of amalgam, Super-EBA, IRM, or MTA, and found MTA leaked significantly less than the other materials ($p < 0.05$) during a 90-day period (9).

In addition to these techniques, confocal microscopy (4, 13) and scanning electron microscopy (SEM) have also been used to assess the adaptation and sealing ability of commonly used and potential root-end filling materials (12, 14–16). Using the confocal microscope, Torabinejad et al. (13) compared the sealing ability of MTA with those of amalgam and Super-EBA and found that MTA leaked significantly less than the others.

Moodnik et al. (14) used the SEM to measure "defects" in the amalgam-dentin interface on amalgam retrofillings and found gaps ranging from 6 to 150 μm. Tanzilli et al. (15) used SEM to determine marginal adaptation of some retrofilling techniques to dentin and found that cold-burnished gutta-percha had smaller defects than heat-sealed gutta-percha and amalgam as root-end filling materials. Stabholz et al. (8, 16) compared the marginal adaptation of several materials using SEM with the sealing ability of the same materials using a radionuclidic model and found a correlation. However, Yoshimura et al. (12) found a lack of correlation between the microleakage (using pressurized fluid filtration) of amalgam and its marginal adaptation under SEM. A lack of correlation was also reported by Abdal and Retief (3), who used

SEM and passive dye penetration to determine the sealing ability of potential root-end filling materials.

The purpose of this study was to investigate the marginal adaptation of MTA, amalgam, Super-EBA, and IRM, comparing original longitudinal sections with resin replicas of root-end-filled teeth under SEM.

MATERIALS AND METHODS

To measure the gap size between the root-end filling materials and dentin, longitudinal sections of root-end-filled teeth, as well as resin replicas of resected root ends, were prepared.

Preparation of Teeth for Longitudinal Sections

Forty single-rooted freshly extracted human teeth were used for this part of the study. After extraction, the teeth were fixed in 10% buffered formalin and kept at 4°C in a refrigerator for <4 wk before use. Following previously described procedures (13), the root canals were cleaned, shaped, and obturated with gutta-percha and Roth root canal sealer (Roth Intl., Ltd., Chicago, IL) before the teeth were apicected with a fissure bur under constant water spray. After preparing a 3-mm-deep root-end cavity with a 170 L fissure bur on the resected root end, each cavity was filled with amalgam (Sybraloy, Kerr Mfg. Co., Romulus, MI), Super-EBA (Harry J. Bosworth Co., Skokie, IL), IRM (L. D. Caulk Co., Milford, DE), or MTA (Loma Linda University, Loma Linda, CA), and stored in 100% humidity for 48 h.

Using a slow-speed diamond saw (Labcut Agar Scientific, Cambridge, England), the roots were longitudinally sectioned into two halves. Dehydration of tooth samples was performed in a graded series of aqueous ethanol (30, 50, 70, 90, and 100%) for 10 min at each concentration. Each half was mounted on an aluminum stub, sputter-coated with gold and examined under a Philips XL 20 SEM (Philips, Eindhoven, the Netherlands).

The distance between the root-end filling materials and cavity walls was measured to the nearest 0.01 μm directly in the SEM at four corners of each half of the specimen (Fig. 1) by an observer who was not aware of the nature of the study. The means ± SDs were calculated. One-way ANOVA and Newman-Keuls multiple comparisons were used to determine statistical differences between the groups.

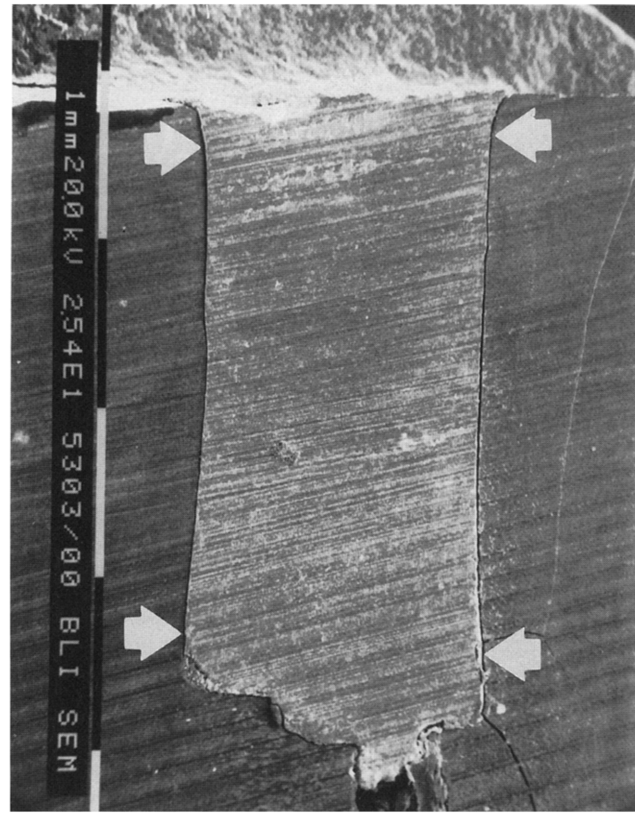

Fig 1. Scanning electron micrograph of longitudinal section of original sample filled with amalgam, with *arrows* showing points where gaps were measured (original magnification ×25). Note variable gaps between amalgam and dentinal walls, and the presence of cracks in dentin.

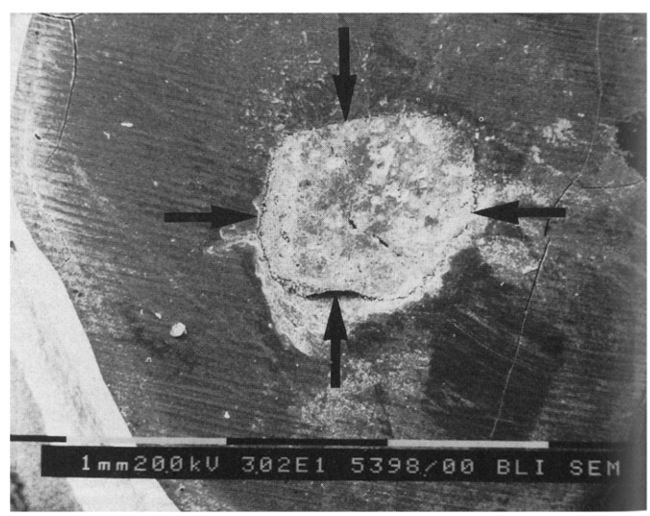

Fig 2. Scanning electron micrograph of an original root-end cavity filled with Super-EBA, with *arrows* showing points where gaps were measured (original magnification ×30).

Preparation of Resin Replicas

Another 48 single-rooted freshly extracted human teeth were fixed, stored, cleaned, shaped, obturated, and apicected as described. Root-end cavities were prepared in 24 resected root ends using a bur. These were then divided into four equal groups of six each and filled with the test root-end filling materials. With the use of ultrasonic tips (Excellence in Endodontics, San Diego, CA), 3-mm-deep root-end cavities were prepared in the remaining 24 roots. These roots were also divided into four equal groups of six roots each, and were filled with the test materials and stored in 100% humidity for 48 h. After filling plastic trays to a depth of 3 mm with a slow setting Epoxy Resin (Buehler Ltd., Lake Bluff, IL), the coronal ends of roots (12 at a time) were placed in the resin and the set-ups were placed in a humidifier for 24 h. An impression of resected root ends was taken by using a polysiloxane impression material (Reprosil Hydrophilic Vinyl Polysiloxane, L. D. Caulk Co.). After mixing an epoxy resin (Magnolia Plastics, Inc., Chamblee, GA) in a ratio of 1:1, as recommended by the manufacturer, the resin models were poured and placed in an oven preheated to

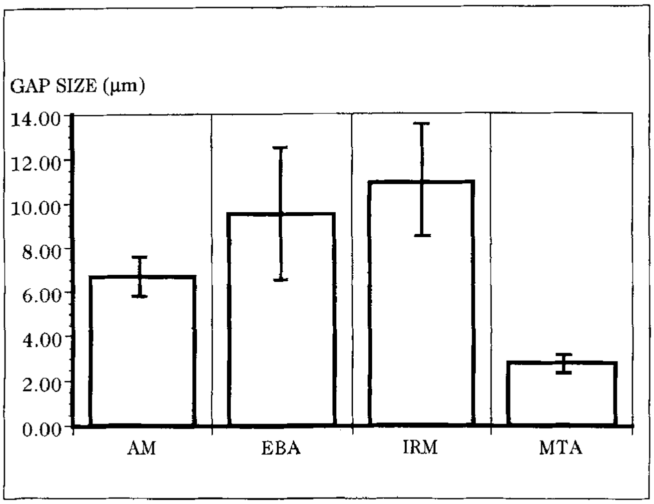

FIG 3. Mean gaps (μm) between the filling materials and dentinal walls in longitudinal sections. *Bars* = SEs; *AM* = amalgam.

60°C overnight. The replicas were removed, individually trimmed and mounted (without dehydration) on aluminum stubs, sputter-coated, and examined under the SEM. The distance between the root-end filling materials and the dentin of the cavity walls was measured by the same method as previously described at four points (Fig. 2). The means ± SDs were calculated. Kruskal-Wallis one-way ANOVA and multiple comparisons were used to determine statistical differences between various groups.

RESULTS

The SEM examination of the longitudinal sections of the root-end-filled teeth showed cracks in the tooth substance and increased marginal gaps at the dentin-filling interface. Figure 1 is a representative picture of a root-end cavity filled with amalgam. Figure 3 shows the means ± SEs of gaps found at the four corners between the materials and dentinal walls. Variable gaps were observed between the materials and dentinal walls. MTA had the smallest gaps (2.68 ± 1.35 μm), whereas IRM had the largest gaps (11.00 ± 7.9 μm) and poorest adaptation among the four materials. The gaps observed between the root-end cavity walls and Super-EBA and amalgam were smaller than those with IRM, but larger than those in cavities filled with MTA. One-way ANOVA showed that there were significant statistical differences between the materials ($p < 0.0001$). The Newman-Keuls multiple comparisons showed significant differences between MTA and the other root-end filling materials ($p < 0.01$); no significant differences were found between the other materials.

The apical surfaces of resected root ends of the second group of teeth viewed directly also showed cracks in dentin and marginal gaps around the root-end fillings (Fig. 2). In contrast to teeth viewed directly (Figs. 1 and 2), the resin replicas of resected root ends revealed no cracks. Figure 4 shows representative resin replicas of the apical surfaces of root-end cavities filled with the test materials. Figure 5 shows the mean gaps found at the apical dentin-material interfaces from resin replicas. Comparing the gaps observed in longitudinal sections with those seen in resin replicas, the gaps were smaller in replicas. The method by which the root-end cavities were prepared (ultrasonic versus bur) had no significant effect on the gap sizes between root-end filling materials and their surrounding dentin. Every sample filled with IRM had gaps, which ranged from 3.8 to 14.6 μm (with mean 8.37 ± 4.61 μm). Six of 12 samples filled with amalgam had no apparent gaps. The maximum gap found between amalgam and dentin was

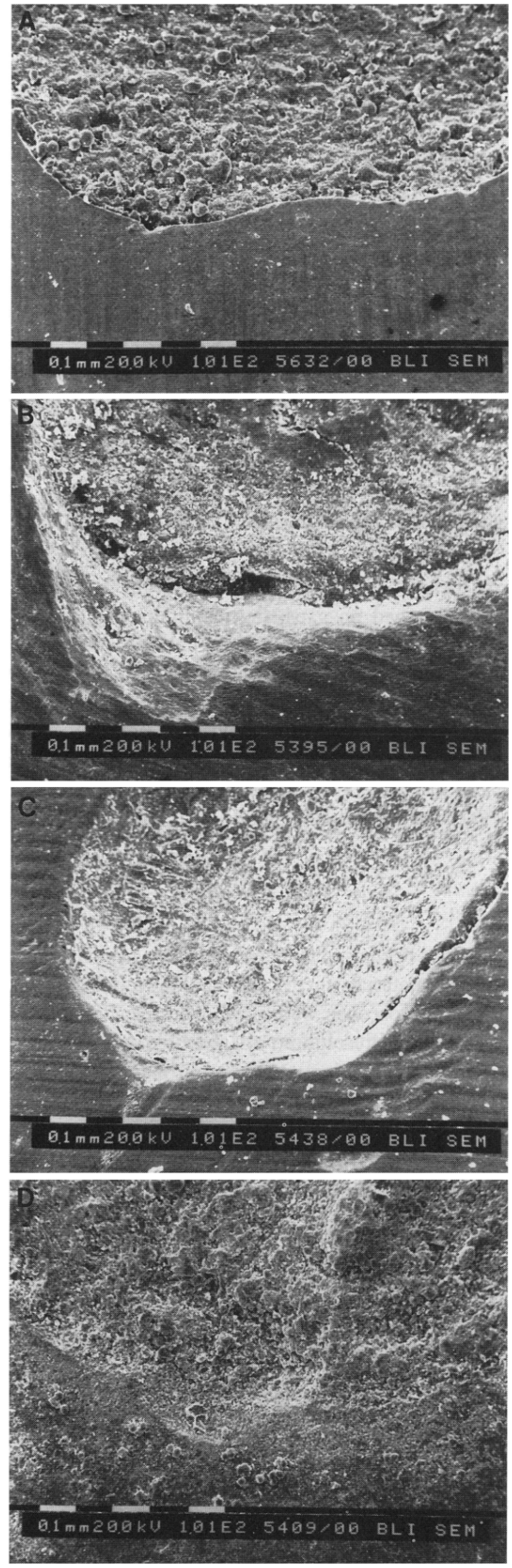

FIG 4. Scanning electron micrographs of replicas of resected root ends filled with (*A*) amalgam, (*B*) Super-EBA, (*C*) IRM, and (*D*) MTA (original magnification ×100).

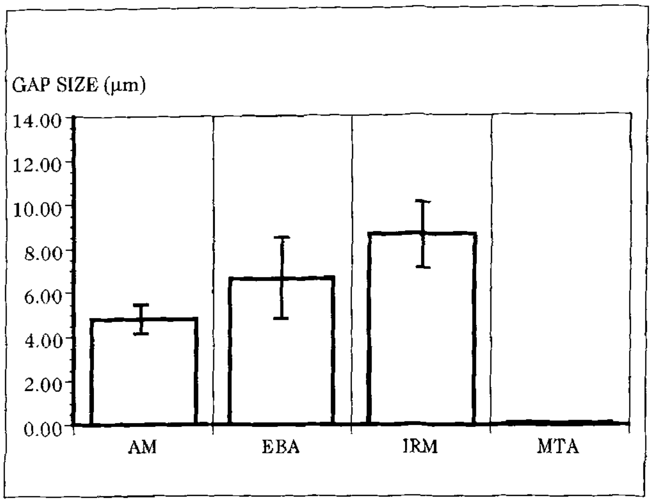

FIG 5. Mean gaps (μm) between root-end filling materials and dentinal walls from resin replicas. *Bars* = SEs; *AM* = amalgam.

18.8 μm (mean 4.8 ± 5.65 μm). Six of the teeth filled with Super-EBA also had no gaps; the maximum gap was 14.9 μm (mean 6.31 ± 5.57 μm). None of the samples filled with MTA had any noticeable marginal gap. Kruskal-Wallis one-way ANOVA test showed significant differences between filling materials ($p < 0.0001$). Multiple comparisons showed a significant difference between the adaptation of MTA to dentin compared with amalgam, Super-EBA, and IRM ($p < 0.01$). A significant difference was found between IRM and amalgam ($p < 0.05$).

DISCUSSION

The SEM has been used to determine the marginal adaptation of various filling materials to the surrounding tooth structures (12, 14–18). The microscopes were developed because of high magnification and good resolution, not possible with optical microscopes. The SEM examination of the filling–tooth interface has several shortcomings: it is a surface phenomenon and may not represent the adaptation of two surfaces in three dimensions. Conventional preparation of biological samples before SEM observation may be associated with the introduction of many artifacts. High-vacuum evaporation can cause artifacts such as cracks in hard tissue samples, and separation and lifting of the filling material from the surrounding tooth (Figs. 1 and 2). In addition, there may be expansion or contraction of the tooth and/or filling material. To reduce the likelihood of artifacts, several replication methods have been suggested (3, 16, 18–20).

Despite its limitation, SEM examination of marginal adaptation of various root-end filling materials to dentin can provide information that might indicate the sealing ability of these materials (15, 16). Conflicting results have been reported regarding the correlation between marginal adaptation and sealing ability of root-end filling materials. Abdal and Retief (3) evaluated the adaptation of retrograde filling materials in root-end cavities. The adaptation of the filling materials in one of each pair of teeth was evaluated directly and by resin replica of longitudinally sectioned samples. Marginal leakage at the filling–dentin interface was evaluated in the other teeth using a fluorescent dye. Their results showed no correlation between maximum marginal gaps and the degree of dye penetration. Yoshimura et al. (12) placed amalgam in root-end cavities in extracted human teeth and determined the microleakage using a pressurized fluid filtration technique. Selected samples were also observed under SEM to determine the "integrity" of the amalgam–tooth interface after 8 wk. Their results also showed a lack of correlation between microleakage and gaps. Stabholz et al. (16) examined the marginal adaptation of five potential root-end filling materials by replicas under SEM and showed a correlation between marginal adaptation and sealing ability.

Comparing the results obtained from resin replicas in the present investigation with those of our previous leakage studies (5, 9, 13), our findings correlated well and with those of Stabholz et al. (16), but disagreed with those of Abdal and Retief (3), as well as Yoshimura et al. (12). Sectioning of samples as performed by Abdal and Retief (3) and in a part of this study had the potential of creating artificial gaps at the dentin–filling interface as a result of sectioning method. In a pilot study, resin replicas of longitudinally sectioned root-end-filled teeth were prepared, and similar gaps were found to those in the teeth examined directly. This confirms that longitudinal sectioning of root-end-filled teeth has the potential to create artifacts. Absence of dye leakage in root-end cavities filled with MTA (5, 13), the presence of only small gaps (2.68 ± 1.35 μm) in longitudinal sections, and the absence of gaps in the replica specimens indicate the suitability of MTA.

Based on our findings, it seems that sample preparation for SEM studies played a significant role in the outcome. To reduce artifacts, it seems essential to prepare resin replicas of resected root ends containing filling materials. However, examination of resin replicas of the resected root ends shows the filling–tooth interface in one plane and may not represent the adaptation of the two surfaces in the entire specimen.

Examination of resin replicas showed differences in marginal adaptation between filling materials. Super-EBA and IRM had greater gaps than amalgam or MTA. These differences could be related to the physical and chemical properties of the materials, as well as to their handling during mixing and insertion. The difference between the gap sizes found in the present study and those of previous SEM studies (12, 14–16) might be due to the types of amalgam used and elimination of artifacts by preparing resin replicas in our investigation. The absence of gaps in samples filled with MTA could have been due to the presence of a thin layer of MTA at its junction with dentin and possible expansion of this material on setting.

Although the results of this study and previous leakage investigations (5, 9, 13) show that MTA provides better adaptation and seal than commonly used root-end filling materials, physical properties as well as in vitro and in vivo biocompatability tests of this material should be performed.

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You Might be Interested

Public education efforts notwithstanding, dental procedures are still equated by many with pain, and a corollary is that dental scientists remain interested in the neural substrate of discomfort. It behooves those of us still having potential exposure to examinations—boards, graduate programs, etc.—to therefore be aware of the latest pain theories. A fair amount of scientific noise has been generated because a group (Nature 372:770) recently located a thalamic nucleus, the posterio ventral medial, which appears specific for pain and thermal activation. No doubt a flurry of papers will follow this "new" and "exciting" discovery—ignoring the fact that Mountcastle postulated a similar structure decades ago.

William Cornelius