Effect of a temporary sealing material on the bond strength of CAD/CAM inlay restorations with resin-coating technique

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This study aimed to assess the effects of a temporary sealing material and cleaning method of resin-coated dentin on the bond strength of computer-aided design/computer-aided manufacturing (CAD/CAM) inlay restorations. Resin-coated dentin surfaces were unsealed or temporarily sealed for 1 h or 1 week. For the temporarily sealed group, a hydraulic temporary sealing material was removed and further divided into four groups: without cleaning, cleaned with a rotational brush, a universal cleaner or an air-polishing device. Some specimens were investigated with energy dispersive X-ray spectroscopy and the others were used for microtensile bond strength (MTBS) test. A sealing material could not be removed with a rotational brush, which resulted in pretest failures in all specimens after 1 h and which resulted in low MTBS after 1 week. An air-polishing device can clean resin-coated dentin temporarily sealed with a hydraulic temporary sealing material and resulted in the similar MTBS as in the unsealed group.

Keywords: Resin coating, Temporary sealing, Resin cement, Microtensile bond strength, CAD/CAM

INTRODUCTION

Resin coating is one of the promising techniques used for indirect restorations2,3. In order to protect exposed dentin and enamel surfaces after cavity preparation, application of a dentin bonding agent and a flowable resin composite immediately after tooth preparation was introduced as a resin-coating technique in the early 1990s. Several studies have revealed that this technique not only protects the prepared tooth but also improves dentin bond strength and marginal adaptation2,3. Magne reported a similar idea, immediate dentin sealing (IDS), to seal the exposed dentin using a coating material4.

In conventional indirect restoration, the prepared cavity should be temporized prior to the final restoration setting in order to provide positional stability, adequate occlusion and proper oral hygiene5. An adequate removal of temporary sealing material from the prepared cavity is important in order to acquire good bonding performance of final restoration. Several researches have conducted to evaluate the removal methods of temporary sealing material6-11. Recently, newly developed universal cleaner which contains 10-methacryloyloxydecyl dihydrogen phosphate (MDP) was launched on the market. The components of a temporary sealing material should ideally be completely removed from the surface.

Nikaido et al. reported that resin-based filling materials may react with resin-coating material and deteriorate the bond strength of final luting cement12.

A water-setting material has been recommended for temporary sealing of the resin-coated cavity in conventional indirect restoration procedure, since it does not deteriorate the final bonding13. A chairside computer-aided design/computer-aided manufacturing (CAD/CAM) system becomes popular and enables single-visit treatment, i.e., the completion of a series of processes, including the preparation of a tooth, impression-taking with an intraoral scanner, fabrication of restoration and setting a final restoration within 1 h at the earliest14. Comparing conventional indirect restoration to single-visit treatment, some factors are different, viz., length of time to cementation and necessity of temporary filling. Previous studies have evaluated the bonding performance of resin cement without/with resin coating under the conventional method and single-visit treatment independently2,3,10,15,16. It was revealed that the application of resin coating was preferable under both the conventional method and single-visit treatment2,3,10,15,16. However, little information is available about the bonding performance, with regard to direct comparison of conventional method with single-visit treatment. In addition, no standardized removal methods of temporary sealing material from resin-coated dentin have been established.

Thus, the aim of this study was to assess the effects of a temporary sealing material, length of time from tooth preparation to cementation and cleaning method of resin-coated dentin on the bond strength of CAD/
CAM inlay restorations. The null hypothesis tested was that a temporary sealing material, length of time from tooth preparation to cementation and cleaning method of resin-coated dentin do not affect the bond strength of resin cement to CAD/CAM inlay restorations and resin-coated dentin.

MATERIALS AND METHODS

The materials used in this study are listed in Table 1. A light-emitting diode (LED) light-curing unit (VALO, Ultradent, South Jordan, UT, USA) with standard mode (1,000 m W/cm²) was used for light curing in this study. All procedures were conducted by a single operator in order to standardize each step.

Ten CAD/CAM resin blocks (Katana Avencia Block, Kuraray Noritake Dental, Tokyo, Japan) were sectioned with a low-speed diamond saw (Isomet, Buehler, Lake Bluff, IL, USA) to obtain sixty slabs with a thickness of 1 mm each. The surfaces of the slabs were finished with 600-grit silicon carbide paper under running water. Each sectioned slab was measured with a digital caliper (Mitutoyo CD-15C, Mitutoyo, Kanagawa, Japan) to ensure a final thickness of 1.00±0.05 mm.

Seventy extracted caries-free human third molars were stored in a storage solution (0.1% thymol) at 4°C until commencement of the experiment. The teeth were used within two months from the extraction. The collection of teeth for this study was approved by the Ethics Committee of the Graduate School and Hospital of Tokyo Medical and Dental University (No. D2013-022-2). Preparation of the tooth surfaces involved the process of making a flat surface in superficial dentin with a model trimmer (Y-230, Yoshida, Tokyo, Japan). The region to be bonded was then finished with 600-grit silicon carbide paper under running water to create uniform surfaces. The microtensile bond strength (MTBS) test was carried out on sixty teeth, while ten teeth were used for energy dispersive X-ray spectroscopy (EDS) analysis.

**MTBS test**

A combination of a two-step self-etch adhesive (Clearfil SE Bond 2; SE2, Kuraray Noritake Dental) and a flowable resin composite (Clearfil Majesty ES Flow; ES flow, Shade A2, Kuraray Noritake Dental) was used as the resin-coating material. The SE2 primer was first applied to dentin surfaces for 20 s and air dried. Then, the bonding agent of SE2 was spread, gently air-dried and light cured for 10 s. Afterwards, ES flow was daubed thinly on SE2 applied dentin surfaces with a disposable applicator brush (3L orange, Sun Medical, Shiga, Japan) and light-cured for 20 s. Then resin-coated dentin surfaces were wiped with alcohol pellets. The thickness of resin-coating layer was checked by confocal laser scanning microscopy (VK-X150, Keyence, Osaka, Japan) observation of perpendicular cut specimen in preliminary experiment. The thickness of SE2 was approximately 20 μm, the thickness of ES flow was approximately 80 μm and the thickness of resin-coating layer was approximately 100 μm.

Ten resin-coated dentin surfaces were used for the unsealed group, while fifty resin-coated dentin surfaces were used for the temporarily sealed group. For the unsealed group, resin-coated dentin surfaces were left unsealed and stored in distilled water at 37°C for 1 h or 1 week. For the temporarily sealed group, the resin-coated dentin surface was covered with a hydraulic temporary sealing material (Caviton EX, GC, Tokyo, Japan). The samples were then stored in distilled water at 37°C for 1 h or 1 week. After that, for the temporarily sealed group, a hydraulic temporary sealing material (Caviton EX) was carefully removed from the surface with a spoon excavator. Specimens were further divided into four sub-groups: without cleaning group, rotational brush (RB) group, universal cleaner (KC) group and air-flow (AF) group. The RB group specimens were cleaned with a rotational brush (Merssage brush CA No.1, Shofu, Kyoto, Japan) at 600 rpm for 5 s under water with a slow-speed hand piece (Ti-Max X25L, NSK, Tochigi, Japan). The KC group specimens were cleaned with a universal cleaner (Katana Cleaner, Kuraray Noritake Dental) with a rubbing motion with the applicator brush for 10 s, rinsed with water and then air dried. The AF group specimens were cleaned with the air-polishing device with 65 μm diameter glycine-based particles (air-flow powder SOFT, EMS, Nyon, Switzerland) at 0.75 MPa at a distance of 10 mm from the surface for 10 s.

Just prior to cementation, each prepared CAD/CAM slab was air-abraded using a blasting machine (Basic eco, Renfert, Hilzingen, Germany) with 50 μm alumina powder (Heraeus Kulzer Japan, Tokyo, Japan) at 0.1 MPa at a distance of 10 mm from the surface for 10 s, and then cleaned ultrasonically for 3 min in distilled water. 35% phosphoric acid (K-Etchant Syringe, Kuraray Noritake Dental) was applied to the adherent surface of the slabs for 5 s, rinsed with water and then air dried. Afterward, a ceramic primer (Clearfil Ceramic Primer Plus, Kuraray Noritake Dental) was applied to the adherent surface and gently air dried.

A tooth primer (Panavia V5 Tooth Primer, Kuraray Noritake Dental) was applied to the resin-coated dentin surface, left for 20 s and then gently air dried. The first 1 cm of a dual-cured resin cement (Panavia V5; PV5, Kuraray Noritake Dental) dispensed was discarded in order to ensure evenly mixed cement. A thin layer of the mixed cement was applied to the adherent surface of the prepared slab. A load of 0.5 kg was applied to extrude the excess resin cement which was wiped with a cotton pellet. The seating force was removed, and the specimens were light cured from an occlusal direction for 20 s.

All specimens were stored in distilled water at 37°C for 24 h. Before subjecting the specimens to the MTBS test, the top surface of each slab was cleaned with K-Etchant Syringe for 10 s, rinsed with water and air dried. A ceramic primer (Clearfil Ceramic Primer Plus) was applied to the top surface of each slab and gently air dried. The SE2 bonding agent was applied to the surface and light cured for 10 s, following which a direct resin composite (Clearfil AP-X, Shade A3, Kuraray Noritake Dental) was built up to create a slab approximately 3
Table 1 Materials used in this study

<table>
<thead>
<tr>
<th>Material</th>
<th>Code</th>
<th>Manufacturer</th>
<th>Compositions</th>
<th>Procedure</th>
<th>Batch No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resin-coating materials</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clearfil SE Bond 2 SE2</td>
<td>SE2</td>
<td>Kuraray Noritake Dental, Tokyo, Japan</td>
<td>Primer: 10-MDP, HEMA, hydrophilic dimethacrylate, water, photo initiator pH=2.0 Bond: 10-MDP, HEMA, hydrophobic dimethacrylate, dl-camphorquinone, photo initiators, Bis-GMA, silanated colloidal silica</td>
<td>Apply and leave primer for 20 s, and then gently air-dry. Apply bond, gently air-dry, and then light cure for 10 s.</td>
<td>000001</td>
</tr>
<tr>
<td>Clearfil Majesty ES Flow</td>
<td>ES flow</td>
<td>Kuraray Noritake Dental</td>
<td>silanated barium glass filler, prepolymerized organic filler, Bis-GMA, hydrophobic aromatic dimethacrylate, di-camphorquinone</td>
<td>Extend ES flow thinly with a brush, and then light cure for 20 s.</td>
<td>9D0024</td>
</tr>
<tr>
<td>Resin cement</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Panavia V5 PV5</td>
<td>PV5</td>
<td>Kuraray Noritake Dental</td>
<td>K-Etchant Syringe: 35% phosphoric acid, water, colloidal silica, dye Clearfil Ceramic Primer Plus: 3-trimethoxysilylpropyl methacrylate, MDP, ethanol Panavia V5 Tooth Primer: MDP, original multifunctional monomer, new polymerization catalysts, stabilizer, HEMA, water pH=2.0 Paste A: Bis-GMA, TEGDMA, hydrophobic aromatic dimethacrylate, hydrophilic aliphatic dimethacrylate Paste B: Bis-GMA, hydrophobic aromatic dimethacrylate, hydrophilic aliphatic dimethacrylate (Filler: 98 vol%)</td>
<td>Block treatment: Apply K-Etchant GEL for 5 s, rinse with water, and then air-dry. Apply Clearfil Ceramic Primer Plus and gently air-dry. Dentin treatment: Apply and leave Panavia V5 Tooth primer for 20 s, and then gently air-dry. Place paste from automix syringe, and then light cure for 20 s.</td>
<td>A50092 2U0035 3F0051</td>
</tr>
<tr>
<td>CAD/CAM resin block</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Katana Avencia Block</td>
<td></td>
<td>Kuraray Noritake Dental</td>
<td>UDMA, TEGDMA, aluminum filler (20 nm), silica filler (40 nm), pigments (Filler: 62 wt%)</td>
<td>—</td>
<td>000357</td>
</tr>
<tr>
<td>Temporary sealing material</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Caviton EX GC</td>
<td></td>
<td>GC, Tokyo, Japan</td>
<td>zinc oxide, plaster of paris, vinyl acetate, others</td>
<td>—</td>
<td>1806211</td>
</tr>
<tr>
<td>Universal cleaner</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Katana Cleaner (KC)</td>
<td></td>
<td>Kuraray Noritake Dental</td>
<td>MDP, phosphate ester monomer, triethanolamine, thickener, purified water, colorant, stabilizer</td>
<td>Apply with a rubbing motion with the applicator brush for 10 s, rinsed with water and then air-dry.</td>
<td>5J0009</td>
</tr>
</tbody>
</table>

Bis-GMA: bisphenol-A-diglycidyl methacrylate; HEMA: 2-hydroxyethyl methacrylate; MDP: 10-methacryloyloxydecyl dihydrogen phosphate; TEGDMA: triethyleneglycol dimethacrylate; UDMA: urethane dimethacrylate
mm high for the MTBS test.

Each tooth was cross-sectioned longitudinally using Isomet to obtain beam-shaped specimens with an approximate bonded surface area of 1×1 mm². Before the MTBS test, the dimensions of each beam were checked with a digital caliper (Mitutoyo CD-15C). Each specimen was then attached to a customized microtensile jig with a cyanoacrylate adhesive (Model Repair II Blue, Dentsply-Sankin, Tokyo, Japan) and placed in the test apparatus (EZ-SX, Shimadzu, Kyoto, Japan) for the MTBS test at a crosshead speed of 1 mm/min. The MTBS test data were statistically analyzed by Kruskal-Wallis test followed by Dunn’s test with Bonferroni correction. All analyses were performed using the statistical software SPSS version 26 (IBM, Chicago, IL, USA), with the statistical significance set at 0.05.

**Failure mode analysis**

After the MTBS test, the fractured specimens were placed horizontally in epoxy resin (EpoxiCure 2, Buehler). The resin-embedded specimens were polished after 24 h with a sequence of wet silicon carbide papers (600-, 800-, 1000-, 1200-, 1500-, and 2000-grit) and diamond pastes (6, 3, 1, and 0.25 μm). The specimens were ultrasonically cleaned for 3 min in distilled water. Then, the specimens were kept in a desiccator for 24 h, sputtered with a gold coating and examined by scanning electron microscopy (SEM; JSM-IT100, JEOL, Tokyo, Japan) at 50× magnification. The failure modes were classified into the following seven categories, as illustrated in Fig. 1: blo: cohesive failure in the resin block; blo-cem: complete adhesive failure at the interface between resin block and resin cement; cem: cohesive failure in resin cement; cem-cr: complete adhesive failure at the interface between resin cement and resin-coated dentin; cr: cohesive failure in resin-coating material; inter-den: complete adhesive failure between resin-coating material and dentin; and den: cohesive failure in dentin. When pre-test failures occurred during specimen preparation for MTBS, failure mode analysis was carried out.

**SEM observations and EDS analysis**

Sample preparation for each group was carried out in the same manner as for MTBS test. Just before the cementation procedure, the root was cut and discarded with Isomet so that the dentin remained of 2 mm thickness. Then the specimens were stored in a desiccator for 24 h. Following this, the specimens were carbon coated to 4 μm thickness. The microstructure morphology was analyzed with SEM at 300× magnification and EDS (JSM-IT100) at a working distance of 10 mm and beam voltage of 20.0 kV.

**RESULTS**

**MTBS test and failure mode analysis**

The results of MTBS test and failure mode analysis are summarized in Table 2. There were no significant differences among unsealed after 1 h, unsealed after 1 week, cleaned with AF after 1 h and cleaned with AF after 1 week groups (p>0.05). These four groups showed more than 50 MPa mean MTBS. As for the sealed groups without cleaning and cleaned with RB, pre-test failures occurred in all specimens after 1 h at “cem-cr” during specimen preparation for the MTBS test. After 1 week, the sealed without cleaning group showed the lowest mean value. There were no significant differences between the groups without cleaning after 1 week and cleaned with RB after 1 week (p>0.05). The predominant failure mode of these two groups was “cem-cr”. For the groups cleaned with KC, there were no significant differences between after 1 h and 1 week (p>0.05). For the group cleaned with AF, the predominant failure mode was “blo-cem”.

**SEM observations and EDS analysis**

SEM images are presented in Fig. 2. In the sealed without cleaning and the RB groups, more debris was observed in the after 1 h groups (see Figs. 2c and 2e) than in the after 1 week groups (see Figs. 2d and 2f). As for the KC group, small amount of debris was observed after 1 h group (see Fig. 2g). As for the AF group, some tiny pits were observed in both after 1 h and after 1 week groups (see Figs. 2i and 2j).

The results of EDS analysis are summarized in Table 3. All groups showed dominant proportions of carbon (C) and oxygen (O). Silica (Si), aluminium (Al) and barium (Ba) were detected in all groups. More than 4% of zinc (Zn) was detected in the sealed without cleaning, the RB after 1 h and the RB after 1 week groups. More than 9% of Zn was detected in the sealed without cleaning and the RB after 1 h groups. No Zn was detected in either the unsealed group, in the KC after 1 week group or in the AF group. Only 0.1% of Zn was detected in the KC.
Table 2  Microtensile bond strength (MPa) and failure modes

<table>
<thead>
<tr>
<th>Temporary sealing</th>
<th>Time</th>
<th>Cleaning method</th>
<th>MTBS (MPa)</th>
<th>Failure modes (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>blo</td>
</tr>
<tr>
<td>unsealed</td>
<td>1 h</td>
<td>—</td>
<td>54.8±4.9(^{a,b})</td>
<td>6.9</td>
</tr>
<tr>
<td></td>
<td>1 week</td>
<td></td>
<td>63.4±10.1(^{a})</td>
<td>0</td>
</tr>
<tr>
<td>sealed</td>
<td>1 h</td>
<td>—</td>
<td>n.d.</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>1 week</td>
<td>—</td>
<td>13.0±8.3(^{c})</td>
<td>0</td>
</tr>
<tr>
<td>sealed</td>
<td>1 h</td>
<td>RB</td>
<td>n.d.</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>1 week</td>
<td>RB</td>
<td>23.6±6.7(^{d})</td>
<td>0</td>
</tr>
<tr>
<td>sealed</td>
<td>1 h</td>
<td>KC</td>
<td>38.3±10.4(^{d})</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>1 week</td>
<td>KC</td>
<td>47.9±13.4(^{d})</td>
<td>0</td>
</tr>
<tr>
<td>sealed</td>
<td>1 h</td>
<td>AF</td>
<td>61.7±14.1(^{e})</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>1 week</td>
<td>AF</td>
<td>58.5±17.7(^{h})</td>
<td>0</td>
</tr>
</tbody>
</table>

MTBS are given as the mean±SD.

n.d. = not detected

The values with the same small superscript letters are not statistically different (p>0.05).

blo: cohesive failure in the resin block; blo-cem: complete adhesive failure at the interface between resin block and resin cement; cem: cohesive failure in resin cement; cem-cr: complete adhesive failure at the interface between resin cement and resin-coated dentin; cr: cohesive failure in resin-coating material; inter-den: complete adhesive failure between resin-coating material and dentin; and den: cohesive failure in dentin.

Table 3  Results of EDS analysis (mass%)

<table>
<thead>
<tr>
<th>Temporary sealing</th>
<th>Time</th>
<th>Cleaning method</th>
<th>C</th>
<th>O</th>
<th>Si</th>
<th>Ca</th>
<th>Na</th>
<th>P</th>
<th>Zn</th>
<th>S</th>
<th>Al</th>
<th>Ba</th>
</tr>
</thead>
<tbody>
<tr>
<td>unsealed</td>
<td>1 h</td>
<td>—</td>
<td>28.1</td>
<td>23.2</td>
<td>15.1</td>
<td>0</td>
<td>0.3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2.9</td>
<td>10.5</td>
</tr>
<tr>
<td></td>
<td>1 week</td>
<td>—</td>
<td>26.3</td>
<td>42.2</td>
<td>17.3</td>
<td>0.2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>3.4</td>
<td>10.6</td>
<td></td>
</tr>
<tr>
<td>sealed</td>
<td>1 h</td>
<td>—</td>
<td>34.6</td>
<td>42</td>
<td>4.4</td>
<td>3.8</td>
<td>0</td>
<td>0</td>
<td>9.2</td>
<td>3.4</td>
<td>0.5</td>
<td>1.2</td>
</tr>
<tr>
<td></td>
<td>1 week</td>
<td>—</td>
<td>44.2</td>
<td>44.3</td>
<td>3.2</td>
<td>1.1</td>
<td>0</td>
<td>0</td>
<td>4.0</td>
<td>1.3</td>
<td>0.5</td>
<td>1.6</td>
</tr>
<tr>
<td>sealed</td>
<td>1 h</td>
<td>RB</td>
<td>38.2</td>
<td>35.7</td>
<td>7.1</td>
<td>1.7</td>
<td>1.2</td>
<td>0</td>
<td>10.2</td>
<td>1.7</td>
<td>0.8</td>
<td>3.5</td>
</tr>
<tr>
<td></td>
<td>1 week</td>
<td>RB</td>
<td>44.4</td>
<td>39.3</td>
<td>4.0</td>
<td>1.7</td>
<td>0.8</td>
<td>0</td>
<td>6.8</td>
<td>0.4</td>
<td>0.5</td>
<td>2.1</td>
</tr>
<tr>
<td>sealed</td>
<td>1 h</td>
<td>KC</td>
<td>34.5</td>
<td>42</td>
<td>12.3</td>
<td>0</td>
<td>0.2</td>
<td>0</td>
<td>0.1</td>
<td>0</td>
<td>2.3</td>
<td>8.6</td>
</tr>
<tr>
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<td>1 week</td>
<td>KC</td>
<td>36.1</td>
<td>40</td>
<td>12.7</td>
<td>0</td>
<td>0.2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2.3</td>
<td>9.1</td>
</tr>
<tr>
<td>sealed</td>
<td>1 h</td>
<td>AF</td>
<td>31.8</td>
<td>41.7</td>
<td>14.2</td>
<td>0</td>
<td>0.2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2.6</td>
<td>9.5</td>
</tr>
<tr>
<td></td>
<td>1 week</td>
<td>AF</td>
<td>29.3</td>
<td>41.0</td>
<td>15.7</td>
<td>0</td>
<td>0.2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2.9</td>
<td>11.0</td>
</tr>
</tbody>
</table>


after 1 h group.

**DISCUSSION**

In the groups without cleaning and cleaned with RB after 1 h, pre-test failures occurred in all specimens. All failures were complete adhesive failure at the interface between resin cement and resin-coated dentin. As for the groups without cleaning and cleaned with RB after 1 week, MTBS were lower than those of the other groups, and the predominant failure mode was "cem-cr". It has been reported that a rotational brush is an effective method to clean the dentin surface prior to restoration cementation procedure\(^{4,10,11}\). In addition, cleaning with a rotational brush is a simple and widely used method in clinical practice\(^{4,10}\). Nevertheless, it seemed that cleaning with rotational brush was insufficient in the present study. According to SEM observation, debris on the resin-coated dentin surface was observed in the RB group (Figs. 2e and 2f). Thus, it can be said that Caviton EX could not be removed with RB, which resulted in pretest failures or low MTBS. The present study was conducted simulating inlay restorations and a hydraulic temporary sealing material was used. The previous studies were conducted simulating crown restorations and non-eugenol zinc-oxide cement\(^{10}\) or a polycarboxylate cement\(^{11}\) was used. The difference of used materials might cause different results after cleaning with a rotational brush.

In addition, SEM observation of the without cleaning and the RB groups revealed that more debris was observed in the after 1 h groups (Figs. 2c and 2e) than in
the after 1 week groups (Figs. 2d and 2f). The probable reason for this result was that the after 1 h condition was in the middle of hardening of the Caviton EX. Thus, unhardened Caviton EX adhered to the resin-coated surface firmly. EDS analysis clarified this fact (see Table 3). Carbon shadowing was applied to all groups. Carbon shadowing contained C and O. ES Flow which was used as resin-coating material contained Si and Ba. Zn was the component of Caviton EX. EDS analysis revealed that more than 4% of Zn was detected in the without cleaning and the RB groups. It was also revealed more Zn was detected in the after 1 h group than in the 1 week group. These findings indicate that the debris of Caviton EX remained on the resin-coated dentin surface after cleaning with rotational brush and interfered with the adhesion of resin cement.

Contrary to our results, Nikaido et al.\textsuperscript{13} reported that in the group temporarily sealed with a hydraulic temporary sealing material for 1 week the bond strength of resin cement increased, although the debris of a hydraulic temporary sealing material remained on the resin-coated dentin. Nikaido et al.\textsuperscript{13} removed the hydraulic temporary sealing material with a dental probe, and they did not use RB. Removal of temporary sealing material with RB should be more effective than dental probe. The probable reason for the inconsistency was the difference in the materials used. As for a hydraulic temporary sealing material, Cavit-G (3M ESPE) was used in the previous study, whereas Caviton EX was used in the present study. With regard to resin-coating material, Protect Liner F (Kuraray Noritake Dental) was used in the previous study, while ES flow was used in the present study. In addition, resin cement of the previous study was different from that of the present study. Although the reason was not clear, there may be some interaction among the hydraulic temporary sealing material, resin-coating material and resin cement.

The study which investigated the effect of MDP containing cleaner revealed that the structure of MDP was expected to have a strong surfactant effect\textsuperscript{11}. MDP has a structure with both hydrophilic and hydrophobic groups\textsuperscript{19}. Thus MDP binds to the surface of two substances with different polarities at the end of the hydrophobic\textsuperscript{11}. Consequently, the temporary cement is easily separated from the adhered surface\textsuperscript{11}. However, a small amount of Zn was detected from SEM observation and EDS analysis in the KC after 1 h group in the present study. Similar to the results of the sealed without cleaning after 1 h and the RB after 1 h groups, unhardened Caviton EX adhered to the resin-coated surface firmly and was not able to be completely removed even with the agitation of MDP containing cleaner.

As for the KC after 1 week group, Zn was completely removed. However, the KC after 1 week group showed lower MTBS than that of the unsealed after 1 week. In addition, 25.9 % of “cem-cr” failure was observed in the KC after 1 week group. The previous study stated that any MDP remaining from MDP containing cleaner at the bonding interface after removal of temporary cement is not problematic\textsuperscript{11}. The reason for this inconsistency was not clear, further investigations are necessary in the future.

In the present study, the AF group showed similar MTBS to the unsealed group. EDS analysis revealed that Zn was completely removed in the AF after 1 h and after 1 week groups. These results indicate that an air-polishing device with air-flow SOFT powder can clean temporarily sealed resin-coated dentin with Caviton EX surface. Our results were in accordance with the results of Sato et al.\textsuperscript{18}. Air-polishing device is widely used for stains and plaque removal\textsuperscript{20,21}. There are several types of air-flow powders. Air-flow powder SOFT which is
composed of glycine (an amino acid with high water solubility) powder is recommended by the manufacturer to clean the tooth prior to restoration cementation procedure. Glycine powders have a lower hardness than sodium bicarbonate powders, and cause less damage to the dentin surface and the gingival epithelium. In addition, glycine powders produced smaller changes in dentin surface parameters than sodium bicarbonate powders. Therefore, air-flow powder SOFT was used to remove the temporary sealing material. However, tiny pits were detected with the AF groups in SEM observations (see Figs. 2 i and 2j). While the tiny pits probably increase mechanical retention, care should be taken not to damage the resin-coated dentin.

The reasons stated above lead to the null hypothesis being rejected, that temporary sealing material, length of time from tooth preparation to cementation and cleaning method of resin-coated dentin do not affect the bond strength of CAD/CAM inlay restorations.

CONCLUSIONS

Within the limitations of this study, the conclusions are as follows:

(i) Caviton EX adhered firmly to the resin-coated dentin surface after 1 h. This Caviton EX could not be removed with a rotational brush.
(ii) Caviton EX adhered to the resin-coated dentin surface even after 1 week.
(iii) An air-polishing device with air-flow SOFT powder can clean a surface temporarily sealed with Caviton EX.

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