Shear bond strengths of various resin cements between three types of adherends and bovine teeth with and without thermocycling

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This study evaluated the shear bond strengths of various types of resin cements between three types of adherends (composite resin, metal, and ceramic) and bovine teeth with and without thermocycling. A conventional resin cement (Variolink N), two adhesive resin cements (PANAVIA F 2.0, Multilink N), and three self-adhesive resin cements (MAXCEM ELITE, Rely X Unicem 2, Speed CEM) were used. The adherends were cemented on the superficial dentin of bovine incisors using each resin cement. Herein, 10 specimens from each group were thermocycled 5,000 times, and the other 10 were stored without thermocycling. With the resin and ceramic adherends, the shear bond strengths of Rely X Unicem 2 were significantly higher than those of the other resin cements both with and without thermocycling (p<0.05). With the metal adherend, the shear bond strengths were not significantly different among the cement groups, except MAXCEM ELITE, which showed the lowest strength.

Keywords: Shear bond strengths, Resin cement, Adherend, Bovine teeth, Thermocycling

INTRODUCTION

The resin cements that are commonly employed as luting cements for ceramic, indirect composite resin, and metal restorations exhibit excellent mechanical properties and esthetics1-3). These cements have a shorter setting time, better bond strength, and lower solubility than water-based cements4,5).

Resin cements can be classified as conventional resin cement (esthetic resin cement), adhesive resin cement (chemically adhesive resin cement), and self-adhesive resin cement6,7).

Conventional resin cement is a total-etch type (etch and rinse) and requires application of etchant, primer, and adhesive to the tooth surface because it does not contain adhesive components8). Conventional resin cement (esthetic resin cement) is mainly used for luting ceramics or the laminate veneers of anterior teeth9). The adhesion procedure of conventional resin cement is complicated and technique sensitive, and the bond strength between the tooth and adherend decreases if the moisture-proofing and dentin wettability are not properly maintained10).

Adhesive resin cement contains reactive monomers such as Phenyl-P, 4-methacryloyloxyethyl trimellitate anhydride (4-META), or 10-methacryloyloxydecyl dihydrogen phosphate (10-MDP), which facilitate the adhesion to metallic oxides or zirconia11,12). Because only a self-etching primer is applied to the dentin surface, the procedure is simpler than that used for conventional resin cement13).

Self-adhesive resin cement has alkaline fillers and acid-functionalized monomers, the latter of which demineralize enamel and dentin14). Free radical polymerization is initiated by visible light and/or chemical curing mechanism in the same way as in composite resin15). In addition, an acid–base reaction is initiated between the monomers with functional groups modified by phosphoric acid and the basic fillers and tooth apatite16). During this process, the cement becomes neutralized, and water is formed, which increases hydrophilicity17). This water is reused by the acidic functional groups in reactions with acid-soluble and ion-leachable fillers18). The latter reactions change the properties of the cement, thus making it hydrophobic15,16,19). In contrast with conventional and adhesive resin cements, self-adhesive resin cements do not require treating the tooth surface, thereby reducing technique sensitivity and chair time6).

In previous studies on the bond strengths between the tooth surface and the resin cement, conventional resin cement was reported to exhibit the highest bond strengths, followed by adhesive resin cement and self-adhesive resin cement in that order6,20). However, the bond strength of self-adhesive resin cements has been reported to display wide variations depending on the products21). Therefore, the bond strengths of various self-adhesive resin cements must be compared with those of conventional and adhesive resin cements.
Most prior studies focused on the shear bond strengths between the resin cement and teeth or between the resin cement and the adherend\(^1,4,20\). In many of these studies, resin cement was filled into a cylinder-shaped mold on the tooth or adherend and subsequently polymerized, and the bond strengths were evaluated after polymerization\(^6,20,23\). This model is suitable for evaluating the bond strengths between restorative composite resins and teeth. However, a different model is required to simulate the clinical conditions for resin cements, which are applied in a thin layer for luting between the teeth and adherend. There are no studies that have compared the shear bond strengths according to the type of resin cement, various adherends, and specimens with and without thermocycling using an appropriate model.

The purpose of this study was to evaluate the shear bond strengths of three types of resin cements (conventional, adhesive, and self-adhesive) applied in a thin layer, as practiced in clinical settings, between three kinds of adherends (resin, ceramic, and metal) and bovine teeth, specimens with and without being subjected to thermocycling. In addition, the flexural strength, water sorption, solubility, and film thickness of each resin cement were measured to determine the factors affecting the bond strength and the most appropriate resin cement for each adherend.

The null hypotheses are as follows: (1) There are no differences in the shear bond strengths depending on the type of resin cement and the type of adherend. (2) There are no differences in the shear bond strengths of specimens with or without thermocycling.

**MATERIALS AND METHODS**

*Materials and fabrication of adherend blocks*

We used three types of resin cements used in the study; one conventional resin cement, two adhesive resin cements, and three self-adhesive resin cements (Table 1). To fabricate the adherend blocks, we employed metal, ceramic, and composite resin (Table 2). Each adherend block was made into a cylindrical shape with a diameter of 2.3 mm and a height of 2.2 mm, according to ISO/TC 16506\(^{24}\). Resin blocks were prepared by filling a metal stainless steel mold having the same internal diameter and height as the adherend block with composite resin (Clearfil AP-X, Kuraray, Tokyo, Japan).

To fabricate the ceramic block, a cylindrical plastic with dimensions of 2.3 mm (diameter)×15 mm (length) was invested using a phosphate-bonded investment (Press VEST Speed, Ivoclar Vivadent, Schaan, Liechtenstein) and burned out at 850°C in a furnace for 1 h (Ring furnace, Seki-Dental, Seoul, Korea). Subsequently, the ring was transferred to another furnace (IPS E.max Press EP 500 press furnace, Ivoclar Vivadent), and IPS E.max MO2 Ingots (Ivoclar Vivadent) were inserted into the mold at 925°C for 15 min and cooled slowly. The investment was removed using 50-µm glass beads (Shofu, Kyoto, Japan). The ceramic block was cut to a height of 2.2 mm.

To fabricate the metal block, a metal cylinder with a diameter of 2.3 mm and length of 15 mm was invested with a phosphate-based investment (Univest Plus, Metalor, Neuchâtel, Switzerland). During the burn-out procedure, the metal cylinder was removed, and the burned-out ring was transferred to an electric resistance heating casting machine (Super Cascom, KDF, Kyoto, Japan). Then, casting was performed using a Ni–Cr alloy (Vera Bond 2, Albadent, Cordelia, CA, USA). After bench cooling, the investment was removed and cut to a height of 2.2 mm.

Any excessive flash material on each adherend block was removed using #220 abrasive SiC paper, and the end of each block that would be adhered to the tooth surface was polished using #600 abrasive paper. In the case of the metal block, the polished surface was sandblasted for 20 s at a pressure of 0.24 MPa using 50-µm aluminum oxide.

**Shear bond strength**

A total of 360 bovine incisors extracted within three days were used. The coronal part of each incisor was used to make specimens. The pulp in the tooth crown was removed, and the pulp cavity was blocked using a utility wax (Daedong, Daegu, Korea). The incisors were placed in distilled water at 4°C, which was exchanged daily. The teeth were embedded in acrylic resin (OrthoJet, Lang Dental Manufacturing, Wheeling, IL, USA) using a cylindrical mold with an inner diameter of 25 mm and a height of 25 mm, which was composed of polytetrafluoroethylene. The labial surface of the bovine incisor was exposed and polished with abrasive paper (#120 and #400) under wet conditions until the superficial dentin was exposed\(^26\). Twenty tooth specimens were prepared per group. The conventional resin cement was not used with the metal adherend. The teeth and adherend blocks were pretreated as indicated by the manufacturer’s instructions for each resin cement (Table 3).

After applying the resin cement between the adherend block and superficial dentin of the tooth, the specimens were subjected to a 5 N compression force by a constant load compression tester (A-001, Seiki, Tokyo, Japan). Subsequently, the specimens were light-polymerized in locations at four positions spaced at 90° angular intervals for 20 s each with a light-curing unit (Elipar TriLight, 3M ESPE, St. Paul, MN, USA) with the exception of Speed Cem (SC). Instead, SC cement required 4 min to self-cure. For each group, half of the specimens (n=10) were stored in distilled water at 37°C for 24 h before undergoing shear bond strength testing; the remaining specimens (n=10) were thermocycled 5,000 times (30 s at 5°C and 30 s at 55°C) using a thermocycling system (KD-TCS30, Gwangeok P.A., Kwangju, Korea). The shear bond strength was measured with a universal testing machine (Z020, Zwick, Ulm, Germany) having a hemicircular blade with a diameter of 2.38 mm using a 0.75 mm/min crosshead speed (Fig. 1)\(^{24,25}\).
### Table 1: Resin cements used in the study and their compositions

| Type       | Brand name | Code | Manufacturer | Curing mode | Composition                                                                                           | Lot number |
|------------|------------|------|--------------|-------------|-------------------------------------------------------------------------------------------------------|------------|
| Conventional | Variolink N | VN   | Ivoclar Vivadent, Schaan, Liechtenstein | Light-cure   | Polymer (Bis-GMA, UDMA, TEGDMA), filler (73.4 wt%; barium glass, ytterbium trifluoride, Ba-Al-fluorosilicate glass), initiators, stabilizers, pigments | R62687    |
|            | PANAVIA F 2.0 | PF   | Kuraray Noritake Dental, Tokyo, Japan | Light-cure   | A Paste: 10-MDP, hydrophobic ARDM, hydrophobic ALDM, hydrophilic ALDM, fillers B Paste: hydrophobic ARDM, hydrophobic ALDM, hydrophilic ALDM, fillers (filler load 70.8%) | 051374    |
| Adhesive   | Multilink N | MN   | Ivoclar Vivadent | Light-cure   | Base: dimethacrylate, HEMA, barium glass and silicon dioxide filler (45.5 wt%), ytterbium trifluoride (23 wt%), catalyst, stabilizer, pigment Catalyst: dimethacrylate, HEMA, barium glass and silicon dioxide filler (45.5 wt%), ytterbium trifluoride (23 wt%), catalyst, stabilizer | R35531    |
| Self-adhesive | MAXCEM ELITE | MC   | Kerr, Orange, CA, USA | Light-cure   | Resin: HDDMA, GDMA, DUDMA, GPDMA Catalyst: TMBHP, CQ, stabilizer Filler: FAISiO4, glass, silicon dioxide, Ba-glass, yttrium fluoride (67 wt%) | 4676812   |
|            | RelyX Unicem2 Automix | UC   | 3M ESPE, St. Paul, MN, USA | Light-cure   | Methacrylate monomers containing phosphoric acid groups, methacrylate monomers, fillers (filler load 70 wt%) | 479508    |
|            | Speed CEM SC | SC   | Ivoclar Vivadent | Self-cure    | Base: dimethacrylate, glass filler, silicon dioxide (75 wt%), initiators, stabilizers, pigments Catalyst: dimethacrylate, ytterbium trifluoride (45.2 wt%), copolymer, silicon dioxide (2.2 wt%), adhesive monomer, initiators, stabilizers, pigments | P71810    |

Bis-GMA, bisphenol A-glycidyl methacrylate; UDMA, urethane dimethacrylate; TEGDMA, triethyleneglycol dimethacrylate; 10-MDP, 10-methacryloyloxydecyl dihydrogen phosphate; ARDM, aromatic dimethacrylate; ALDM, aliphatic dimethacrylate; GPDM, glycerol dimethacrylate dihydrogen; HDDMA, hexanediol dimethacrylate; DUDMA, diurethane dimethacrylate; GPDMA, glycerol phosphate dimethacrylate; HEMA, 2-hydroxyethyl methacrylate; TMBHP, tetramethylbutyl hydroperoxide; CQ, camphorquinone.

### Table 2: Adherend materials and their compositions

| Adherend   | Brand name | Manufacturer             | Composition                                                                 | Lot number |
|------------|------------|--------------------------|-----------------------------------------------------------------------------|------------|
| Metal      | Vera Bond 2 | Albadent, Cordelia, CA, USA | Ni 77.05%, Cr 12.50%, Mo 4.25%, Nb 4.00%, Al 2.25%, Ti 0.45%, Si 0.50%    | 120801     |
| Ceramic    | IPS E.max Press | Ivoclar Vivadent, Schaan, Liechtenstein | SiO₂ (57–80 wt%), Li₂O (11–19 wt%), K₂O (0–13 wt%), P₂O₅ (0–11 wt%), ZrO₂ (0–8 wt%), ZnO (0–8 wt%), other oxides (0–10 wt%) | R41055     |
| Composite resin | CLEARFIL AP-X | Kuraray Medical Tokyo, Japan | Bis-GMA, TEGDMA, silanated colloidal silica, silanated barium glass and filler | 1421AA     |
| Type           | Brand name          | Code | Adherend | Tooth surface | Adherend surface |
|---------------|---------------------|------|----------|---------------|------------------|
| Conventional  | Variolink N         | VN   | Resin    | (1) 37% phosphoric acid (N-etch) | (1) Polishing |
|               |                     |      |          | (2) Adhesive (Excite F DSC)       | (2) Monobond-S (silane) |
| Ceramic       |                     |      |          | (1) N-Etch     | (1) Polishing |
|               |                     |      |          | (2) Excite F DSC | (2) IPS ceramic etching gel (5%HF) |
|               |                     |      |          |                | (3) Monobond-S |
| PANAVIA F 2.0 | PF                  |      | Resin, Ceramic | ED primer II A&B | (1) Polishing |
|               |                     |      |          |                | (2) Etchant gel (40% phosphoric acid) |
|               |                     |      |          |                | (3) Clearfil SE BOND primer: Porcelain bond activator (silane)=1:1 mix. |
| Metal         |                     |      | ED primer II A&B |                | (1) Polishing |
|               |                     |      |          |                | (2) Sandblasting |
|               |                     |      |          |                | (3) Alloy primer |
| Adhesive      |                     |      | Resin    | Mix Multilink N primer A&B | (1) Polishing |
|               |                     |      |          |                | (2) Monobond-S |
| Multilink N   | MN                  |      | Ceramic  | Mix Multilink N primer A&B | (1) Polishing |
|               |                     |      |          |                | (2) IPS ceramic etching gel |
|               |                     |      |          |                | (3) Monobond-S |
| Metal         |                     |      | Mix Multilink N primer A&B | (1) Polishing |
|               |                     |      |          |                | (2) Sandblasting |
|               |                     |      |          |                | (3) Metal/Zirconia primer |
| Self-adhesive |                     |      | Resin, Ceramic | — | (1) Polishing |
|               |                     |      |          |                | (2) Clearfil ceramic primer (silane) |
| Maxcem Elite  | MC                  |      | Metal    | — | (1) Polishing |
|               |                     |      |          |                | (2) Sandblasting |
| Relyx Unicem  | UC                  |      | Resin    | — | (1) Polishing |
| Automix2      |                     |      |          |                | (2) IPS ceramic etching gel |
|               |                     |      | Ceramic  | — | (3) Clearfil ceramic primer |
| Speed CEM     | SC                  |      | Metal    | — | (1) Polishing |
|               |                     |      |          |                | (2) Sandblasting |
|               |                     |      | Ceramic  | — | (1) Polishing |
|               |                     |      |          |                | (2) IPS ceramic etching gel |
|               |                     |      |          |                | (3) Monobond-Plus |

Polishing, polishing with abrasive papers #200 and #600; Sandblasting, sandblasting with 50 μm aluminum oxide for 20 s at a pressure of 35 psi; —, not applicable.

Monobond-S (Ivoclar Vivadent, Schaan, Liechtenstein), IPS ceramic etching gel (Ivoclar Vivadent), Etchant gel (Kuraray, Tokyo, Japan), Clearfil SE BOND primer (Kuraray), Porcelain bond activator (Clearfil, Kuraray), Alloy primer (Kuraray), Metal/Zirconia primer (Ivoclar Vivadent), Clearfil ceramic primer (Kuraray).
RESULTS

Shear bond strength
For the resin adherend, the shear bond strengths of UC were significantly higher than that of other resin cements (p<0.05), with no significant differences from those of VN and SC without thermocycling or those of VN, PF, and MN with thermocycling (p>0.05) (Fig. 2). Thermocycling significantly reduced the shear bond strengths of the self-adhesive resin cements only (p<0.05).

For the ceramic adherend, the shear bond strengths of UC were also significantly higher than that of other resin cements (p<0.05), with no significant differences from those of MN and SC without thermocycling or those of VN and MN with thermocycling (p>0.05) (Fig. 3). The bond strengths of PF and SC were significantly decreased by thermocycling (p<0.05).

For the metal adherend without thermocycling, only MC exhibited a significantly lower bond strength (p<0.05), whereas there were no significant differences in

Flexural strength
To fabricate a specimen for testing the flexural strength, a metal mold having a length of 25 mm, a width of 2 mm, and a thickness of 2 mm was prepared. After placing the resin cement into the mold, a load was applied at a pressure of 1 kg for one minute using the constant load compression tester. The specimens were light-cured at the center for 20 s, and the exit window was moved throughout the specimen, such that each half of the light irradiator tip overlapped with the previous section of the specimen until the entire specimen was irradiated. The cured specimen was then placed in a 37°C water bath for 15 min. The SC cement specimens were instead maintained at room temperature and then stored at 37°C in a water bath for 24 h. The flexural strength was measured using a universal testing machine (Z020) with a crosshead speed of 0.75 mm/min. The expression for the flexural strength, \( \sigma \), is given by

\[
\sigma = \frac{3Fl}{2bh^2}
\]

where \( F \) is the maximum load exerted on the specimen (N); \( l \) is the distance between the supports (mm); \( b \) is the width (mm) at the center of the specimen; and \( h \) is the height (mm) at the center of the specimen, measured immediately before testing.

Water sorption and solubility
Each cement was inserted into a mold having a diameter of 15.0 mm and 1.0 mm thickness. Five disc specimens were fabricated for each group. The specimens were light-cured for 20 s per section, as described in Section 2.3, but circularly, while the SC group specimens were self-cured for 4 min and then left for 60 min. The cured specimens were then stored in a closed container at 37°C in a drying oven (JeioTech, Kimpo, Korea) for 22 h and moved to a desiccator, where they were maintained at 23°C for 2 h. The cycle was repeated, and each specimen’s weight was measured every 24 h, until a constant mass, \( m_1 \), was obtained, i.e., when the mass loss was less than 0.1 mg in any 24 h period. Then, the specimen volume, \( V \), was calculated by measuring the thickness and the diameter of the specimen. Next, the specimen was stored in water at 37°C for 7 days. At 1 min after removing the specimen from the water, moisture was removed from the specimen surface, and then, the weight, \( m_2 \), was measured. The cycle mentioned above was then repeated until the specimen reached a constant weight, \( m_s \). Water sorption, \( W_w \), and solubility, \( W_s \), were calculated using

\[
W_w = \frac{(m_1 - m_3)}{V}
\]

and

\[
W_s = \frac{(m_3 - m_2)}{V}
\]

where \( m_1 \) is the constant mass (µg) measured initially, \( m_2 \) is the mass after water immersion for 7 days (µg), \( m_3 \) is the final constant mass (µg), and \( V \) is the volume of the specimen (mm³).

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Fig. 2 Shear bond strengths of the resin cements for the resin adherend with and without thermocycling. Different uppercase and lowercase letters show statistically differences among the groups without and with thermocycling, respectively ($p<0.05$). * indicates a significant difference between the shear bond strengths before and after thermocycling ($p<0.05$).

Fig. 3 Shear bond strength of the resin cements for the ceramic adherend with and without thermocycling. Different uppercase and lowercase letters show statistically differences among the groups without and with thermocycling, respectively ($p<0.05$). * indicates a significant difference between the shear bond strengths before and after thermocycling ($p<0.05$).

Flexural strength
The flexural strengths of the resin cements are shown in Fig. 5. MN showed significantly higher flexural strength than the other resin cements ($p<0.05$), and the next-highest bond strengths were exhibited by VN and UC, with no significant differences from PF and SC ($p>0.05$).

Water sorption and solubility
The water sorption and solubility are shown in Fig. 6. The water sorption of PF was significantly lower than that of the other resin cements ($p<0.05$), but it was not significantly different from that of VN ($p>0.05$). VN, MN,
and UC showed significantly lower solubility than the other resin cements \( (p<0.05) \). MC exhibited the highest water sorption and solubility \( (p<0.05) \).

**Film thickness**

As shown in Fig. 7, the film thicknesses of VN and MC were significantly smaller than those of other resin cement groups \( (p<0.05) \), and PF showed the largest film thickness \( (p<0.05) \).

**DISCUSSION**

The shear bond strengths of conventional, adhesive, and self-adhesive resin cements between each of the three types of adherend and bovine tooth surface, with and without thermocycling, were evaluated in the study. In addition, the flexural strength, water sorption, solubility, and film thickness of each resin cement were assessed to establish the clinical suitability of resin cement. The first null hypothesis was rejected. Although the shear bond strengths did not differ according to the cement type, they showed significant differences depending on the adherend type (resin, ceramic, or metal). The second null hypothesis that there are no differences in shear bond strength by thermocycling was thus also rejected.

Considering the types of resin cement and adherend, UC continued to show the highest shear bond strengths for all types of adherends, with and without thermocycling. For the resin adherends, the bond strength of UC with thermocycling was not significantly different from those of the conventional and adhesive resin cements. For the ceramic adherend, UC showed the highest bond strength, although there were no significant differences from MN with and without thermocycling. For the metal adherend, the bond strength of UC was not significantly different from those of the other cements, except for MC, which exhibited the lowest bond strength. The shear bond strengths within the self-adhesive resin cements varied widely depending on the product, especially for resin and ceramic adherends, which is consistent with the results of previous studies\(^{20,28}\). Therefore, when using self-adhesive resin cement, clinicians must carefully select the appropriate product. From these results, we can infer that the bond strengths depend on the adherend type and the particular cement product rather than on the type of cement.

The bond strengths of self-adhesive resin cements were reported to be lower than those of conventional and adhesive resin cements\(^{8,21,29}\). However, the bond strengths may vary depending on the experimental method, the type of adherend, and the occurrence of thermocycling. Most previous studies measured the bond strength only between teeth and the resin cement, or between adherends and the resin cement\(^{8,30,31}\). However, the present study used a specimen design wherein resin cement was applied between dentin and the adherends\(^{24}\). In this model, both the bonding between the dentin and resin cement and that between the adherend and resin cement are essential. This model is more relevant to clinical situations, such as inlay, onlay, crown, and bridge cementation\(^{32}\). According to the results of this study, the bond strengths did not depend on the cement type. UC, which showed the highest bond strength, belongs to a type of self-adhesive resin cements. Individual cement characteristics are considered to be more important than the cement type.

One reason why UC displayed the highest shear bond strengths for the resin and ceramic adherends is its lower solubility. Marghalani found that water sorption and solubility were lower for UC than for other self-adhesive resin cements\(^{33}\). Water sorption and solubility affected the physical properties of the resin cements, so they can also affect the bonding strength\(^{34}\). In the present study, MC showed the highest water sorption and solubility and the lowest flexural strength, which might be related to their lower shear bond strengths.
Another reason why UC exhibited the highest bond strength is because it can more effectively neutralize low pH than other self-adhesive resin cements. Low pH after curing also causes high water absorption, which degrades mechanical properties. Roedel et al. reported that the hygroscopic expansion stress of UC was lower than those of other self-adhesive resin cements.

Among the two adhesive resin cements, MN exhibited a higher bond strength to the ceramic adherend than PF. This finding might be related to the fact that 2-hydroxyethyl methacrylate (HEMA) is a component of MN. HEMA can effectively fill the gap between collagen fibers (39). Another reason for the high bond strength could be its flexural strength; MN exhibited the highest flexural strength among all the resin cements in this study. As demonstrated by Li, when the flexural strength of cement increased, the bond strength also increased (40). The flexural strengths of the resin cements are closely related to the degree of polymerization, the size and content of the filler, and the silane treatment of the filler. All resin cements used in this experiment showed values exceeding the ISO standard of 50 MPa. For conventional resin cement, primer and adhesive must be applied on dentin to improve the bond strengths as this type of cement does not contain any functional monomers. Thus, this complex and technique-sensitive bonding procedure could be the reason for the lower shear bond strengths.

Thermocycling significantly decreased the bond strengths of all the self-adhesive resin cements when used against the resin adherend. Thermocycling is a method of accelerated aging. Water can permeate and swell the polymer matrix, degrading its physical properties and causing bonding failure. By reproducing the temperature changes that occur in the oral cavity, thermocycling induces cracks at the interface through repeated contraction and expansion stress. The bond strengths of SC, which was only self-cured, significantly decreased for all adherends after thermocycling. When the self-adhesive resin cement was cured in self-cure mode, the bond strengths and the degree of conversion were lower than those of the self-adhesive resin cements cured via the dual-cure mode (41). Light-curing can enhance the bond strength; thus, it is recommended for dual-cured-type resin cement. Because the bond strengths of PF significantly decreased with the ceramic adherend after thermocycling, the surface of ceramics must be carefully treated to facilitate an increase in the bond strength. UC showed the highest bond strengths, even after thermocycling. Maintaining a high bond strength after thermocycling is important for the survivability of materials in the mouth.

The film thickness of all resin cements was less than 50 µm, which is the upper limit for resin cements according to ISO 4049. In addition, all resin cements, except for PF, showed a film thickness lower than 25 µm, which is the upper limit for water-based cements. Film thickness can be affected by the filler contents, the viscosity of the cement, ingredients, and the curing reaction. The lower film thickness and relatively low filler content of MC might be related to its low bond strengths.

Shear bond strengths can also be affected by the crosshead speed, the shape of the blade, and the surface treatment applied to the teeth and adherend. In this study, the crosshead speed of the universal testing machine was 0.75 mm/min, as recommended by ISO/TS 16506; however, this speed is different from those applied in other studies, e.g., 0.5 mm/min and 1 mm/min. The shape of the blade of the loading device of the universal testing machine is also an important factor in the shear bond strength. In this study, a semicircular-shaped blade was used according to ISO/TS 16506 and ISO 29022. The semicircular blade spans a large area, which minimizes the load concentration, while the knife blade used in other studies makes contact at a single point, resulting in lower shear bond strengths.

For the metal adherend, a primer indicated by the manufacturer was applied before application of the adhesive resin cements, while the self-adhesive resin cements were applied without any additional treatment. Nevertheless, there were no significant differences in the shear bond strengths between the adhesive and self-adhesive resin cements for the metal adherend, except for MC. Therefore, self-adhesive resin cement is considered to be more convenient for metal adherends in clinical applications.

This study suggests that the product characteristics of resin cements such as composition, type of adherend, thermocycling, flexural strength of the cement, film thickness, water sorption, and solubility affect the shear bond strength. Because the shear bond strength of UC was the highest for the resin and ceramic adherends, regardless of thermocycling, UC can be recommended to achieve high bond strength in clinical applications.

CONCLUSIONS
Within the limits of the study, the shear bond strengths of conventional, adhesive, and self-adhesive resin cements were determined with or without thermocycling for resin, ceramic and metal adherends. When a resin or ceramic adherend was used, UC showed significantly higher shear bond strengths than the other resin cements, regardless of thermocycling. For the metal adherend, the shear bond strengths were not significantly different, except for MC, which displayed the lowest strength. Therefore, we conclude that UC would be the most useful and convenient resin cement for all adherent types in clinical use.

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