INTRODUCTION

Enamel demineralization and caries commonly occur with the use of bonded brackets and cemented bands. Because of their posterior position in the mouth, banded teeth are more difficult to clean, resulting in greater plaque accumulation. Consequently, orthodontic bands are believed to cause a greater amount of enamel demineralization than brackets.

Glass-ionomer cements (GICs) show long-acting fluoride release and reduced demineralization both in vitro and in vivo, but they have weaker bond strengths than composite resins. Resin-modified GICs (RMGICs) can overcome this problem. Komori and Ishikawa found that the bond strength of an RMGIC, in response to shear and tensile forces, was almost double that of the conventional GICs used for bonding orthodontic brackets. In addition, Yamazaki et al. suggested that an RMGIC for luting had greater shear strength than the conventional GICs during water immersion. Furthermore, the fluoride release ability of RMGICs is comparable to that of the conventional GICs in the long term. Polyacid-modified composite resin (compomer) cements, which are similar materials, combine certain features of the traditional dental composite resin and GIC. Therefore, they have a predominantly composite structure and many properties of the conventional composite resins and GICs.

For orthodontic band cementation, RMGICs and compomer cements can release fluoride and associate with less microleakage; therefore, they have favorable properties. However, few experiments of the caries-preventive effect of orthodontic band cements have been conducted. The purpose of this in vitro study was to evaluate the caries-preventive effect of three orthodontic band cements (an RMGIC and two compomer cements) in terms of fluoride release, retentiveness, and microleakage after thermocycling.

MATERIALS AND METHODS

Measurement of fluoride release

We used three commercially available orthodontic band cements: Transbond Plus (TBP), Ultra Band-Lok (UBL), and Ortholy Band Paste (OBP) (Table 1). Disk specimens of all the materials were prepared by using acrylic molds (internal diameter of 7 mm and height of 2 mm). The filled molds were covered with polyester film (0.1 mm in thickness), and the light-curing cements were irradiated with a high-power light-emitting diode (G-Light Prima II, GC, Inc., Tokyo, Japan) for 30 s (or 10 s for the dual-curing cement). All the disk specimens were stored for 1 h at 37°C and 100% relative humidity.

To measure fluoride release, the disk specimens were placed in the test solution (two disk specimens per 8 mL distilled water [DW]) for 180 days (n=7/cement type). The fluoride concentration in the test solution was measured (in μg/cm²) by using a fluoride-detecting electrode (Ion Meter IM-40s, DKK-TOA Co., Tokyo, Japan) on days 1, 7, 30, 90, and 180.

Retention analysis

Bovine incisors were used for this experiment. After confirming the absence of abnormalities such as discoloration or hypoplasia on their labial side, the labial enamel surface was smoothened with silicon carbide paper until grit 2,400. Then, with the exception of a window (internal diameter of 3 mm) serving as the...
Table 1  Banding cements used in this study

<table>
<thead>
<tr>
<th>Material</th>
<th>Type</th>
<th>Chemical components</th>
<th>Composition (wt%)</th>
<th>Manufacturer</th>
</tr>
</thead>
<tbody>
<tr>
<td>TBP</td>
<td>Light-curing compomer</td>
<td>Silane-treated glass</td>
<td>70–80</td>
<td>3M Unitek, Monrovia, CA, USA</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Glycerol 1,3-dimethacrylate</td>
<td>10–20</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Citric acid dimethacrylate oligomer</td>
<td>5–10</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Silane-treated silica</td>
<td>&lt;2</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Diphenyliodontum hexafluorophosphate</td>
<td>&lt;1</td>
<td></td>
</tr>
<tr>
<td>UBL</td>
<td>Light-curing compomer</td>
<td>Glass frit</td>
<td>4–70</td>
<td>Reliance Orthodontic Products, Inc., Itasca, IL, USA</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Amorphous silica</td>
<td>3–7</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bisphenol A diglycidyl methacrylate</td>
<td>8–30</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sodium fluoride</td>
<td>1–3</td>
<td></td>
</tr>
<tr>
<td>OBP</td>
<td>Dual-curing RMGIC</td>
<td>Paste A</td>
<td></td>
<td>GC Ortholy, Inc., Tokyo, Japan</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fluoroaluminosilicate glass</td>
<td>60–65</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Urethane dimethacrylate</td>
<td>1–5</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Dimethacrylate</td>
<td>25–30</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Silicon dioxide</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Polymerization catalyst</td>
<td>Trace amounts</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Colorant</td>
<td>Trace amounts</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Paste B</td>
<td>Polycrylic acid</td>
<td>30–35</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Polybasicity carboxylic acid</td>
<td>5–10</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Distilled water</td>
<td>30–35</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Silica fine powder</td>
<td>23</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Polymerization catalyst</td>
<td>1–5</td>
<td></td>
</tr>
</tbody>
</table>

Abbreviations: TBP, Transbond Plus; UBL, Ultra Band-Lok; OBP, Ortholy Band Paste; RMGIC, resin-modified glass ionomer cement; compomer, polyacid-modified composite resin

experimental area on the smoothened enamel surface, the whole specimens were coated with a Teflon seal and divided into three cement groups: the TBP, UBL, and OBP groups. In each case, after the cement was applied on the experimental area, the site was pressed with a stainless steel rod, polished with grit 120 sandpaper, and sandblasted with aluminum oxide particles at 0.4 MPa. After removing surplus material, the cement was irradiated on the right and left ends (TBP and UBL, 30 s×2; OBP, 10 s×2). The specimens were stored for 1 h at 37°C and 100% relative humidity and at 37°C for 23 h in DW (n=14/group).

To measure enamel tensile bond strength, half of the specimens (n=7/group) were thermocycled for 2,000 cycles at 5°C and 55°C with a dwell time of 30 s. The tensile bond strengths of the cements before (TCₜ) and after (TC₂₀₀₀) thermocycling were tested by using a universal testing machine at a crosshead speed of 1.0 mm/min (AG-50kNG, Shimadzu Co., Kyoto, Japan). The data (in MPa) were calculated from the peak load at failure divided by the cement surface area.

Microleakage analysis
Cavities (2 mm in depth and 3 mm in diameter) were prepared at the center of the labial aspect of bovine incisors. The specimens were randomly divided into the three cement groups (n=24/group), and the cavities were filled with the respective cements. After the filled cavities were covered with polyester film, the materials were irradiated (TBP and UBL, 30 s; OBP, 10 s). The specimens were stored for 1 h at 37°C and 100% relative humidity and at 37°C for 23 h in DW. After removing the polyester film, the specimens were gently polished by using #600 silicon carbide paper under water irrigation. Then, the
whole specimens were thermocycled for 2,000 cycles at 5°C and 55°C with a dwell time of 30 s. Thereafter, they were soaked in 1% methylene blue solution at 37°C for 18 h. They were rinsed in DW, embedded in an acrylic resin (Unifast II, GC, Inc.), sectioned longitudinally with a low-speed diamond blade (IsoMet, Buehler Ltd., Lake Bluff, IL, USA), and evaluated under 50× magnification by using a digital microscope (VHX-100, Keyence Co., Osaka, Japan). The degree of dye penetration was scored on a scale from 0 to 3 according to the ISO/TS 11405: 2003 standard17 (Fig. 1).

**Statistical analysis**

Two-way repeated-measures analysis of variance (ANOVA) was performed to determine significant changes in fluoride release on all the measurement days (group×day) or changes in the enamel tensile bond strength under different conditions (i.e., TC0 and TC2000) (group×condition) among the three cement groups. Differences in fluoride release or enamel tensile bond strength among the cement groups were tested by one-way ANOVA. When ANOVA indicated a significant difference, Bonferroni correction for multiple comparisons was applied to identify the group difference. To compare the enamel tensile bond strength under different conditions, paired t-test was used for each cement group.

The dye-penetration scores among the three cement groups were compared by using the Kruskal-Wallis test. If a significant difference was found, a pair of dye-penetration scores in the groups was tested with the Mann-Whitney U-test. As three pairwise planned comparisons were conducted, $p<0.016$ (i.e., $0.05/3$) was considered significant. All analyses were performed with a statistical software package (SPSS 15.0J for Windows, SPSS Japan, Inc., Tokyo, Japan).

**RESULTS**

**Fluoride release**

Figure 2 shows the amount of cumulative fluoride release from each disk specimen. The main effects of group and day were significant [$F(18,2)=116.329$, $p<0.001$ and $F(72,4)=398.586$, $p<0.001$, respectively]; the interaction effect (group×day) also yielded a significant result for fluoride release [$F(8,72)=101.298$, $p<0.001$]. On day 180, the OBP specimens showed a significantly higher amount of fluoride release than did the other

![Fig. 1](https://example.com/fig1.png)  
**Fig. 1** The dye-penetration scoring system.  
Schematic of the cavity prepared in each bovine incisor. The maximum degree of dye penetration was recorded according to the following scores (ISO/TS 11405:2003): 0, no dye penetration; 1, dye penetration into the enamel part of the cavity wall; 2, dye penetration into the dentinal part of the cavity wall but not including the cavity floor; 3, dye penetration including the cavity floor.

![Fig. 2](https://example.com/fig2.png)  
**Fig. 2** Amount of cumulative fluoride release in each cement group.  
TBP, Transbond Plus; UBL, Ultra Band-Lok; OBP, Ortholy Band Paste. Data represent means (SD).

![Fig. 3](https://example.com/fig3.png)  
**Fig. 3** Enamel tensile bond strength of each cement before (TC0) and after (TC2000) thermocycling.  
TBP, Transbond Plus; UBL, Ultra Band-Lok; OBP, Ortholy Band Paste. Data represent means (SD).
Table 2  Dye-penetration scores and significance of between-group differences

<table>
<thead>
<tr>
<th>Group</th>
<th>n</th>
<th>Dye-penetration score</th>
<th>Statistical groups*</th>
</tr>
</thead>
<tbody>
<tr>
<td>TBP</td>
<td>24</td>
<td>0 2 22 0</td>
<td>a</td>
</tr>
<tr>
<td>UBL</td>
<td>24</td>
<td>2 9 9 4</td>
<td>a, b</td>
</tr>
<tr>
<td>OBP</td>
<td>24</td>
<td>2 16 6 0</td>
<td>b</td>
</tr>
</tbody>
</table>

Abbreviations: TBP, Transbond Plus; UBL, Ultra Band-Lok; OBP, Ortholy Band Paste.

*Values with the same letter imply no significant differences in the group means and those with different letters imply significant differences in the group means (p<0.016) by post-hoc comparison.

cement specimens (p<0.001 for both groups). The TBP specimens also showed fluoride release, which was significantly higher than that of the UBL specimens (p<0.001). The amount released by the UBL specimens was low during the experimental period.

Retention
Figure 3 shows the enamel tensile bond strength values of the tested cements at TC₀ and TC₂₀₀₀. Significant main effects of group and condition were observed [F(2,18)=32.831, p<0.001 and F(1,18)=15.496, p<0.001, respectively]; however, no significant interaction effect (group×condition) was noted. At TC₂₀₀₀, the bond strength was significantly higher in the OBP group than in the other cement groups (p<0.001 for both groups). Further, no significant differences were found between the UBL and TBP groups (p=1.00). In the comparison of the bond strength values between TC₀ and TC₂₀₀₀, the UBL and TBP groups showed significantly decreased bond strength after thermocycling (p<0.05 for both groups), whereas no significant differences were found in the OBP group (p=0.343).

Microleakage
The dye-penetration scores and significance of the between-group differences are reported in Table 2. The median dye-penetration scores were 2, 2, and 1 for the TBP, UBL, and OBP groups, respectively. Significant differences were found among the three cement groups (p<0.001). The OBP group had significantly less microleakage than the TBP group (p<0.001), but showed no significant difference when compared with the UBL group (p=0.044).

DISCUSSION
Orthodontic band cements are used to enhance retention between the band and the tooth. However, inadequate bond strength, seal breakdown, cement solubility, and poor oral hygiene can contribute to the initiation of decalcification[18]. Therefore, the ideal band cement should be retentive, release fluoride, and adhere strongly to enamel.

In this study, OBP (an RMGIC) showed the highest amount of fluoride release among the three tested cements. According to Lim et al.[19], the order of effective fluoride release by orthodontic adhesives is RMGIC>compomer>fluoride-releasing composite resin>non-fluoride-releasing composite resin. In this experiment, interestingly, the amount of fluoride release was different between the compomer cements (TBP and UBL), and no significant differences in fluoride release were found between UBL and a zinc phosphate (non-fluoride-releasing) cement (data not shown). A compomer cement can promote an acid-base neutralization reaction following the absorption of water after polymerization to release fluoride ion from the filler (e.g., fluoroaluminosilicate glass), as in the case of GICs. The amount of eluted fluoride ion may differ among compomer cements, because each cement has various fillers; the filler of UBL may have little or no ability to release fluoride, although UBL contains sodium fluoride (Table 1).

Thermocycling is the in vitro process of subjecting a restoration and tooth to temperature extremes similar to those found in the oral cavity[20-24]. Therefore, it is a potential method to simulate in vivo challenges. In in vitro studies, water storage and thermocycling are two important factors that decrease bond strength[25-28]. However, in the present study, the bond strength of the RMGIC (OBP) did not decrease after thermocycling. On the other hand, the bond strength of the compomer cements (TBP and UBL) and a conventional GIC (Fuji I, GC, Inc.) was significantly decreased by thermocycling (data of the GIC are not shown). Differences in the clinical outcomes of RMGICs and other cements may appear over a long period of use. This suggests the necessity for rebonding after band removal and tooth cleaning when using the conventional GICs or compomer cements in the short term.

Microleakage can occur by saliva contamination during setting and oral thermal changes before band removal. The consequent gaps may result in the formation of caries around orthodontic band cements. Uysal et al.[29] found no significant microleakage difference between an RMGIC (Multi-Cure, 3M Unitek) and a compomer cement (TBP) for band cementation. The specimens in their experiment were placed in DW for 24 h before
estimating microleakage without thermocycling. In the present study, after thermocycling, the RMGIC (OBP) showed significantly less microleakage than did TBP. In another study, TBP showed lower bond strength in the presence of moisture\(^{10}\). According to these results, microleakage in the TBP group could have been greatly affected by thermocycling. This may be explained by water absorption and thermal expansion or contraction at the cement-tooth interface, weakening the material properties. Therefore, the resistance of TBP to water and thermal changes may be less than that of the other cements.

In addition, Gillgrass et al.\(^{30}\) noted no significant difference in microleakage at the cement-enamel interface between a conventional GIC (Ketac-Cem, 3M ESPE, St. Paul, MN, USA) and UBL after thermocycling, but a borderline difference existed between the cements at the cement-band interface. In the present study, the dye-penetration scores after thermocycling were calculated only between the cement and enamel. A future study is needed to investigate microleakage at the cement-band interface of RMGICs for orthodontic band cementation.

In conclusion, OBP (an RMGIC) showed superior fluoride release and retentiveness both before and after thermocycling compared with TBP and UBL (compomer cements). Moreover, it was associated with less microleakage. These results suggest that OBP is suitable for long-term orthodontic banding from the perspective of its caries-preventive effect, and the compomer cements may be useful for short-term orthodontic banding.

REFERENCES