Evaluation of Wear and Subsequent Dye Penetration of Endodontic Temporary Restorative Materials

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This study evaluated the wear resistance and sealing property of endodontic temporary restoratives by means of functional stressing using a wear simulator. The pulp chamber of 28 extracted molars was opened and filled with cotton, and then the cavity was filled with a temporary material — Caviton, Temporary Pack, Neodyne-α, or TERM. Specimens were subjected to a wear test, and data for wear and dye penetration were analyzed by one-way ANOVA independently (p<0.05). Wear values of Neodyne-α (0.09±0.05 mm) and TERM (0.24±0.06 mm) were significantly less than those of Caviton (1.79±0.15 mm) and Temporary Pack (1.02±0.40 mm). In terms of dye penetration, Neodyne-α leaked significantly less than the other materials at 0.40±0.32 mm. On the other hand, there were no significant differences between TERM (1.30±0.57 mm) and Temporary Pack (2.10±1.12 mm), and between Caviton (2.60±0.41 mm) and Temporary Pack.

Key words: Dye penetration, Temporary sealing material, Wear

INTRODUCTION

In endodontic treatments, infection elimination for pulp chamber and root canal contributes significantly to healing. This is especially so for root canal treatments where patients are required to make multiple visits. Infection during treatment impedes healing and can delay the completion of root canal therapy. Therefore, the sealing ability of temporary restoratives plays a key role in shielding pulp chamber and root canal from bacterial infection.

Zinc oxide-eugenol cement has been reported to have excellent sealing ability, and thus it is highly recommended as a temporary restorative material for endodontic treatments. However, the disadvantages of this material pertaining to endodontics and vital pulp therapy have also been identified. These include soft tissue irritation by eugenol and inhibited polymerization of polymeric restoratives by residual eugenol on tooth surface. Therefore, eugenol-free cement has been used when resin composite materials are chosen for definitive restorations. In particular, a hydraulic temporary restorative has been frequently used because of its eugenol-free characteristic and ease of manipulation. Likewise, a photopolymerizing resin composite has also been suggested as a possible temporary restorative material because of its excellent mechanical properties.

For a temporary restoration during endodontic treatment, an effective seal usually needs to be maintained for a relatively short period, such as one to two weeks. During this time, it should ideally have excellent resistance to mechanical stresses such as mastication, wear, fracture, and dislodgment — as these could lead to bacterial infection.

Several studies have evaluated the sealing ability of temporary restoratives. However, researchers have mainly focused on dye penetration to evaluate the sealing property of temporary restoratives in static situation. None of these studies evaluated the sealing property under functional stresses simulating oral conditions. Therefore, the purpose of this study was to evaluate the wear values of endodontic temporary restoratives and the subsequent dye penetration at tooth/restorative interface.

MATERIALS AND METHODS

Product names, manufacturers, types, and lot numbers of materials used in this study are presented in Table 1. Four types of material were used: a hydraulic setting temporary restorative, Caviton (GC, De}
Tokyo, Japan); a eugenol-free temporary cement, Temporary Pack (GC, Tokyo, Japan); a photopolymerizing resin-based temporary restorative, TERM (Dentsply/Maillefer, Tulsa, OK, USA); and a zinc oxide-eugenol cement, Neodyne-α (Neo Dental Chemical Products, Tokyo, Japan) as a control material.

Specimen preparation
Twenty-eight non-carious human molars extracted in the Department of Oral Surgery at the University of Alabama at Birmingham were stored in 4°C physiologic saline solution that contained 4% sodium azide. IRB approval was obtained prior to the use of all of the extracted teeth. They were then divided into four groups (n=7).

Root tip of each tooth was ground and mounted in a brass specimen holder using an auto-polymerizing acrylic resin (Crosslinked Flash Acrylic, Chicago, IL, USA). Pulp chamber was opened by a high-speed air turbine with a diamond point (#201R, Shofu, Kyoto, Japan) according to standard procedures for access cavity preparation with a 2° taper (Fig. 1(a))14. To standardize cavity dimensions, each cavity was prepared with 6 mm buccolingual width and 5 mm mesiodistal width. Using a custom-made, handheld device, the occlusal surface within enamel was ground flat using a series of silicon carbide abrasive papers up to 600-grit. The cavity was then irrigated with 5% sodium hypochlorite solution and sterile physiologic saline, followed by wiping and drying with a cotton pellet.

To simulate a clinical procedure during root canal treatment, the pulp chamber was filled with a cotton pellet to control the depth of restoration at 3 mm, and then the cavity was filled with its assigned temporary material. The materials were used according to the manufacturers’ instructions. Caviton was filled using a hand instrument (Plastic filling instrument, American Eagle Instruments, Missoula, MT, USA), and the specimens were stored in 37°C water for 30 minutes to secure material setting. For Temporary Pack, an equal amount of base and catalyst pastes was mixed and immediately filled with the hand instrument. For Neodyne-α, powder and liquid were mixed with 2.0 g/0.4 ml ratio and the mixture was filled with the hand instrument. Both Temporary Pack and Neodyne-α mixtures were stored in 37°C water for 10 minutes. For TERM, the paste was bulk-filled using a compule syringe and photopolymerized for 40 seconds by a visible light curing unit (Astralis 7, Ivoclar/Vivadent, Buffalo, NY, USA).

All restored teeth were resurfaced with a 600-grit silicon carbide paper with copious irrigation (Fig. 1(b)). Completed specimens were immediately fixed to a University of Alabama at Birmingham (UAB) wear simulator to be subjected to repetitive mechanical stressing15.

Wear test
Although the wear simulator used in this study has been used as a device to evaluate the wear values of restorative materials15, it is also capable of simulating the deterioration of restorative/tooth interfaces. Further, as this wear device has been used to evaluate the wear values of resin composite restoratives, it is therefore possible to use it likewise to estimate the wear values of temporary restorative materials. On the other hand, while wear simulators generate wear by continuous contact16-19, the one used in this study was designed to apply repetitive loading on restorative surfaces. Therefore, the apparatus used in this study was adequately designed to simulate repetitive stressing during mastication.

Wear test was carried out according to the method previously reported20. First, the specimen was covered with a tight-fitting ring, and an artificial food bolus was poured onto the specimen surface. The artificial food bolus consisted of a 1:1 weight ratio of polymethyl-methacrylate (PMMA) beads (average diameter: 44 μm) and tap water.25 A flat, polyacetal cylindrical stylus (diameter: 12 mm) was placed vertically on the restored surface, and the
maximum load was adjusted to 75 N (Fig. 2). The stylus rotated clockwise 15 degrees with increasing load up to 75 N, and then counter-rotated to the starting position. In this test, each specimen received 5,000 wear cycles at a frequency of 1.2 Hz.

Next, the specimens were rinsed and dried before their surfaces were impressed with a polyvinyl-siloxane impression material (Reprosil, Dentsply/Caulk, Milford, DE, USA). The deepest portion of the impression was cut into 0.5 mm-thick sections with a surgical blade, photographed with a monochrome CCD video camera (XC-77, Sony, Tokyo, Japan), and the image was digitized (Frame Grabber, NUBus, Neotech Ltd., Estleight, UK). Distance from the cavosurface margin to the bottom of the impression was measured with an image analysis software (Image 1.45, National Institutes of Health, Bethesda, MD, USA).

**Leakage test**

After the completion of wear analysis, the specimens were immersed in 5% methylene blue solution at 37 °C for eight hours. The specimens were cleaned, and the temporary restorative material and cotton pellet removed using a sharp spoon excavator. The root was cut at the enamel-cementum junction, and the crown was broken into half parallel to the tooth axis. The deepest portion of dye penetration was measured by a digital caliper (Absolute Digimatic, Mitsutoyo, Kawasaki, Japan). Each measurement was repeated three times, and the average was recorded.

**Statistics analysis**

Data for wear and dye penetration tests were statistically analyzed by one-way ANOVA independently. Multiple comparisons were performed with Fisher’s test, for which significance level was set at p<0.05.

**SEM observation**

Following the wear test, all specimens were duplicated with a polyvinyl impression material and an epoxy resin (Craft Resin, Nissin Resin, Yokohama, Japan). All replicas were sputter coated with gold-platinum (Hummer Sputter Coaters, Anatech, Alexandria, KY, USA), and then a scanning electron microscope (SEM; ISI-100B, International Scientific Instruments, Tokyo, Japan) was used to observe the extent of surface wear.

**RESULTS**

Table 2 presents the wear depth results. Statistical analysis showed that the wear values of Neodyne-α (0.09 ± 0.05 mm) and TERM (0.24 ± 0.06 mm) were significantly less than those of Caviton (1.79 ± 0.15 mm) and Temporary Pack (1.02 ± 0.40 mm) (p<0.05). There were no significant differences in wear value between Neodyne-α and TERM, but the values between Caviton and Temporary Pack were significantly different.

Table 3 presents the results of maximum dye penetration. Statistical analysis showed that the zinc oxide-eugenol temporary restorative leaked significantly less than the other materials at 0.40 ± 0.32 mm

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**Table 2** Results of wear test. Data are represented as mean value ± standard deviation (mm).

<table>
<thead>
<tr>
<th></th>
<th>Caviton</th>
<th>Temporary Pack</th>
<th>TERM</th>
<th>Neodyne-α</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wear depth</td>
<td>1.79±0.15*</td>
<td>1.02±0.40*</td>
<td>0.24±0.06*</td>
<td>0.09±0.05*</td>
</tr>
</tbody>
</table>

Groups with the same superscript letter indicate no statistical differences (p<0.05).

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**Table 3** Results of maximum depth of dye penetration. Data are represented as mean value ± standard deviation (mm).

<table>
<thead>
<tr>
<th></th>
<th>Caviton</th>
<th>Temporary Pack</th>
<th>TERM</th>
<th>Neodyne-α</th>
</tr>
</thead>
<tbody>
<tr>
<td>Penetration depth</td>
<td>2.60±0.41*</td>
<td>2.10±0.12*</td>
<td>1.30±0.57*</td>
<td>0.40±0.32*</td>
</tr>
</tbody>
</table>

Groups with the same superscript letter indicate no statistical differences (p<0.05).
(p<0.05). There were no significant differences between the values of TERM (1.30 ± 0.57 mm) and Temporary Pack (2.10 ± 0.12 mm), and between Caviton (2.60 ± 0.41 mm) and Temporary Pack.

Fig. 3 presents the SEM photographs. The surface of Caviton was deeply worn (Fig. 3(a)), showing the presence of plaster and PMMA beads on the soft matrix (Fig. 3(b)). The surfaces of Temporary Pack (Fig. 3(c)) and Neodyne-α (Fig. 3(e)) were relatively smooth compared to the Caviton specimen; however, small particles – presumably zinc oxide particles – were exposed on the surface (Fig. 3(f)). The surface of TERM exhibited a typical worn surface of resin composite material. Protrusion of large-sized (approximately 100 μm) filler particles could be seen (Fig. 3(d)). Moreover, the cavosurface margin exhibited no gap formation even though no adhesive was applied.

**DISCUSSION**

Caviton is one of the hydraulic-setting temporary restorative materials used frequently in endodontic treatments. This material is used as a ready-made putty that needs no mixing, and so handling is simple and easy. This type of product contains gypsum as a hardening agent which enables the setting reaction to start gradually from the wetted area. Barkhordar and Stark reported that one of the hydraulic-setting products, Cavit, showed better sealing ability than IRM. As for Temporary Pack, its active ingredients are a zinc oxide base and a fatty acid derivative that acts as an accelerator. Mixing and handling are quite easy too as both base and accelerator are provided in paste form. Since this material does not include eugenol, it should invoke less inflammatory reaction in the soft tissue. For Neodyne-α, it is a zinc oxide-eugenol based material used as a temporary cement and/or a temporary restorative. In vitro studies showed that this cement had an excellent sealing ability. However, zinc oxide-eugenol cement stimulates repair only if it is in contact with pulp tissue directly, which then causes inflammation. TERM, on the other hand, is a photopolymerized resin composite that reportedly possesses high mechanical strength due to its cross-linked polymer structure. However, it should be highlighted that it was difficult to remove TERM with a hand instrument compared to the other materials, probably due to the difficulty of obtaining an initial catch with common instruments.

Although profilometric measurement has been widely used for wear evaluation, it was not selected in this study as the wear values of some materials were extremely large. Therefore, the measurement technique used in a previous study was employed instead. As the accuracy of this technique was already proven in published literature, results obtained thereby in this study should be reliable.

In the wear test, there were no significant differences between Neodyne-α and TERM, but statistical differences were observed between Caviton/Temporary Pack and Neodyne-α/TERM. Further, the surfaces of Caviton and Temporary TERM were deeply worn.
worn, while those of Neodyne-α and TERM showed minimal wear.

To simulate the clinical situation as closely as possible, the thickness of temporary restorative materials was set at 3 mm. The wear depth of Caviton was equivalent to two-third of the restoration’s total height. As this material is hydraulic-setting, the superficial area set first whereas the deeper areas remained unset. According to SEM observation, a bulk of set material seemed to be dislodged from the superficial area during repetitive stressing exerted by the wear simulator. PMMA particles were stuck around gypsum crystals, indicating material failure. On the other hand, the occlusal surface of Temporary Pack, which showed the next highest wear value, was very smooth and showed no signs of catastrophic failure. Neodyne-α and TERM exhibited a smooth surface with minimal wear, indicating that these two materials possessed sufficient wear resistance as a temporary restorative for the one- to two-week intervals typically needed for endodontic treatment.

In dye penetration test, Temporary Pack and Caviton exhibited the greatest leakage (2 to 3 mm), and there were no statistically significant differences between them. Dye penetration is generally recognized as an indicator of bacterial invasion degree. Therefore, bacterial invasion to root canal may occur when dye penetration depth is greater than the thickness of temporary restorative material. In such a circumstance, the temporary restorative material provides no protection against bacterial infection.

It was speculated that the wear resistance of material was one of the factors that influenced sealing property. TERM showed a high degree of dye penetration – which was expected due to polymerization shrinkage, and especially when no adhesive was used. However, it leaked less than Temporary Pack. Noguera et al.\textsuperscript{11} reported that TERM showed better sealing ability than Caviton and IRM. This good result might be attributed to the ductility of the material, probably due to the inclusion of soft ingredients to facilitate its removal. At this juncture, it should be noted that although Caviton could be easily removed with a hand instrument, it did not seem to have sufficient sealing capacity as a temporary restorative material if the thickness was less than 3 mm. Nonetheless, for TERM, it apparently deformed during wear cycling, and interfacial gaps were probably sealed by this transformation. Therefore, it could be suggested that the low degree of dye penetration was provided by the deformation of the material during mechanical stressing.

Neodyne-α exhibited the best results in both wear and dye penetration tests. Although Friedman et al.\textsuperscript{25} reported that zinc oxide-eugenol cements showed high sealing ability as endodontic temporary restoratives, results may differ when liquid/powder ratios vary as the setting reaction is dependent upon the mixing procedure. Furthermore, being a eugenol-containing material, it inhibits the polymerization of adhesives by the presence of residual eugenol on cavity walls.\textsuperscript{25,75}

Wear rates of various materials, including resin composites, metal alloys, ceramics, and enamel, have been obtained by tests similar to the one used in this study.\textsuperscript{16–20} The wear test used in this study simulated the wear generated by a food bolus during the masticatory process.\textsuperscript{20} According to calibrations in a previous study, the results obtained after 400,000 cycles correlated well with those obtained after three years of clinical performance.\textsuperscript{75} In this study, we used 5,000 cycles – presumably equivalent to two weeks of clinical performance, a typical interval between visits in root canal treatment. Moreover, our test used a flat occlusal surface and flat wear stylus to simplify the wear process. Accordingly then, this study did not perfectly reflect the clinical situation as various factors including occlusion type, occlusal configuration, and parafunctional habits that influence intraoral wear were not taken into consideration and examined.

Caviton was subjected to occlusal loading after 30 minutes, as permitted by the manufacturer’s recommendation, and the result was unexpectedly satisfactory. The reason for this satisfactory performance could be due to better condensation as set material was dislodged from the unset soft material during testing. Therefore, we proposed that in a clinical setting, hydraulic-setting temporary restoratives for posterior teeth – which are subjected to severe occlusal stressing – should be allowed time to set fully. As for Temporary Pack, an eugenol-free cement, it exhibited poor wear resistance. We therefore suggested that it should not be used for restorations expecting severe occlusal loading. This is because sealing property is related to wear resistance since the distance to the pulp chamber decreases with decrease in material thickness. Therefore, temporary restorative materials should have good wear resistance.

TERM, a resin composite material, exhibited good wear resistance and moderate sealing property. It may thus be appropriate to be used for teeth expecting occlusal force as its material distortion aids in improving its sealing ability. As for Neodyne-α, it showed the best results in both wear resistance and sealing property. Although it seemed to be the best-performing temporary restorative for endodontic treatment, it is plagued with problems associated with eugenol. We therefore recommend that there be further investigations and research to develop a new, non-eugenol temporary restorative material to circumvent the eugenol-associated problems.

It is important to evaluate the synergistic effect of material deformation and destruction on wear and
subsequent dye penetration. However, this effect was not clarified in the present study as many thus-related parameters were not evaluated. With further study, there is a promising likelihood that the deterioration mechanism of endodontic temporary restorative materials can be better understood.

Based on the results of this study, it is recommended that the material selected to seal the endodontic access between appointments be chosen based on material characteristics, occlusal conditions, and type of subsequent restoration.

CONCLUSIONS

Within the limitations of this study, the following conclusions were drawn based on the obtained results:

2. Caviton exhibited the lowest mean value of dye penetration among the materials tested.
3. It is suggested that temporary restorations for endodontic treatment be based on material characteristics, occlusal conditions, and type of subsequent restoration.

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REFERENCES