Effects of aging on the bond strength of self-etching adhesives and resin luting cements

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Abstract
Background/purpose: This study was designed to evaluate the microtensile bond strengths of self-etching adhesives and resin luting cements immediately after bonding and after exposure to aging.

Materials and methods: Forty noncarious human molars were divided into five groups and randomly assigned to self-etching systems [AdheSE Bond(ASE), Prompt L-Pop(PLP), and TyranSPE Plus(OSP)] or resin luting cement systems [Panavia F(PF) or Duolink(DL)]. All adhesives were applied in accordance with the manufacturers’ instructions. A composite resin build-up was created with composite resins from each respective company (Tetric EvoCeram, Filtek Supreme XT, Aelite Aesthetic, Estenia, and Tescera ATL). Half of the specimens were tested immediately after bonding. The remaining specimens were mechanically loaded in artificial saliva for 60,000 cycles with a wear simulator at 37 °C and were then stored in artificial saliva at room temperature for 1 year before undergoing a microtensile test. Data were analyzed using one-way analysis of variance and Tukey’s honestly significant difference test.

Results: Differences in immediate bonding values were observed among the adhesives, ASE demonstrating the greatest bond strength. After aging (with loading and after 1 year), a reduced interfacial bond strength was observed for the ASE, OSP, and DL adhesives.

Conclusion: PF luting cement and PLP dentin adhesive were less affected by aging than the other dentin adhesive systems studied. Additional in vivo data should be acquired to complement these findings and clarify the clinical efficacies of the tested adhesives.

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Introduction

To increase the clinical performance of resin restorations, various composite resins and adhesive systems have been developed over the years. Polymerization shrinkage of composite resins appears to be one of the most important problems. Therefore, both the development of adhesives and the reduction in polymerization shrinkage of composite resins were studied.

Different adhesive formulations have recently been proposed to reduce the polymerization shrinkage of composite restorations. Nevertheless, for new adhesive systems, the main focus of researchers is to reduce the clinical steps, avoid mistakes, and improve the bonding stability.1,2 Recently, some composite resins that use a dedicated two-step, self-etching adhesive system claimed shrinkage of nearly 1% by volume, which is lower than the 2–5% exhibited by some bisphenyl-glycidyl-methacrylate composites.3 Although much reduced, all current resin composites still shrink.

At the beginning of the 1990s, indirect composite restorations were shown to improve clinical conditions with respect to proximal contact, occlusal anatomy, and marginal adaptation.4 The esthetic results and longevity of these indirect composite resin restorations depend on each step of the clinical and laboratory procedures. Cementation is the most critical step, and involves application of an adhesive system and a resin luting agent.5 The clinical protocol for placing laboratory-processed composite resins includes the use of dual-polymerizing resin cements.6,7

Recently, self-etching adhesives were also introduced to further simplify the bonding procedure. These adhesives combine the etching and priming processes into a single step.8 The bonding mechanism of self-etching adhesives is based upon the simultaneous etching and priming of smear-covered dentin, which uses an acidic primer followed by the application of an adhesive resin.9 Self-etching primers eliminate the separate acid-etching and rinsing steps, which simplifies the bonding technique and reduces its technical sensitivity.10 However, only a few studies exist in the literature regarding the bond strengths of self-conditioning systems and resin cements.11,12

In addition to the materials (adhesives and composites), aging is an important factor that may influence the long-term performance of resin restorations. Several in vitro studies without aging reported high bond strengths for these self-etching and dual-cure resin materials.13,14 Because factors such as normal daily functioning, thermal stresses, malocclusion, and habitual bruxism stresses throughout the tooth and restorative system may affect and destroy adhesive bonds, optimal dentin bonding might not always be obtained in clinical practice.15

The clinical longevity of a hybrid layer seems to involve both physical and chemical factors. Physical factors, such as occlusal chewing forces and repetitive expansion and contraction stresses caused by temperature changes within the oral cavity have been proposed as affecting the interface stability.16,17 Acidic chemical agents in dentinal fluid, saliva, food, beverages, and bacterial products further influence the tooth–biomaterial interface, resulting in various patterns of degradation of unprotected collagen fibrils, elution of resin monomers (probably due to suboptimal polymerization), and degradation of resin components.18–20

Areas within the hybrid or adhesive layers that are not completely polymerized may allow water to diffuse, which may impair the bond strength and compromise the longevity of adhesive restorations.21,22 A high-quality hybrid layer requires optimal infiltration of the adhesive monomer into the enamel and dentin substrates, and optimal polymerization within the substrate.23 Application of cyclic mechanical stress can be used to simulate physiological conditions and allows researchers to examine the effects on a restoration and storage in saliva. This simulation can provide valuable information on the durability of dentin bonding, especially for newly introduced agents.

The purpose of this in vitro study was to evaluate the effects of mechanical load cycling and 1 year of storage in artificial saliva on the microtensile bond strength (μTBS) values of two dual-polymerizing luting cements and three self-etching dentin adhesives. As a null hypothesis, it was proposed that the bond strengths of the adhesive systems after aging would be lower than the bond strengths of the adhesive systems before aging.

Materials and methods

This study used 40 freshly extracted noncarious human third molars. Following a positive review by the Dental Faculty Ethics Committee of Selçuk University (no:2006/02-04; Konya, Turkey), the extracted teeth were thoroughly cleaned to remove hard and soft deposits and then stored at 4°C in a 0.5% chloramine solution prior to use. The occlusal dentin surfaces of the teeth were exposed by removing the occlusal enamel and superficial dentin with a slow-speed diamond saw (Isomet; Buehler, Lake Bluff, IL, USA) under water-cooling. The teeth were randomly assigned to five experimental groups: three self-etching systems [AdheSE Bond (ASE), Prompt L-Pop (PLP), and Tyran SPE-1; Onestep Plus (OSP)] and two resin luting cement systems [Panavia F (PF) and Duolink (DL)]. The compositions of the adhesive systems and their uses are summarized in Table 1.

A smear layer was applied to the dentin surface by polished the occlusal surface with 600-grit silicon carbide sandpaper. The bonded interface was prepared according to each adhesive group and applied in accordance with the manufacturers’ instructions (Table 1). After adhesive application, the dentin surfaces were restored with composite resins obtained from the respective producer of each adhesive (Tetric Evo Ceram, Filtek Supreme XT, Aelite Aesthetic, Estenia, and Tescera ATL) (Table 2). However, the direct composites have different volumetric shrinkage values of 3.18% for Aelite Aesthetic, 2.09% for Filtek Supreme XT, and 1.49% for Tetric Evo Ceram,24 so to compensate for this difference, we used an incremental placement technique. Direct composite resins were built up incrementally on the bonded surface to a height of 4 mm.

Each 2-mm increment of resin composite was then cured for 40 seconds with a light source (Hilux Expert; Benlioglu Dental, Ankara, Turkey) at a 0.5-mm standard curing distance and a light intensity of 660 mW/cm², as constantly
monitored with a radiometer. The inlays were incremen-
tally built up on the dentin surface to a height of 4 mm, and
each increment was polymerized for 120–180 seconds in
the occlusal direction with a curing unit. The inlays were
then postcured in a light oven for 180 seconds, placed in
a heat oven for 10 minutes at 114–14°C, and luted with resin
cement. After bonding, each group was further divided into
two subgroups (n = 4) to be tested either immediately or
after artificial aging. Samples from one of the subgroups,
which was tested immediately, were stored for 24 hours
before their μTBSs were determined, while the remaining
specimens were mechanically loaded.

Mechanical load-cycling test

The root surfaces of the teeth were covered with a 1-mm-
thick light polyether impression material (Impregum Penta
DuoSoft; 3M ESPE, Seefeld, Germany) with a dispenser gun
(3M ESPE), and the excess silicone material was removed
with a scalpel blade to provide a flat surface 2 mm below
the facial cementoenamel junction of each tooth. The teeth
were then embedded in acrylic resin (GC Pattern
Resin LS; GC, Alsip, IL, USA). The thin layer of silicone
material simulated the periodontal ligament on the root
surfaces of the teeth. Occlusal contact loading was simu-
lated in an artificial oral environment sliding wear tester
(Chewing Simulator; University of Selcuk, Research Labo-
ratory Center, Konya, Turkey).25

Specimens were stored in artificial saliva in a simulator
chamber at 37°C in occlusal contact similar to physiolog-
ical conditions (Fig. 1). Four specimens of each material
were tested in a pin-on-block design with a 0.3–0.8 mm
radius with eccentric sliding of a spherical natural enamel
antagonist (palatinal cusps of human maxillar molars,
which were extracted and embedded in acrylic resin)
under permanent contact with specimens at a vertical
loading of 50 N for 60,000 cycles at a frequency of 1.2 Hz.26

<p>| Table 1 | Chemical compositions, dentin pretreatment, and bonding procedures of the dentin adhesives tested. |</p>
<table>
<thead>
<tr>
<th>Adhesive system</th>
<th>Principle ingredients</th>
<th>Steps of application</th>
</tr>
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<tbody>
<tr>
<td>AdheSE Bond Пример</td>
<td>Dimethacrylate, phosphoric acid acrylate, water, stabilizers</td>
<td>Apply primer, leave for 30s, air-dry</td>
</tr>
<tr>
<td>Lot:17659 Bond</td>
<td>Dimethacrylate, HEMA, silica, initiators and stabilizers</td>
<td>Apply bond, air-thin, light-cure for 10s</td>
</tr>
<tr>
<td>Prompt L-Pop Пример</td>
<td>Liquid 1 (red blister): methacrylated phosphoric esters; Bis-GMA; Initiator: camphorquinone; stabilizers</td>
<td>Mix blisters A and B, scrub continuously for 15s, gently air-dry, re-apply, light-cure for 10s</td>
</tr>
<tr>
<td>Lot:7187444 Bond</td>
<td>Liquid 2 (yellow blister): water; HEMA; Polyalkenoic acid; stabilizers</td>
<td>Mix primers A and B, apply primer(2 coats), air-dry</td>
</tr>
<tr>
<td>TyranSPE Пример</td>
<td>A: Ethanol B: 2-Acrylamidio-2-methyl propanesulfonic acid, bis 2-methacryloyloxy-ethylphosphate, ethano</td>
<td></td>
</tr>
<tr>
<td>Lot:0600004679 Bond</td>
<td>Bis-GMA, BPDM, HEMA acetone, glass frit HEMA,5-NMSA, MDP, sodiumbenzenesulfonate, water</td>
<td></td>
</tr>
<tr>
<td>Panavia F Пример</td>
<td>A and B pastes</td>
<td></td>
</tr>
<tr>
<td>Lot:00366A Bond</td>
<td>Paste A: MDP, dimethacrylate, filler, photoinitiator, chemical initiator</td>
<td></td>
</tr>
<tr>
<td>Prompt L-Pop Пример</td>
<td>Paste B: dimethacrylate, photoinitiator</td>
<td></td>
</tr>
<tr>
<td>Lot:00366A Bond</td>
<td>Bis-GMA, BPDM, HEMA, acetone HEMA,5-NMSA, MDP, sodiumbenzenesulfonate, water</td>
<td></td>
</tr>
<tr>
<td>A and B pastes</td>
<td>Paste A: MDP, dimethacrylate, filler, photoinitiator, chemical initiator</td>
<td></td>
</tr>
<tr>
<td>Lot:00366A Bond</td>
<td>Paste B: dimethacrylate, photoinitiator</td>
<td></td>
</tr>
<tr>
<td>Duo-Link Пример</td>
<td>A and B Paste</td>
<td></td>
</tr>
<tr>
<td>Lot:060009836 Bond</td>
<td>Paste A: Bis-GMA, TEGDMA, UDMA, glass filler</td>
<td></td>
</tr>
<tr>
<td>0459 Bond</td>
<td>Paste B: Bis-GMA, TEGDMA, glass filler</td>
<td></td>
</tr>
<tr>
<td>Onestep Plus Пример</td>
<td>A and B Paste</td>
<td></td>
</tr>
<tr>
<td>Bond</td>
<td>Bis-GMA, BPDM, HEMA acetone, glass frit</td>
<td></td>
</tr>
<tr>
<td>Panavia F Пример</td>
<td>Paste A: Bis-GMA, TEGDMA, UDMA, glass filler</td>
<td></td>
</tr>
<tr>
<td>Lot:0459 Bond</td>
<td>Paste B: Bis-GMA, TEGDMA, glass filler</td>
<td></td>
</tr>
<tr>
<td>Prompt L-Pop Пример</td>
<td>Apply bond 15s, air-thin,light-cure for 10s</td>
<td></td>
</tr>
<tr>
<td>Lot:00366A Bond</td>
<td>Mix primers A and B, apply primer for 30s, gently air-dry</td>
<td></td>
</tr>
<tr>
<td>Panavia F Пример</td>
<td>Mix A and B pastes for 20s minimum, apply the mixture of paste, light-cure the margins for 20s</td>
<td></td>
</tr>
<tr>
<td>Lot:00366A Bond</td>
<td>Mix A and B pastes for 10–15 s, apply the mixture of paste, light-cure each surface of the restoration for 40 s</td>
<td></td>
</tr>
</tbody>
</table>

Abbreviations: 5-NMSA = N-methacrilol-5-aminosalicylic acid; Bis-GMA = bisphenyl-glycidyl-methacrylate; BPDM = biphenyl dimethacrylate; HEMA = 2-hydroxyethyl methacrylate; MDP = 10-methacryloxydilhydrogen phosphate; MMA = methyl methacrylate; TEGDMA = triethylene glycol dimethacrylate; UDMA = urethane dimethacrylate.

<p>| Table 2 | Color, manufacturer, and lot numbers of the composite resins used in this study. |</p>
<table>
<thead>
<tr>
<th>Composite materials for adhesive systems</th>
<th>Manufacturer</th>
<th>Lot number</th>
<th>Color</th>
</tr>
</thead>
<tbody>
<tr>
<td>Filtek Supreme XT for Prompt L-Pop</td>
<td>3M ESPE (USA)</td>
<td>6ER</td>
<td>A2 Enamel</td>
</tr>
<tr>
<td>Tetric Evo Ceram for AdheSE Bond</td>
<td>Ivoclar Vivadent (Liechtenstein)</td>
<td>J23353</td>
<td>A2 Enamel</td>
</tr>
<tr>
<td>Aeelite Aesthetic for Tyran SPE+Onestep Plus</td>
<td>Bisco (USA)</td>
<td>05697</td>
<td>A2 Enamel</td>
</tr>
<tr>
<td>Tescera ATL for Duolink</td>
<td>Bisco (USA)</td>
<td>0004691</td>
<td>A2 Body</td>
</tr>
<tr>
<td>Estenia for Panavia F</td>
<td>Kuraray (Japan)</td>
<td>00239A</td>
<td>A2 Enamel</td>
</tr>
</tbody>
</table>
Loaded specimens were then stored in artificial saliva\textsuperscript{27} (0.4 g NaCl, 0.4 g KCl, 0.795 g CaCl\textsubscript{2}$\cdot$2H\textsubscript{2}O, 0.78 g NaH\textsubscript{2}PO\textsubscript{4}$\cdot$2H\textsubscript{2}O, 0.005 g Na\textsubscript{2}S$\cdot$9H\textsubscript{2}O, 1 g urea, and 1000 mL distilled water) at room temperature for 1 year before undergoing the microtensile test. The artificial saliva solution was changed monthly, and its pH was monitored weekly. To avoid bacterial growth, we added 0.05% by weight thymol to the artificial saliva.

**Microtensile test procedures**

After the aging period (load cycling and 1 year of storage), specimens were retrieved from the storage medium for \(\mu\)TBS determination. Microtensile testing was undertaken using the nontrimming technique, which was first described by Sano et al.\textsuperscript{28} Four teeth were used for each bonding system, and each tooth was sectioned with a slow-speed saw (Isomet; Buehler) under water-cooling, into multiple 0.9-mm \(\times\) 0.9-mm beams. Five standard beams for both the aging period and the control were obtained from each tooth.

Specimens were then attached to a Bencor Multi-T testing apparatus (modified by Bernard Ciucchi, Danville Engineering, Danville, CA, USA) with cyanoacrylate adhesive (Zapit; DVA, Anaheim, CA, USA) and subjected to tensile forces in a microtensile testing machine (Microtensile Tester; Bisco, Schaumburg, IL, USA) at a crosshead speed of 1 mm/min. The cross-sectional area at the site of failure was measured to the nearest 0.01 mm with digital calipers (model CD-6BS; Mitutoyo, Tokyo, Japan), and this area was used to calculate the \(\mu\)TBS value, which was expressed in MPa:

\[
\text{MPa} = \frac{F(N)}{\text{bond area} (\text{mm}^2)}.
\]

**Failure mode analysis**

After microtensile testing, the fractured surfaces of all specimens were examined using a stereomicroscope (LG-P52; Olympus, Tokyo, Japan) to determine the mode of failure at 50\(\times\) magnification. Failure was classified as adhesive (interfacial failure), cohesive in dentin, cohesive in resin (including failures either within the resin composite or adhesive layer), or mixed failure.

**Statistical analysis**

Data were analyzed using one-way analysis of variance (ANOVA) to evaluate the effects of the two experimental factors: the type of adhesive and the aging regimen. Tukey’s honestly significant difference (HSD) test was used to compare between adhesives at a significance level of 0.05. Statistical analyses were performed using SPSS software (version 13.0; SPSS Inc., Chicago, IL, USA).

**Results**

The means and standard deviations of the \(\mu\)TBSs of each group are summarized in Table 3. Statistically significant differences were found among \(\mu\)TBS values of the materials \((P < 0.05)\). In the control group, ASE showed the greatest bond strength, while DL showed the weakest bond strength. In the aging group, PF showed a higher bond strength than OSP. ANOVA revealed a significant influence of both the adhesive system and aging on \(\mu\)TBS values \((P < 0.05)\). The results of Tukey’s HSD test showed that \(\mu\)TBS values of the load-cycled groups of ASE, OSP, and DL were significantly lower than those of the respective control groups of ASE, OSP, and DL \((P < 0.05)\). However, no significant differences were observed between mean \(\mu\)TBS values of the load-cycled and control groups for the PLP and PF adhesives \((P > 0.05)\).

The distribution of failure modes among the materials is shown in Table 4. The light microscopic analysis demonstrated that load-cycled groups showed exclusively adhesive-type failures (100%) for both the DL and OSP materials. After aging, adhesive-type failure was mainly observed in ASE, PLP, and PF materials (at 60%, 65%, and 70%, respectively). In the control groups without aging, adhesive-type failure was mainly observed in the DL, OSP, and PLP groups (at 55–85%). However, for the ASE and PF.
materials, mixed-type failure was more dominant in the control groups (50%) (Table 4).

Discussion

In this study, load cycling and water storage negatively affected the bond strengths of some dentin adhesives (ASE, DL, and OSP), while not negatively affecting the bond strengths of others (PLP and PF). The PF luting cement and PLP dentin adhesive were more resistant to the effects of load cycling and water storage.

Compared to other adhesive bond-strength tests, the µTBS test has several advantages, including an improved stress distribution during testing, prevention of cohesive failure in the dentin, the ability to measure regional differences in resin—dentin bond strength, and the ability to measure higher bond strengths of newly developed materials. Therefore, the µTBS test method was used in this study.

Reliable and durable bonding between resin materials and dentin is important in the field of adhesive dentistry, and long-term clinical trials have been the gold standard for evaluating the quality of new bonding systems. The execution of a long-term clinical trial, however, is difficult due to operator variability, substrate differences, recall failure, and the time and resources involved. Thus, the present study, which subjected samples to loading and artificial salivary aging, was designed to simulate clinical situations while trying to avoid some of the usual hurdles of clinical studies.

As a hybrid layer is created by a mixture of the dentinorganic matrix, residual hydroxyapatite crystallites, resin monomers, and solvents, aging may affect each of the individual components differently or may result in synergistic combinations of degradation phenomena within the hybrid layer. Except for the PLP bonding resin and PF luting cement, the results of our study showed that loaded and aged specimens had lower µTBS values than unloaded specimens. Lodovici et al reported that, in self-etching adhesive dentin bonding systems, the presence of acidic monomers resulted in the formation of a thin hybrid layer on the dentin surface. This layer provides micromechanical retention for restorations. It is thought that this hybrid layer is the weakest link in achieving long-term durable bonding. Thus, according to our results, the weakest hybrid layer of self-etching bonding systems tested may be considered to be one of the reasons for the reduced bond strengths of dentin adhesives.

After the aging of resin-bonded specimens in artificial saliva, Tay et al described the transition from initial nanoleakage from isolated silver grains to water trees in the adhesive-resin matrices as a series of events starting with water sorption. Water movement was shown to begin as a diffusion-type mechanism and become more rapid as transport pathways formed relatively larger water-filled channels. Similar water movements within the adhesive layer can be driven by osmotic pressure gradients due to high concentrations of dissolved inorganic ions and hydrophilic resin monomers, which were shown to result in the formation of water blisters over the adhesive layer.

According to results of the present study, when mechanical load cycling was applied, a concentration of main stresses in the hybrid layer interface may have led to plastic deformation of the adhesive interface. In addition,
fatigue could be a facilitating factor for failure in the hybrid layer. Moreover, Hashimoto et al.\textsuperscript{19} described two degradation patterns within a hybrid layer after 1 year of storage in water. These degradation patterns included disorganization of collagen fibrils and hydrolysis of resin from interfibrillar spaces within the hybrid layer, which subsequently weakened the strength of the resin–dentin bond.

Hydrolysis is a chemical process that breaks covalent bonds between polymers through the addition of water to ester bonds, which was shown to result in loss of the resin mass.\textsuperscript{17} This is considered to be one of the main reasons for resin degradation within the hybrid layer and contributes to reductions in bond strengths of dentin adhesives over time.\textsuperscript{34,35} In our study, failure in specimens restored with these adhesive systems predominantly occurred as adhesive failure in the aged groups (Table 4), which in turn may be considered to be the weakest portion of the bonded interface. Although many other factors may affect the mechanical properties of resin–dentin interfaces, it is possible that such differences in failure patterns may be indirect evidence of water absorption and hydrolysis of the hybrid layer. However, the PLP resin and PF luting cement showed no significant decreases in bond strengths, probably due to their individual chemical components.

In the present study, a functional monomer in the composition of PF luting cement, 10-methacryloylodisil dihydrogen phosphate (MDP), contains phosphate groups in its molecular structure that effectively chemically interact with hydroxyapatite; this might also have contributed to the superior and stable bonding effectiveness.\textsuperscript{36,37} The chemical bonding potential of MDP with hydroxyapatite was significantly high and hydrolytically stable.\textsuperscript{37} Additionally, Hashimoto et al.\textsuperscript{1} found that crystal growth formed within the resin–dentin bonds during long-term water storage of fluoride-containing resins.\textsuperscript{38} They speculated that fluoride released from restorative materials might be a factor responsible for crystal formation, and the ability to grow crystals between fluoridated restorative compounds and hard dental tissues may protect tooth surfaces in interfacial gaps and thus contribute to long-term stability.\textsuperscript{39} The PLP resin is composed of zinc fluoride complex, and our results are in agreement with those data. Thus, water absorption and hydrolysis of the bonded interface may have affected these adhesive systems less.

Our results confirm previous studies suggesting that fatigue and water storage can decrease resin–dentin bond strengths.\textsuperscript{39–41} It was reported that demineralized dentin becomes weaker after cyclic loading.\textsuperscript{42} Nikaido et al.\textsuperscript{11} evaluated the effects of thermocycling and mechanical loading on the bond strengths of a self-etching primer system and concluded that surface preparation, the C-factor, cavity depth, and dentin substrate all influence bond strength values after thermal and fatigue loadings. In our study, bond strengths of the PLP adhesive and PF luting cement also decreased after loading and aging, but the results were not statistically significant. Within the limitations of our study, it could be hypothesized that using the PLP resin and PF luting cement for restoration of the posterior teeth could be beneficial because of their more-durable bonding.

A study on a total-etching adhesive system showed that mechanical cycling alone does not affect bond strength. When thermal and mechanical load cycling was performed, however, the bond strength significantly decreased.\textsuperscript{43} When both compressive loading and water aging were applied in our study, significant decreases were observed in the bond strengths of all of the groups except PF and PLP (i.e., the bond strengths of the unloaded and loaded samples in the PF and PLP groups did not significantly differ). In contrast to our study, some studies indicated that no significant differences existed between the shear bond strengths of unloaded and loaded samples when cyclic compressive loading was applied.\textsuperscript{44,45} However, it should be emphasized that randomized controlled clinical trials are the most reliable way to assess the long-term behavior of adhesive systems. Therefore, further studies regarding the bond durability of the resin systems used in this study are needed.

Under the limitations of the present study, the $\mu$TBS values of ASE dentin adhesive and PF luting cement were found to be significantly greater than those of OSP and PLP dentin adhesives and DL luting cement in the control groups. Moreover, load cycling and water storage negatively affected the bond strengths of these dentin adhesives. However, the PF luting cement and PLP dentin adhesive were more resistant to the effects of load cycling and water storage.

Acknowledgments

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References