To examine the bonding of flowable resin composite restorations (F-restoration) to class 1 occlusal cavities with and without cyclic load stress, compared with that of a universal resin composite restoration (U-restoration). Two flowable composites and one universal composite (control) were applied with an adhesive system to 42 standardized class 1 occlusal cavities. The restored specimens were subjected to cyclic load stress and no stress modes. The microtensile bond strength (μ-TBS) of the dentin floor was measured. The U-restoration did not show pretesting failure. The F-restorations exhibited pretesting failure, regardless of the stress mode. The μ-TBS was not significantly different among the three restorations, regardless of the stress mode. The cyclic load stress did not influence the μ-TBS of the F-restorations; however, it significantly reduced μ-TBS in the U-restoration. The bonding reliability of the F-restorations was inferior to that of the U-restoration, for both stress modes.

Keywords: Flowable resin composite, Microtensile bond strength, Class 1 posterior occlusal restoration, Cyclic load stress, Weibull analysis

INTRODUCTION

All patients typically desire high esthetic dental treatments to involve minimum surgical intervention of cavitated lesions with minimal intervention dentistry. A direct composite restoration that can protect sound tooth substance and achieve esthetic restoration significantly contributes to the realization of minimally invasive dental treatment. Previously, resin composites were not recommended for large posterior restorations because of their potential for excessive wear, microleakage, and fracture. However, after numerous improvements, recent hybrid resin composites have been clinically accepted for posterior applications and exhibit very low annual failure rates of 2.2% or lower. Furthermore, in 1996, the clinical application of first-generation flowable resin composites was introduced.

The filler content of these traditional flowable resin composites is 20–25% less than that of hybrid resin composites. Flowable composites flow well due to their low viscosity, facilitating simple administration via a syringe. However, due to their poor mechanical properties, flowable composites cannot be applied to a region subjected to strong external forces. Therefore, flowable composites are considered suitable for some clinical cases (i.e., liners in areas of difficult access or flow; margin repairs for amalgam, composite, porcelain, or crown; pit and fissure sealing; and small class 3 and 5 restorations). Kubo et al. confirmed that the clinical and in vitro marginal sealing performance of flowable resin composites applied to cervical lesions is similar to those of hybrid resin composites. However, it is important that the resin composite exhibit excellent durability and high wear resistance in posterior restorations.

Higher filler loading flowable resin composites have recently been developed. Depending on the manufacturer, the filler content and polymerization shrinkage of the new resins are comparable to those of the conventional hybrid resin composites. Manufacturer instructions for several of the new flowable resin composites state that the resins can be applied to a posterior occlusal restoration. Some of the new flowable resin composites for posterior restorations have better wear resistance compared with some hybrid resin composites. They have been shown to exhibit a wear resistance similar to an amalgam restoration. However, the actual bonding state of a posterior occlusal cavity restored with the new flowable resin composites has not been examined. The microtensile bond test introduced by Sano et al. is an effective means for determining internal bond strength obtained from specimens subjected to thermal cycle stress or cyclic load stress. The International Organization for Standardization (ISO) technical specification 11405 guidelines state that the use of probability of failure calculated from the Weibull distribution function provides a suitable means of comparing many materials. The purpose of this study was to examine the bond strength of flowable resin composite restorations to class 1 occlusal cavity floors with and without cyclic load stress to simulate the intraoral environment, in comparison with a universal resin composite. In addition, the bonding reliability of the flowable resin composite restorations under the two stress conditions was investigated by Weibull analysis.

MATERIALS AND METHODS

Resin composite restoratives, adhesive system, and light curing unit

Table 1 presents the composition, lot number, and
### Table 1 Composite resin restoratives and resin adhesive system

<table>
<thead>
<tr>
<th>Type</th>
<th>Composite resin restorative</th>
<th>Composition</th>
<th>Lot No.</th>
<th>Manufacturer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flowable resin composites</td>
<td>Clearfil Majesty ES Flow (Shade: A3)</td>
<td>Barium glass filler, Silica filler, TEGDMA, Hydrophobic-aromatic dimethacrylate, dl-Camphorquinone, Photo initiator</td>
<td>2Q0019</td>
<td>Kuraray Noritake Dental</td>
</tr>
<tr>
<td></td>
<td>MI Low Flow (Shade: A3)</td>
<td>Strontium glass filler, Silica filler, TEGDMA, UDMA, Bis-MEPP, Photo initiator</td>
<td>1409021</td>
<td>GC</td>
</tr>
<tr>
<td>Universal resin composite</td>
<td>Filtek Supreme Ultra Universal Restorative (Shade: A3B)</td>
<td>Zirconia nanofiller, Silica nanofiller, Zirconia·Silica cluster filler, Bis-EMA, Bis-GMA, UDMA, PEGDMA, TEGDMA, Photo initiator</td>
<td>N552585</td>
<td>3M ESPE</td>
</tr>
</tbody>
</table>

### Type Resin adhesive system Composition Lot No. Manufacturer

<table>
<thead>
<tr>
<th>Type</th>
<th>Resin adhesive system</th>
<th>Composition</th>
<th>Lot No.</th>
<th>Manufacturer</th>
</tr>
</thead>
<tbody>
<tr>
<td>One-bottle one-step all-in-one adhesive</td>
<td>Scotchbond Universal Adhesive</td>
<td>MDP, Dimethacrylate resins, HEMA, Methacrylate-modified polyalkenoic-acid copolymer, Filler, Ethanol, Water, Photo initiators, Silane</td>
<td>558335</td>
<td>3M ESPE</td>
</tr>
</tbody>
</table>

Bis-EMA, bisphenol A ethoxylated dimethacrylate; Bis-GMA, bisphenol A glycidyl methacrylate; Bis-MEPP, 2,2-bis(4-methacryloyloxyethoxyphenyl) propane; HEMA, hydroxyethyl methacrylate; MDP, 10-methacryloyloxydecyl dihydrogen phosphate; PEGDMA, polyethylene glycol dimethacrylate; TEGDMA, triethyleneglycol dimethacrylate; UDMA, urethane dimethacrylate.

The manufacturer of the two flowable composite restoratives, one universal resin composite restorative, and one one-bottle one-step all-in-one adhesive system used in this study. Two flowable resin composites were used for posterior occlusal restoration: Clearfil Majesty ES Flow (EF; Kuraray Noritake Dental, Kurashiki, Japan) and MI Low Flow (LF; GC, Tokyo, Japan). One nanohybrid universal resin composite, Filtek Supreme Ultra Universal Restorative (SU; 3M ESPE, St Paul, MN, USA), was used as the control. One all-in-one adhesive system, Scotchbond Universal Adhesive (3M ESPE, Seefeld, Germany), was applied to all cavities in accordance with the manufacturer’s instructions, regardless of type of resin composite. Each resin composite restorative and resin adhesive system was light-cured with a high-power light-emitting diode (LED) curing unit (G-Light Prima II, GC) in the “normal” modus with an output of 900 mW/cm². Before and after each light irradiation, the light intensity was measured and checked with a radiometer (Demetron L.E.D. Radiometer, Kerr, CA, USA).

### Tooth selection and restorative procedures

This study utilized 42 caries-free extracted human maxillary molars stored in 0.1% thymol solution at 24°C, used within one year after extraction. It was approved by the Ethics Committee of the Nippon Dental University School of Life Dentistry at Tokyo (approval number NDU-2012-36). A schematic flow chart of experimental procedures is shown in Fig. 1. Each extracted human maxillary molar was embedded in a standardized resin mold by establishing a plane settled with the three apexes of the buccomesial cusp, buccodistal cusp, and mesiopalatal cusp parallel to the base plane of the mold with an acrylic resin (Adfa, Shofu, Kyoto, Japan). An occlusal shape stent for each molar was prepared by a transparent composite material (Palfique Clear, Tokuyama Dental, Tokyo, Japan). Standardized occlusal simple class 1 cavities (5.0 mm mesiodistal length; 3.0 mm buccolingual width; 3.0 mm depth from the central fossa) were prepared with a straight cylinder round-end diamond point (FG114, Shofu) mounted in a custom-made cavity duplicator (Tokyo Giken, Tokyo, Japan). The cavity was pretreated with Scotchbond Universal Adhesive (3M ESPE) and then restored by a two-layered incremental technique. The first horizontal layer (2.0 mm) of the composite restorative was applied on the cavity floor, and then light-cured for 20 s. The second layer of the remaining space of the cavity was filled with the restorative, press-formed with an occlusal shape stent, and then light-cured for 20 s. After 24 h of water storage at 37°C, all specimens restored with the three composite restoratives were polished and divided into two groups: with cyclic load stress group (S+, n=21) and without cyclic load stress group (S−, n=21).

### Cyclic load and microtensile bond strength testing

For the S+ group, the opposing object was made by an acrylic resin (Adfa, Shofu) to load the cyclic stress on the inner inclined surfaces of occlusal cusps. The S+ group specimen was subjected to cyclic load stress at 157 N for 90 cycles/min for 3×10⁵ cycles in total, in water at 37°C. The load was administered by a custom-
(a) Each extracted human maxillary molar was embedded in standardized resin mold by establishing a plane settled with the three apexes of the buccomesial cusp, buccodistal cusp, and mesiopalatal cusp parallel to the base plane of the mold with an acrylic resin. (b) An occlusal shape stent for each molar was created by a transparent composite material. (c) A standardized occlusal simple class 1 cavity is prepared. (d) The cavity was pretreated with Scotchbond Universal Adhesive (3M ESPE, Seefeld, Germany) and then restored by the two-layered incremental technique. The first layer, 2.0 mm thick, is filled and light-cured. (e) The second layer for the remaining space of the cavity is filled with the restorative and press-formed with the occlusal shape stent, and then light-cured for 20 s. (f) All restored specimens were stored in 37°C water for 24 h. (g) One-half of the specimens are subjected to dynamic cyclic load stress. (h and i) Each restored specimen with and without the stress are sectioned intermittently and vertically. (j) Three standardized beam-shaped test pieces are trimmed and obtained from each restored specimen. (k) The microtensile bond strength is measured at 1.0 mm/min crosshead speed.

made multiple function apparatus (Tokyo Giken). Each restored specimen with and without the load stress was sectioned intermittently and perpendicular to the resin composite-dentin interface using a water-cooled microtome (Leitz 1600 Saw Microtome, Ernst Leitz, Wetzlar, Germany). Three standardized beam-shaped test pieces with a cross-sectional area of 1.0×1.0 mm were obtained from each restored specimen. The microtensile bond strength (μ-TBS) of each test piece was measured at a crosshead speed of 1.0 mm/min with a universal testing machine (Autograph AG-1, Shimadzu, Kyoto, Japan). When test pieces debonded during trimming before the μ-TBS test (pretesting failure; ptf), the pieces were recorded as 0 MPa and included into the statistical analysis.

Statistical analysis

The μ-TBS data (n=21) expressed in MPa were statistically analyzed with the Kruskal-Wallis test, followed by multiple comparison testing using Statistical Package for Social Sciences software (SPSS v. 16.0, Chicago, USA) with two-sided significance levels of 5% and Bonferroni adjustment, and with the Steel-Dwass test using JMP11 software (SAS, Tokyo, Japan) with a level of significance set at 0.05. To estimate bonding reliability, the Weibull modulus and the Weibull stress, based on the μ-TBS data that excluded 0 MPa values recorded by pretesting failures, were statistically determined in Excel (Excel 2010 for Windows, Microsoft, Redmond, WA, USA).

Mode of failure observation

After μ-TBS measurements, the mode of failure was...
Table 2  Microtensile bond strength test results

<table>
<thead>
<tr>
<th>Stress mode</th>
<th>Restoration</th>
<th>S−</th>
<th>S+</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Median</td>
<td>Max/Min</td>
<td>Q1</td>
</tr>
<tr>
<td>EF</td>
<td>23.3&lt;sup&gt;a&lt;/sup&gt;</td>
<td>47.2/0.0</td>
<td>19.5</td>
</tr>
<tr>
<td>LF</td>
<td>27.0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>46.2/0.0</td>
<td>17.1</td>
</tr>
<tr>
<td>SU</td>
<td>24.6&lt;sup&gt;a&lt;/sup&gt;</td>
<td>34.4/10.6</td>
<td>18.5</td>
</tr>
</tbody>
</table>

Values with different letters indicate a statistically significant difference (p<0.05) (uppercase letters=column and lowercase letters=rows).

Q1, first quartile; Q3, third quartile; ptf, pretesting failure.

observed under a light-microscope (Measurescope MM-1200, Nikon, Tokyo, Japan) at a magnification of ×200 and classified as either “mixed failure” (interfacial failure at the resin composite-dentin interface and cohesive failure within the resin composite and adhesive), “interfacial failure” (occurring at the resin-dentin interface), or “cohesive failure” (comprising two types: those occurring within the dentin and those occurring within the resin composite).

**SEM observation**

Four types of fracture mode (mixed failure, interfacial failure, cohesive failure in dentin, and cohesive failure in composite) and pretesting failure were randomly selected from the specimens with and without cyclic load stress. The dentin-side surfaces of the post-test specimens were osmium coated and observed under a scanning electron microscope (SEM, S-4000, Hitachi, Tokyo, Japan) at ×50 and ×500 magnifications and an accelerating voltage of 5.0 kV.

**Basic measurement data of the resin composite restoratives**

The inorganic filler weight content, linear polymerization shrinkage, flexural strength, and flexural modulus of the three resin composite restoratives were measured since these factors may influence the bonding of a class 1 restoration. The inorganic filler weight content of five specimens was determined by the standard ash method<sup>17</sup>). The weight of each resin composite specimen was measured using an analytical balance (Sartorius BP221S, Sartorius AG, Göttingen, Germany) and then heated in an electric furnace at 500°C for 60 min to burn out the organic ingredients. Residual inorganic filler was weighed and the inorganic filler weight content (wt%) was calculated. Linear polymerization shrinkage was measured with a custom-made noncontact diode-laser displacement sensor (HL-C105B-BK, SUNX, Kasugai, Japan; n=5) accurate to 1.0 μm, as described in detail by Miyasaka <sup>110</sup> et al.<sup>17</sup>). Each resin composite was inserted into an acrylic cylindrical tube mold 8.0 mm in height with a 4.0 mm inner diameter. The composites were then light-cured with a high-power LED curing unit (G-Light Prima II, GC) in the “normal” modus with an output of 900 mW/cm<sup>2</sup>. The dimensional change of the filled resin composite was measured from the initiation of light irradiation and lasted for 180 s with a laser displacement sensor (n=5). The linear polymerization shrinkage ratio was then calculated.

The flexural strength and flexural modulus (n=5) were measured using a three-point flexural strength test. Each resin composite was applied to a 2×2×25 mm stainless steel mold and then light-cured by three 20 s overlapping irradiations on the upper specimen side with a high-power LED curing unit. The cured resin composite specimens were then loaded in a universal testing machine (Autograph AG-1, Shimadzu) at the crosshead speed of 0.75 mm/min until fracture occurred, as recommended in the ISO 4049 guidelines<sup>18</sup>). The flexural modulus was calculated from the slope of a load stress-strain curve obtained by the flexural strength test. The data were analyzed by one-way analysis of variance. When factors were significantly different, Tukey’s q test was performed between each level using SPSS 16.0 software with the level of significance set at 0.05.

**RESULTS**

**Microtensile bond strength**

The μ-TBS test results are shown in Table 2 and box plots are presented in Fig. 2. Under the S− condition,
one test piece of the EF restoration and two pieces of the LF restoration were debonded during trimming before the μ-TBS test (i.e., the ptf); however, there was no ptf evident in the SU restoration. In contrast, under the S+ condition, ptf occurred in two pieces of the EF restoration and in six pieces of the LF restoration, but not in the SU restoration. There were no significant differences in the μ-TBS among the three restorations, including 0 MPa values recorded by ptf, regardless of the cyclic load stress mode (Table 2). The EF and LF restorations were not influenced by the cyclic load stress; however, the μ-TBS of the SU restoration reduced significantly with load stress (Table 2).

Distribution of the failure modes observed under light-microscopy and SEM

The distribution of the failure modes observed by using a light-microscope is presented in Fig. 3. The following five types of failure were observed: mixed failure, interfacial failure, two types of cohesive failure (occurring within the dentin and resin composite), and ptf. Most of the post-test specimens (76–95%), except for the LF restoration specimens under the St condition, that exhibited the mixed failure mode consisted of interfacial failure, cohesive failure in adhesive resin, and cohesive failure in composite (Fig. 4-1 and 2, a test piece of EF restoration under the S− condition). For the EF and LF restorations, cohesive failures within the composite (Fig. 4-3 and 4, a test piece of EF restoration under the S+ condition) and dentin (Fig. 4-5 and 6, a test piece of LF restoration under the S+ condition) increased with cyclic load stress. However, the failure mode of the SU restoration was not influenced by load stress. Interfacial failure was observed only in the flowable restoration under the S− condition (Fig. 4-7 and 8, a test piece of EF restoration under the S− condition). All ptf specimens of the EF and LF restorations exhibited interfacial failure at the resin-dentin interface (Fig. 4-9 and 10, a test piece of LF restoration under the S− condition).

Bonding reliability

Table 3 presents the Weibull parameters for the three restorations with and without cyclic load stress, including the Weibull modulus (Wm), stress value for 10% probability of failure (PF10), and 95% confidence intervals (lower limit value-upper limit value). Figure 5 shows the three regression lines calculated by Gauss’s least squares method, based on the Weibull plots of the three restorations. The Wm values of the three restorations with and without the cyclic load stress were examined by a significance test for the slope of regression line with the level of significance set at 0.05. Under the S− condition, the Wm values of EF and LF restorations were significantly smaller than that of SU restoration (Table 3).

The bonding reliability evaluation was based on the μ-TBS while excluding the ptf 0 MPa values of the two flowable resin composite restorations. The bonding reliability of flowable resin composite restorations under S− condition was statistically inferior to that of the universal resin composite restoration. However, under the S+ condition, the bonding reliability of the LF restoration was significantly greater than the two other restorations (Table 3). The bonding reliability of the LF restoration consequently exhibited statistical superiority in comparison with that of the EF and SU restorations. The Wm value of EF restoration was not influenced by the cyclic load stress. The Wm value of LF restoration significantly increased with load stress; however, the Wm of the SU restoration statistically decreased with load stress (Table 3). These results may indicate that the influence of the cyclic load stress on the bonding reliability among the three resin composite restorations varied.

The differences in the stress values for the PF10 level between test groups subjected to Weibull analysis were significant when the 95% confidence intervals did not overlap (Table 3)\(^{19}\). Based on the evaluation for the Weibull results under the S− condition, excluding 0 MPa values recorded by ptf, the stress value of the EF restoration at PF10 was significantly smaller than the values of the LF and SU restorations. Under the S+ condition, excluding ptf 0 MPa values, the stress was statistically smaller in the EF and SU restorations at PF10 than in the LF restoration. In addition, no significant differences in the stress values of EF and LF restorations at PF10 between the two stress conditions were evident. However, for the SU restoration, the stress value at PF10 with the cyclic load stress was statistically smaller than the value without the stress.

Basic properties of three composite resin restoratives

Table 4 shows the mean inorganic filler content, linear polymerization shrinkage, flexural strength, and flexural modulus of the three resin composite restoratives. The inorganic filler content in LF was significantly lower than in EF and SU, and was statistically lower in EF than in SU. The linear polymerization shrinkage of LF was significantly greater than that of EF and SU. There was no statistical difference between EF and SU. There was no significant difference in flexural strength among the three resin composite restoratives. The flexural modulus of EF and LF was significantly smaller than that of SU.
Fig. 4 Representative SEM images (×50 and ×500 magnifications) of the dentin-side surfaces of the post-test specimens. 4-1 (×50) shows the mixed failure mode consisting of interfacial failure at the resin-dentin interface, cohesive failure in adhesive resin, and cohesive failure in composite (a test piece of EF restoration under the S− condition). Several punctiform open dentinal tubules and tubules filled with adhesive resin can be observed in the area of the interfacial failure. The smooth and wavy surface of the cohesive failure in adhesive resin and the slightly coarse surface of the cohesive failure in composite (EF) are depicted in 4-2 (×500). 4-3 (×50) shows cohesive failure in the composite (a test piece of EF restoration under the S+ condition), and 4-4 (×500) shows the slightly coarse surface of the cohesive failure in composite (EF). 4-5 (×50) shows the cohesive failure in dentin (a test piece of LF restoration under the S+ condition), and 4-6 (×500) shows many punctiform open dentinal tubules. 4-7 (×50) shows the interfacial failure (a test piece of EF restoration under the S− condition) that was observed only in the flowable restoration without cyclic load stress. 4-8 (×500) depicts many punctiform open dentinal tubules and tubules plugged with adhesive resin. 4-9 (×50) shows the interfacial failure of a ptf specimen (a test piece of LF restoration under the S− condition), and 4-10 (×500) shows dentinal tubules packed with adhesive resin.

I: Interfacial failure, CA: Cohesive failure in adhesive resin, CC: Cohesive failure in composite, CD: Cohesive failure in dentin

Table 3 Weibull parameters of the three restorations

<table>
<thead>
<tr>
<th>Stress mode Restoration</th>
<th>S−</th>
<th>S+</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wm PF10</td>
<td>Wm PF10</td>
<td></td>
</tr>
<tr>
<td>EF</td>
<td>2.1a</td>
<td>9.6 (7.8–11.3)b</td>
</tr>
<tr>
<td>LF</td>
<td>2.7bc</td>
<td>12.8 (11.8–13.8)bc</td>
</tr>
<tr>
<td>SU</td>
<td>3.7cd</td>
<td>14.3 (13.8–14.8)cd</td>
</tr>
</tbody>
</table>

Data presented are the stress value (confidence interval). Values with different letters indicate a statistically significant difference (p<0.05) (uppercase letters=column; lowercase letters=rows).

Wm, Weibull modulus; PF10, stress for 10% probability of failure level (95% confidence interval).
Fig. 5 Difference in the probability of failure against the microtensile bond strength among the three restorations.

Table 4 The mean values (SD) of inorganic filler content, linear polymerization shrinkage, flexural strength, and flexural modulus

<table>
<thead>
<tr>
<th>Resin composites</th>
<th>Inorganic filler contents (wt%)</th>
<th>Linear polymerization shrinkage (%)</th>
<th>Flexural strength (MPa)</th>
<th>Flexural modulus (GPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EF</td>
<td>66.0 (0.1)(^a)</td>
<td>1.6 (0.1)(^a)</td>
<td>162.2 (24.1)(^a)</td>
<td>7.4 (0.6)(^a)</td>
</tr>
<tr>
<td>LF</td>
<td>63.9 (0.1)(^b)</td>
<td>2.8 (0.2)(^b)</td>
<td>155.3 (21.2)(^a)</td>
<td>6.5 (0.3)(^a)</td>
</tr>
<tr>
<td>SU</td>
<td>72.1 (0.1)(^c)</td>
<td>1.5 (0.2)(^a)</td>
<td>184.9 (26.2)(^a)</td>
<td>11.7 (1.1)(^b)</td>
</tr>
</tbody>
</table>

Values with different letters in the columns are statistically significantly different (p<0.05).

DISCUSSION

Materials and experimental conditions

Two flowable resin composites and one universal resin composite were investigated in this study. Since August 2015, only six flowable resin composite products utilized globally have been manufactured by three companies that provide instructions for their use in posterior occlusal restorations. The basic properties of the six flowable resin composites for posterior restoration are reported by manufacturers individually, the inorganic filler weight content; 67–78 wt%, the flexural strength; 126–167 MPa, the compressive strength; 350–449 MPa, and the volume polymerization shrinkage; 2.9–4.1 vol%. There is no flowable resin composite indicating the intermediate values in all the basic properties. Therefore, two flowable resin composites, Clearfil Majesty ES Flow (EF) exhibiting relatively large value in the filler weight content; 75 wt%, an intermediate value in the flexural strength; 151 MPa, relatively low values in the flexural modulus; 6.6 GPa, the compressive strength; 373 MPa, the volume polymerization shrinkage; 3.0 vol%, and MI Low Flow (LF) showing relatively low value in the filler weight content; 69 wt%, relatively large value in the flexural strength; 160 MPa, and relatively large values (confidential) in the flexural modulus, the compressive strength, the volume polymerization shrinkage were selected and used as the materials representing flowable resin composite. EF and LF has occupied large market shares in the United States\(^{20}\) and Japan\(^{21}\) in comparison with other flowable composite products. Many universal resin composite products have been used not only for anterior and posterior restorations but also for repair restoration worldwide. Maruyama et al.\(^{22}\) selected five popular products from many universal resin composites in the global market and measured the basic properties of those restoratives. The results indicated that Filtek Supreme Ultra Universal Restorative (SU) exhibited moderate values and was therefore used as control in the study of Maruyama’s group and in this study. Scotchbond Universal Adhesive (3M ESPE), a typical one-bottle all-in-one adhesive system utilized globally, was selected for this study due to its superior in vivo/in vitro performance\(^{13,23-26}\). In the present study, all cavities were pretreated with Scotchbond Universal Adhesive and then restored by a two-layered incremental technique. Van Ende et al.\(^{27}\) used an adhesive system in combination with three low-shrinkage composites to investigate the effect of curing time and filling method when high C-factor cavities were filled with the low-shrinkage composites. Baracco et al.\(^{28}\) and Mine et al.\(^{29}\) used a fixed resin composite with several resin adhesive systems to examine the microtensile bond strength of those adhesive systems. Hashimoto et al.\(^{30}\) and Shinkai et al.\(^{31}\) found that the combinations with the resin composite restorative and the other manufacturer’s adhesive system do not influence significantly the bond strength. The first layer was filled horizontally by each resin composite restorative to a 2.0 mm thickness from...
the cavity floor. Nikolaenko et al.\textsuperscript{32} examined various incremental techniques and concluded that horizontal layering is the most effective way to achieve a sufficient bond to the cavity floor for deep class 1 cavities. In general, a 20 s light irradiation period is sufficient to cure a light shade of composite to a depth of 2.0–2.5 mm\textsuperscript{30}. Ferracane\textsuperscript{34} recommend layering as the standard of care for applying dental composites in cavity preparations exceeding 2.0 mm.

In the present study, the S+ group specimens were subjected to cyclic load stress at 157 N at 90 cycles/min for $3 \times 10^5$ cycles in total. The force generated during routine mastication of food such as carrots or meat is approximately 70–150 N\textsuperscript{30}. Therefore, the magnitude of the load investigated in the current study (157 N) may be similar or more severe than normal chewing. It has been reported that the chewing rate is approximately 60–104 cycles/min\textsuperscript{36–38}. The average number of chewing cycles per year is approximately $2.5 \times 10^5$ cycles\textsuperscript{40,41}. Both experimental conditions in the current study, with regards to cyclic load rate (90 cycles/min) and number (3.0$ \times 10^5$ cycles), may therefore be similar to or greater than normal chewing. The standardized cavity that was restored by the three resin composite restoratives in this study exhibited a large C-value of 4.2. Feizler et al.\textsuperscript{42} found that an increasing rate of shrinkage stress and an increasing C-value reduced the flow capacity. Furthermore, Mcleod et al.\textsuperscript{43} clarified that shear bond strength is significantly greater at low C-factors (e.g., 0.2) than at high C-factors (e.g., 4.4). He et al.\textsuperscript{44} indicated that a high C-factor comprises a high risk for ineffective bonding in large cavities and that the incremental technique increases the microtensile bond strength to the cavity floor. Therefore, in the present study, the μ-TBS obtained from both specimens with and without cyclic load stress may have been influenced considerably by the large C-value of 4.2.

Difference in μ-TBS between flowable and universal resin composite restorations
Hasegawa et al.\textsuperscript{45} found that measured tensile bond strength is significantly correlated with tensile strength, flexural strength, and the Young's modulus of the composites, while the contraction gap is not significantly correlated with any of these parameters. If the μ-TBS of the three restorations was based on the theories of Hasegawa’s groups, the values of EF and LF restorations should be similar to or smaller than that of the SU restoration, based on the results in Table 4. In this study, however, there were no significant differences in μ-TBS among the three resin composite restorations, regardless of the stress mode. Han et al.\textsuperscript{46} clarified that filler content has no effect on μ-TBS among the resin composite and dentin in a class 1 cavity with a C-factor of 2.3. This may explain why there were no differences observed among the three restorations in the present study; the class 1 cavity with a large C-value of 4.2 may have unified the μ-TBS of the three restorations restored with resin composites with significant different filler contents. The cyclic load did not affect the μ-TBS of EF and LF; however, it reduced the μ-TBS of SU. The EF and LF restorations, with significantly smaller flexural modulus compared with the SU restoration, may have absorbed the cyclic load stress efficiently and were stress-independent (Table 4). Ptf occurred in the flowable resin restorations only (Table 2 and Fig. 3), regardless of the stress mode. Linear polymerization shrinkage of EF and LF flowable resin restoratives was similar to or significantly greater than that of the SU universal resin restorative (Table 4). The number of ptf test pieces of EF and LF increased with cyclic load stress (Table 2 and Fig. 3). The relatively large shrinkage rate of the two flowable restoratives may have produced invisible adhesive failures in the ptf test pieces at the interface between the resin and dentin. The invisible failure appeared and extended with the loading of the stress.

Difference in bonding reliability between flowable and universal resin composite restorations
The Weibull analysis is particularly useful for estimating reliability\textsuperscript{47}. It is characterized by two principal parameters: the Weibull modulus, that is able to predict the reliability of a bond, and the Weibull stress value to give a failure, that can evaluate the performance of a bond at a constant percentage level (e.g., 10% level, 63.2% level, and 90% level). Robin et al.\textsuperscript{10} reported that a high Weibull modulus is desirable for all materials because it indicates increased homogeneity in the flaw population and a more predictable failure behavior. It can take into account the ptf as a practical phenomenon that reduces the bonding reliability at the resin-dentin interface. The Weibull modulus and the Weibull stress value were investigated to estimate bonding reliability; however, μ-TBS data for Weibull analysis excluded 0 MPa values that had been recorded by ptf. Therefore, it appears that bonding reliability should be evaluated by the Weibull modulus and by the state of ptf occurrence. Based on the present Weibull modulus results and the state of ptf occurrence, it could be estimated that the bonding reliability of EF and LF restorations was inferior to the SU restoration, regardless of the stress mode. The effect of the cyclic load stress on bonding reliability, based on the Weibull modulus, only varied with resin composite restoratives. However, the bonding reliability examined by both the state of ptf occurrence and the Weibull modulus decreased with cyclic load stress, regardless of composite restorative.

When data are investigated with the Weibull analysis, the ISO/TS 11405 guidelines\textsuperscript{16} suggest that the stress which results in 10% failure (i.e., PF10) and in 90% failure (i.e., PF90) are convenient ways of characterizing the strength of a bond. Tjandrawinata et al.\textsuperscript{49} examined the stress that results in PF10 and PF90, and Foster et al.\textsuperscript{50} studied the stress that results in PF10 only. However, De Munck et al.\textsuperscript{51} mentioned that the PF10 level may be a more important property than mean values because low values may reflect early failures in clinical situations and may be more important than high values achieved in a few cases. For
the S− condition, the stress value of EF restoration at PF10 was significantly lower than that of the LF and SU restorations; however, for the S+ condition, the stress of EF and SU restorations at PF10 was statistically lower than that of the LF restoration. In addition, no significant differences in the stress values of EF and LF restorations at PF10 between the two stress conditions were evident. For the SU restoration, the stress value at PF10 with cyclic load stress was statistically lower than without stress. However, the PF10-related stress was calculated from μ-TBS data that excluded 0 MPa values recorded by the ptf. Therefore, it appears that the order according to the stress value of PF10 should be evaluated by both the maximum and minimum values of 95% confidence intervals for PF10 level and the state of ptf occurrence. When the order of the three composite restorations is evaluated by the 95% confidence interval values and by the state of ptf occurrence, the stress values under the S+ condition (representative of the intraoral environment) of the two flowable composite restorations may be similar to or lower than that of a universal composite restoration and differ from the Weibull parameters results.

**Difference and appearance change in the failure mode**

The majority of post-test specimens (76–95%) exhibited mixed failure, except for the LF restoration specimens under the S+ condition. For EF and LF restorations, cohesive failures within the composite and dentin increased with cyclic load stress. However, the failure mode of the SU restoration was not influenced by the load stress (Fig. 3). The flexural modulus of human enamel and dentin vary: 60–120 GPa and 18–24 GPa\(^2\), respectively. The flexural modulus of EF, LF, and SU measured in this study was 7.4 GPa, 6.5 GPa, and 11.7 GPa, respectively. The difference in the flexural modulus between the flowable composite restoratives and tooth substance is greater than the difference between the universal composite restorative and the tooth substance. This may explain as one of reasons why the failure modes varied according to the composite restorative and the cyclic load stress.

**CONCLUSION**

Within the limitation of this study, the universal composite restoration (SU) did not show pretesting failure. The flowable composite restorations (EF and LF) exhibited pretesting failure, regardless of the stress mode. The μ-TBS to class 1 occlusal cavity floors did not significantly differ among the three restorations, regardless of the stress mode. The cyclic load stress did not influence the μ-TBS of the flowable composite restorations; however, it significantly reduced μ-TBS in the universal composite restoration. Most post-μ-TBS test specimens exhibited mixed failure. For the flowable composite restorations, cohesive failures within the composite and dentin increased with cyclic load stress. The bonding reliability of the flowable restorations was inferior to that of the universal composite, for both stress modes.

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**CONFLICTS OF INTEREST**

The authors do not have any financial interest in the companies whose materials are mentioned in this article.

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