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Effect of Repeated Vertical Loads on Microleakage of IRM and Calcium Sulfate-Based Temporary Fillings

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Temporary fillings are commonly used to seal endodontic access cavities between visits. IRM and Cavidentin were selected to represent two widely used groups of temporary filling materials. The first is a reinforced zinc oxide-eugenol preparation that is mixed at chairside, whereas the second is a ready-to-use calcium sulfate-based material that gained popularity due to its convenience of application. The seal provided by the aforementioned materials was studied using a radioactive tracer quantitative assay. When compared as passive temporary filling, the two provided a similar quality of seal. However, when subjected to repetitive "occlusal" cyclic loading of 4 kg, IRM was clearly superior to the calcium sulfate-based material. Whereas IRM maintained a reasonable seal, the calcium sulfate-based fillings deteriorated and lost the ability to seal. These results suggest that even though calcium sulfate-based materials may be useful when not subjected to any occlusal forces, IRM should be preferred whenever occlusal loads may be applied. Furthermore it is demonstrated that testing such materials for microleakage with no reference to mastication forces may be of limited value.

Temporary fillings are widely used in endodontics to seal the access cavity between visits or until a permanent restoration will be fitted. As a temporary device they received less attention than materials used for a permanent and prolonged use. Nevertheless they are an essential link in the chain that leads to disinfecting and preventing contamination or recontamination of the root canals (1).

Zinc oxide-eugenol preparations are among the most common materials used as temporary fillings in both restorative dentistry and endodontics. Nevertheless when prolonged use was desired their mechanical properties were inadequate. This led to development of reinforced preparations, in which addition of materials such as polymethyl-methacrylate provided improved prolonged service (2).

These reinforced preparations are usually mixed at chairside by the dental assistant. This time-consuming procedure is avoided by ready-to-use calcium sulfate-based preparations such as Cavit, Cavit G, or Cavidentin that are convenient, easy to use, and inexpensive. Thus they gained popularity in endodontics, mainly for use when a relatively short service is required from a temporary filling.

Comparative studies indicated that the Cavit-like materials provide an adequate seal (3–7) and that Cavidentin used in our study does not differ from Cavit (8) or even has better sealing properties than the latter (3). Nevertheless when used clinically it frequently occurs that a temporary filling of this type is lost, leading to contamination of the pulp chamber and root canal that were meticulously cleaned and disinfected in the former visit. Not only does this represent a failure in the basic chain of procedures designed to eliminate bacterial contamination, it may also have an economic impact, because another visit may be required for a proper completion of the endodontic treatment.

We therefore studied under controlled conditions the maintenance of seal by two representatives of these groups of materials: IRM and Cavidentin and extended former observations by focusing on the effect of repetitive occlusal loads of a magnitude that is relevant to mastication.

MATERIALS AND METHODS

Teeth

Fifty-four caries-free molars were selected from a random collection of extracted teeth stored in buffered 10% formalin (pH 7). The roots were removed at a uniform level of 7 mm apically to the plane half-way between the cusp tips and the central groove, using a rotating diamond wafering blade (Buhler) at slow speed with water cooling.

Access Cavity Preparation

Oval access cavities were prepared, using tungsten carbide high-speed burs, followed by a diamond bur, with a water-air spray cooling. The oval access cavity was 6 × 3 mm. This shape was chosen to avoid irregularities, which differentiate the shapes used in clinical cases, and that may influence the studied parameters. Teeth were kept at 100% humidity at a room temperature of 27°C throughout the experiment.

Volume and Interface Calculation

Leakage in temporary fillings may occur either at the tooth–material interface or through the material itself (3). Therefore uniformity of volume and interface among the specimens should be ensured. Each access preparation was radiographed from an occlusal view, the image scanned, and two quantities calculated, using a Sigmascan software (Jandel Scientific Software, San Rafael, CA): (a) the surface area of the radiographic image of the access cavity and (b) its perimeter. Multiplication of "a" by the 7 mm height of the cavity provided the volume of the cavity, whereas multiplication of the height by the perimeter provided the interface area between the temporary filling and the tooth. Both quantities were considered essential for any comparison of the microleakage. The mean area of the horizontal cross-section of all the cavities was 19.39 ($\pm$1.46) mm^2, and the mean perimeter was 16.01($\pm$0.06) mm. To enhance uniformity among the experimental groups, teeth were initially divided into two groups by their cross-section area: one with cavities with a $>$19.39 mm^2 cross-section and the other with cavities $<$19.39 mm^2. Further random alternate selection of teeth from each of these initial groups resulted in three experimental groups of 16 teeth each, with a mean cross-section area of 19.41($\pm$1.79), 19.23 ($\pm$1.86), and 19.37 ($\pm$1.62) mm^2. The teeth in each of these equalized groups received fillings, and a fourth group of 16 teeth received no fillings.

Experimental Design

Temporary fillings of IRM and $CaSO_4$-based sealer were compared with each other for their sealing ability, after application of cycling vertical loads that represented occlusal forces. Similar fillings, to which no force was applied, served as controls. These temporary fillings were also compared with similar amalgam restorations that were also tested with and without application of occlusal loads and served as negative controls made of a material less sensitive to forces, whereas access cavities with no fillings served as absolute positive controls. A filling was placed in each access cavity, as detailed herein. After setting repeated occlusal forces were applied to the fillings in the loaded groups. The sealing ability of each of the fillings in both the loaded and passive groups was then tested in a radioactive tracer leakage assay.

IRM Fillings

IRM was mixed according to the manufacturer's instructions in manufacturer-loaded capsules (IRM Caps, Caulk, Milford, DE), using a Silamat amalgamator. The material was then placed in each of the 16 access cavities and packed against a glass slab on which the tooth was placed to fill the cavity (Fig. 1). The material was allowed to set for 24 h while being immersed in water at room temperature before application of occlusal forces. Half of the restored teeth were subjected to occlusal loads, whereas the other half remained intact and served as controls.

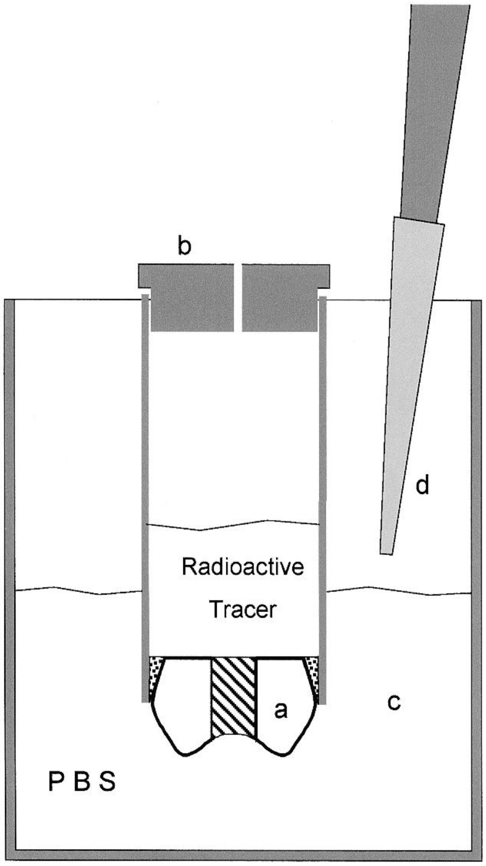

FIG. 1. A tooth adapted with a radioactive tracer reservoir. The crown was cut at a uniform height of 7 mm and the access cavity filled with the tested material from occlusal to the flat cut surface (a). The enamel was etched, bonding agent applied, and the tooth sealed with an epoxy cement to the bottom of a scintillation tube (b) that served as a radioactive tracer reservoir. When forces were applied to the filling it was done before mounting the tooth in the tube. Leakage of the tracer through the filling or around it was monitored by sampling the outer buffer (phosphate-buffered saline [PBS]) (c) in which the tooth was immersed using a micropipette (d).

$CaSO_4$-Based Fillings

"Cavidentin" (Laszlo Laboratories, Netania, Israel) (3, 8), a ready-to-use $CaSO_4$-based temporary filling material, was used to seal 16 access cavities and packed in the same way as IRM. The material was used according to the manufacturer's instructions, allowed to set for 24 h while being immersed in water at room temperature before application of occlusal loads to half of the fillings. The other half remained intact and served as controls.

Amalgam Fillings

Two layers of Copalite varnish were applied to the walls of each of the 16 cavities, followed by packing the cavity with amalgam (admix amalgam, Sphedodon M, Silmet, Or Yehuda, Israel) that was triturated according to the manufacturer's instructions. After a

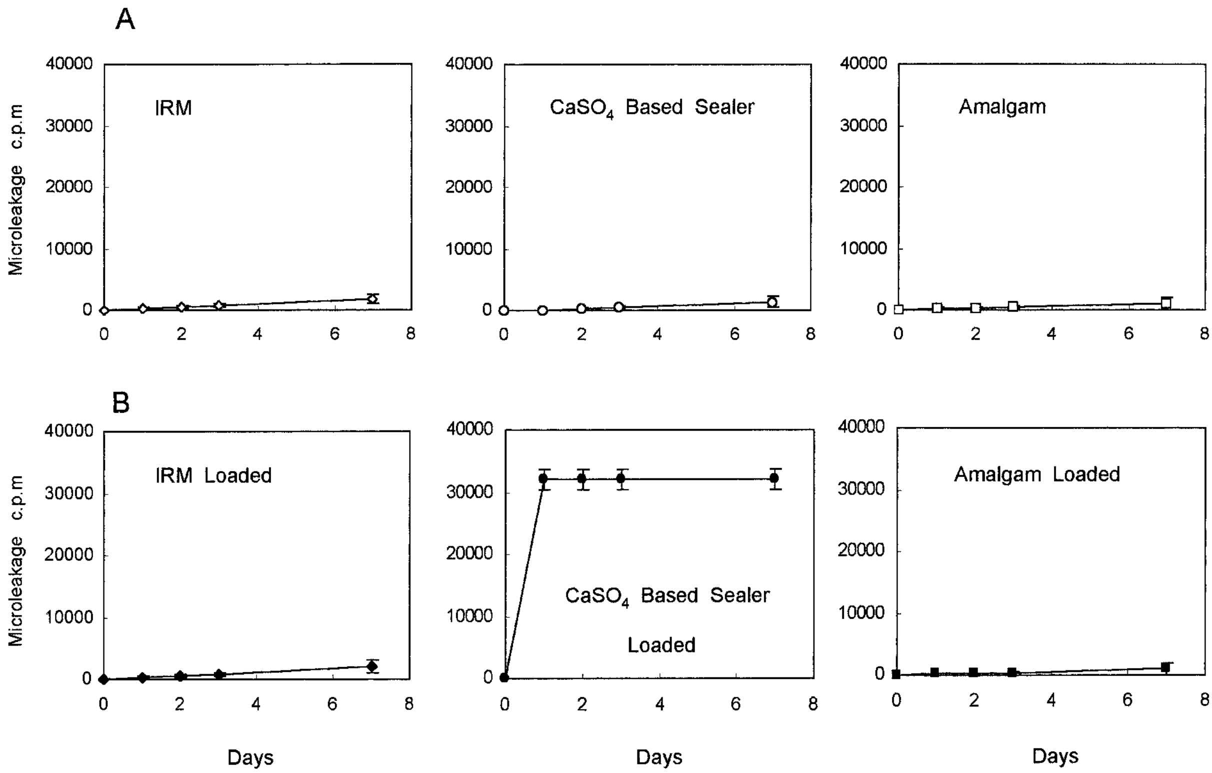

FIG. 2. Effect of loading on the microleakage of IRM and $CaSO_4$-based temporary fillings. (A) No force was applied to the fillings. Both materials behave similarly to an amalgam control. (B) Repetitive application of a force of 4 kg to the fillings. IRM maintains a seal similar to the amalgam control, whereas that of the $CaSO_4$-based material is lost. Each point represents the mean leakage at the given timepoint of eight fillings (±SEM). *Open symbols*: no force applied; *filled symbols*: after loading with repetitive force.

24-h setting, immersed in water, forces were applied to half of the fillings whereas the other half served as controls.

Repeated Occlusal Loads

Repeated occlusal loads were applied, representing the effect of masticatory forces. Each tooth was mounted in a cylindrical depression in a metal mold. The apical flat cut surface was supported by the flat metal base of the depression and the tooth stabilized by packed wet cotton around it. A force of 4 kg (2) was applied by an Instron machine at 400 mm/s through a stainless-steel spherical point with a 3.0 mm diameter. Two hundred cycles of loads were applied to the center of each filling. The specimens were carefully monitored while loaded. When visible cracks appeared during the process, it was stopped and the number of cycles recorded.

Leakage Assay

Each tooth was mounted in a hole formed in the base of a polypropylene scintillation tube, as recently described by Abramovitz et al. (9). The cervical enamel was etched with 35% phosphoric acid for 30 s, followed by washing, drying, and application of a bonding agent (Scotbond 2, 3M) that was light-cured. Epoxy cement was used to fill the gap and seal the interface between the tooth and the tube, followed by a layer of nail polish (Fig. 1). The tube was filled with 1 ml of a radioactive tracer solution (^3H-thymidine, 10 μCi/ml) (9) and the tube placed in a glass scintillation vial containing 4 ml of phosphate-buffered saline containing 0.005% NaN_3 to prevent microbial growth.

Fifty-microliter samples were taken from the outer buffer at 1, 18, and 24 h and then at 2, 3, and 7 days. Each sample was immediately transferred into tubes containing 3-ml scintillation fluid and the amount of radioactivity measured in a scintillation counter (Tri-Carb, Packard, IL) and expressed as counts per minute (cpm). At each timepoint the recorded values were compared with a negative control of tracer-free scintillation fluid, and buffer samples with no radioactivity. They were also compared with a full-strength radioactive tracer solution that served as an absolute positive control.

Statistical Analysis

The mean microleakage was calculated at each timepoint for the eight samples in each group. Differences between the groups were evaluated using one- or two-way analysis of variance (ANOVA).

RESULTS

Microleakage of Nonloaded Fillings

Microleakage in all groups that were not subjected to occlusal loads gradually increased with time. The mean leakage of the IRM fillings was 331 (±213) cpm at 24 h, and it increased to 1,798 (±840) cpm by day 7 (Fig. 2). The $CaSO_4$-based fillings had a mean leakage of 202 (±235) cpm at 24 h, which reached 1,338 (±627) cpm by day 7. The amalgam fillings had a mean leakage of 289 (±235) cpm at 24 h with a leakage of 1,104 (±568) cpm

TABLE 1. Statistical analysis

	IRM Intact	$CaSO_4$-Based Sealer Intact	Amalgam Intact	IRM Loaded	$CaSO_4$-Based Sealer Loaded	Amalgam Loaded
IRM intact	—	NS	NS	NS	$p < 0.001$	NS
$CaSO_4$-based sealer: intact	NS	—	NS	NS	$p < 0.001$	NS
Amalgam intact	NS	NS	—	NS	$p < 0.001$	NS
IRM loaded	NS	NS	NS	—	$p < 0.001$	NS
$CaSO_4$-based sealer: loaded	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$	—	$p < 0.001$
Amalgam loaded	NS	NS	NS	NS	$p < 0.001$	—

NS = not significant.

by day 7. No difference was found between these three groups (Table 1).

Microleakage after Cyclic Occlusal Loading

The microleakage of the IRM fillings was not affected by the repeated occlusal loading (Fig. 2). Similarly the microleakage of amalgam fillings was not affected by the cyclic loads (Fig. 2, Table 1). In contrast to these two groups the $CaSO_4$-based fillings lost their sealing ability when subjected to repeated occlusal loads (Fig. 2). The leakage was total and immediately reached 31,850 (±1,148) cpm: the same level as that of the open access cavities. It was significantly different from that of the former two groups (Table 1).

Macroscopic and Microscopic Observation

The amalgam and IRM fillings displayed no visible cracks when examined either macroscopically or under magnification of ×40. The $CaSO_4$-based fillings cracked during the cyclic loading, and none could be carried through the full 200 cycles. All of them had to be stopped after 50–100 cycles, due to visible deterioration of the filling.

DISCUSSION

Temporary fillings are expected to provide good marginal seal and have dimensional stability, minimal porosity, and resistance to abrasion and compression (7). All the above are essential for their main function in endodontic therapy that is to seal the access cavity adequately. The term "temporary restorations," which is frequently used, may imply an additional attempt to restore form and function that are of a secondary importance in our case. Furthermore in cases of large cavities such an attempt may often jeopardize the integrity of the material that is inadequate for this purpose. Thus it may contradict the main goal. We therefore prefer and use the term "temporary fillings" to indicate its most important goal: to fill and seal the access to the pulp chamber.

Temporary fillings made of IRM and the $CaSO_4$-based materials Cavidentin or Cavit have previously been compared for microleakage. IRM represents a group of reinforced zinc oxide-eugenol preparations in which enhanced mechanical properties were achieved by including materials such as polymethyl-methacrylate in the preparation (2). Compressive strength of 6,000 psi made IRM a material that can better resist masticatory forces as compared with only 2,000 psi in the $CaSO_4$-based Cavit (10). Furthermore the addition of polymethyl-methacrylate made the material relatively hydrophobic, thus maintaining its integrity for prolonged periods when immersed in aqueous solutions.

Cavidentin represents a group of materials that contain $CaSO_4$, which sets when exposed to moisture. These materials are relatively hydrophilic and tend to absorb water (3, 8). The popularity of these materials comes from their convenience of use: the ready-to-use preparation does not require mixing, and if the amount initially taken is not sufficient, additional material can be added in a matter of seconds. With IRM mixing is required and when some additional material is needed, it means waiting for another paste to be mixed. This inconvenience has been solved by the introduction of preweighed IRM capsules that are mixed using an amalgamator, thus ensuring uniform and reproducible IRM mixtures. Such IRM capsules were used in the present study to enhance uniformity of the preparation.

Many comparative studies were conducted to compare these two groups of materials. Most of them used semi-quantitative assays (2–6, 8, 11), whereas only a few used quantitative tools (8, 12–15). A common approach was using dye penetration with or without thermocycling (2–6, 11).

In many of these studies it was demonstrated that microleakage was significantly smaller in $CaSO_4$-based temporary fillings than in those made of IRM. Furthermore some dye penetration studies demonstrated two different penetration patterns: whereas IRM temporary fillings leaked at the tooth–filling interface, in the $CaSO_4$-based fillings penetration occurred through the filling material itself (3, 11, 13). This was attributed to the hydrophilic properties of the latter materials, compared with the relatively hydrophobic properties of the IRM (3, 13).

Thermocycling was commonly used in the comparative studies that resulted in a benefit to the $CaSO_4$-based materials. It may be possible that when this methodology is used the ability of these materials to absorb water allows them to compensate for the microgap opened by the temperature changes.

This may explain the discrepancy between the above results and those of some of the studies that were performed with no thermocycling and that resulted in a different outcome. Friedman et al (8), applying a quantitative radioisotope tracer assay, have found that the sealing ability of IRM was superior to that of the $CaSO_4$-based materials Cavidentin and Cavit G, which did not differ from each other. In a recent study that evaluated bacterial penetration through temporary sealed teeth, Imura et al. (16) have also found that bacterial penetration occurred earlier in teeth sealed with $CaSO_4$-based materials, compared with those sealed with IRM.

The present study focused on the fatigue tolerance of these materials and its effect on marginal leakage. When no forces were applied the two materials had a similar sealing ability that did not differ from that of amalgam restorations. Nevertheless when subjected to cycling occlusal forces the IRM was clearly superior to the $CaSO_4$-based sealer. The difference in compressive strength between these materials could indicate that one may be stronger than the other. Nevertheless it was not that straightforward: compressive strength is measured by applying force until destruction of the specimen. A specimen of $CaSO_4$-based sealer of the size tested in our study (a 7-mm high elliptical cylinder with a base of 19 mm^2) is expected to require $\sim$14 kg to fail in a compressive strength test. The forces used in the present study were much smaller and were selected as a representation of forces that are commonly applied during mastication: 4 kg (2). This force was not strong enough to brake the $CaSO_4$-based filling in the first or even 10th loading; nevertheless when applied repetitively (as occlusal forces are applied) it led to deterioration of the $CaSO_4$-based fillings after 50–100 cycles. IRM, on the other hand, could easily resist these cycling forces without loss of the seal. Such repetitive small forces have also been applied in other microleakage studies of restorative materials (2, 17, 18).

With the mechanical properties of these materials known and with the common clinical experience of occasionally loosing a temporary filling made from $CaSO_4$-based sealer, it is rather surprising that the effect of their mechanical properties on the leakage was hardly studied. Among the many comparative works we are aware of only one study in which the effect of occlusal loads on temporary fillings made from these materials was evaluated. Mayer and Eickholz (2) applied 200 cycles of 40 N ($\sim$4 kg) force application to temporary fillings and studied the penetration of 1% fuchsin red, in a semi-quantitative way. They reported that 2 of the 11 Cavit fillings collapsed into the cavity while loaded and 1 of 11 in the IRM group. The other fillings in the $CaSO_4$-based sealer group had a better seal than the other IRM fillings. It is difficult to directly compare their results to ours for two main reasons. First, their leakage assay, after the application of forces, was 1 h. We used a 7-day assay for the following reasons: (i) this is commonly the minimal time between clinical visits (19), (ii) it is the time required for bacteria to penetrate temporary fillings (16), and (iii) our previous studies (9, 20) have shown that short leakage assays may be misleading. Second, no sufficient information was provided as to the way the load was applied: size and shape of the tip applying the force may be crucial, as may be the rate and angle of force application. Nevertheless collapse of Cavit fillings into the pulp chamber, which may also be encountered clinically, led these investigators to state that, "The use of stronger material seems to be advantageous" (2).

The results of the present study indicate that, when proper maintenance of the seal is important, as in endodontic treatment, IRM is preferable as a temporary filling. The use of $CaSO_4$-based sealers should be limited to areas that are not subjected to direct occlusal loads, such as in a tooth with no antagonist or an access cavity that is covered by a temporary crown. In all other cases the use of this material alone may lead to loss of the seal due to the application of small but repetitive forces that may lead to a fatigue failure of the material. Such a failure will have two consequences (i) contamination or re-contamination of the root canal and (ii) a need for an extra visit for adequate completion of the endodontic treatment. Ignoring "i" to avoid "ii" does not fit into current concepts of endodontic microbiology.

$CaSO_4$-based sealers, such as Cavit, have been extensively used for many years with satisfactory results. If a temporary filling was occasionally lost it was likely viewed as an unpleasant but unavoidable event that required an extra visit to overcome the contamination of the pulp chamber and root canal. Our results suggest that such events may be avoided by proper selection of sealing material.

Better temporary materials should be sought that will combine a long term bacterial tight seal with better mechanical properties. An alternative approach may be a combination of an inner layer of a $CaSO_4$-based sealer and an outer layer of IRM that will protect it from repeated occlusal loads.

In most studies temporary fillings that were placed in ideal small access cavities, prepared in intact teeth, were compared. Nevertheless when a large temporary filling is considered, that may include also one or both proximal surfaces, the mechanical properties of the material become even more important. Therefore one should not deduce that any material that has been successful in maintaining the seal in ideal small access cavities should also do so when large occlusal surfaces are to be temporary sealed. When a temporary filling is lost altogether, due to insufficient resistance to occlusal forces, its theoretical sealing properties are irrelevant.

The present study demonstrated that functional assays should be applied when testing the sealing ability of temporary filling materials. Furthermore many teeth that are subjected to endodontic treatment had been severely damaged by caries. Therefore similar studies that will apply repetitive forces to temporary fillings placed in large access cavities, involving a class II cavity type, will be required to select the best among the modern temporary filling materials for this purpose. The extra cost of such materials should be weighed against the accumulating time devoted to replacing lost temporary fillings and extra visits required as result.

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