Incorporation of a hydrophilic amide monomer into a one-step self-etch adhesive to increase dentin bond strength: Effect of application time

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The purpose was to evaluate the effect of a hydrophilic amide monomer on µTBS of one-step adhesive to dentin at different application times. Clearfil Universal Bond Quick (UBQ), experimental adhesive (UBQexp), same compositions as UBQ but hydrophilic amide monomer was replaced with 2-hydroxyethyl methacrylate), Clearfil SE ONE and Clearfil SE Bond were applied to midcoronal dentin prepared with 600-grit SiC at different application time (0, 10, 20 and 40 s). Water sorption (Wsp) and the ultimate tensile strength (UTS) of polymerized adhesives were also measured. UBQ showed significantly lower Wsp and higher UTS than UBQexp. At each application time, UBQ exhibited significantly higher µTBSs than UBQexp. UBQ showed the highest µTBS at 0 s application time among all the adhesives. When the application time was prolonged from 0 s to 10 s, only UBQ showed no significant difference. The hydrophilic amide monomer increased µTBS with reduction in Wsp and increase in the UTS and may allow a shortened application time.

Keywords: Micro-tensile bond strength, Hydrophilic amide monomer, Application time, Self-etch adhesive systems

INTRODUCTION

Self-etch adhesives with one-step and two-step systems (1-SEAs, 2-SEAs), are now widely used in clinical practice. They are based on the use of acidic functional monomers that simultaneously condition and prime dentin1, and eliminate the rinsing phase, which not only lessens clinical application time, but also significantly reduces technique-sensitivity or the risk of making errors during application.

The bonding ability of 1-SEAs has been increased over the past decade and clinical studies have shown that the more recent 1-SEAs are almost comparable to more proven 2-SEAs2. The hydrophilic monomer, 2-hydroxyethyl methacrylate (HEMA), has been commonly incorporated in adhesive formulations to improve dentine bond strength because it enhances wetting of the dentine subsurface3. However, poly-HEMA in a polymer chain network exhibits hydrophilic properties, leading to water uptake after polymerization4. Thus, HEMA containing 1-SEAs are more hydrophilic in nature5, exhibit higher water sorption5 and show an accelerated reduction in the mechanical properties of the adhesive layer during water-storage6. Therefore, the higher concentrations of HEMA present in 1-SEAs may compromise the bond performance and the durability of resin-dentin bonds8-10. Although some companies have introduced HEMA-free 1-SEAs, HEMA is advisable for maintaining hydrophobic resin monomers and water in one solution and to prevent phase separation5,11.

To overcome the negative effects of HEMA, alternative hydrophilic monomers have been introduced. Glycerol dimethacrylate (GDMA) is a multifunctional hydroxyl-containing hydrophilic monomer with a low molecular weight, generating cross-linked polymers upon polymerization. The replacement of HEMA with GDMA in 1-SEA showed better physicochemical properties and improved dentin bond durability11. Furthermore, a recently launched 1-SEA, (Clearfil Universal Bond Quick, Kuraray Noritake Dental, Tokyo, Japan) contains a multifunctional hydrophilic amide monomer which is more hydrophilic than HEMA before polymerization and more hydrophobic than HEMA after polymerization.

Recently, commercially available 1-SEAs with a zero application time (i.e., no waiting time) concept, including Clearfil Universal Bond Quick, have been introduced. Clinicians desire not only a reduction in the number of application steps but also quicker application times for dental adhesives, however, a shortened application time may fail to maintain their bond ability12-14. Previously, it has been reported that a shorter application time than instructed by manufacturers leads to lower bond strengths to dentin15, but doubling the application time recommended by the manufacturer increases their bonding performance to dentin for 1-SEAs16,17 because the application time could influence smear layer removal and/or infiltration of resin monomers to dentin13. The multifunctional hydrophilic amide monomer in

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Clearfil Universal Bond Quick may allow a shortened application time because it may enhance wetting of the dentine sub-surface, however, there is little published information on the effect of the amide monomer on the microtensile bond strength of 1-SEA to dentin with different application times. Therefore, the purpose of this study was to investigate the bonding performance of 1-SEA containing the amide monomer with different application times to dentin. The two null hypotheses tested in this study were: 1) the amide monomer does not affect the microtensile bond strengths of one-step self-etch adhesive systems to dentin; and 2) the application time does not affect the microtensile bond strengths of self-etch adhesive systems.

**MATERIALS AND METHODS**

Two commercially available 1-SEAs, Clearfil Universal Bond Quick (UBQ; Kuraray Noritake Dental), Clearfil SE ONE (SO; Kuraray Noritake Dental) and an experimental 1-SEA (UBQ<sub>exp</sub>; same composition as UBQ but the hydrophilic amide monomer was replaced with HEMA), and one 2-SEA, Clearfil SE Bond (SE; Kuraray Noritake Dental) were used in this study. Their compositions and manufacturer’s instructions are shown in Table 1. Recommended application time (i.e., waiting time) by manufacturer was 0 s for UBQ, 10 s for SO, and 20 s for the self-etching primer of SE.

**Microtensile bond strength (µTBS) test**

Eighty freshly extracted caries-free human molars were used in this study, according to the protocol approved by the Human Research Ethics Committee, Tokyo Medical and Dental University under protocol No. D2013-022-02. The occlusal enamel was removed at 90º to the long axis of the tooth by means of a model trimmer under running water to obtain mid-coronal dentin. The dentin surfaces were prepared with 600-grit SiC paper to create a standardized smear layer. The prepared teeth were then randomly divided into 16 experimental groups according to the adhesive systems used (UBQ, UBQ<sub>exp</sub>, SO and SE) and application time (i.e., waiting time) (0, 10, 20 and 40 s). The application time of the commercially available adhesives according to the manufacturer are 0 s for UBQ, 10 s for SO, and 20 s for the self-etching primer of SE. After application of the 1-SEA adhesives (UBQ, UBQ<sub>exp</sub>, SO), the specimens were air-dried and cured with a LED light-curing unit (VALO, Ultradent Products, South Jordan, UT, USA, light output>600 mW/cm²) for 10 s according to manufacturer’s instructions (UBQ<sub>exp</sub> followed UBQ’s instruction). For SE, after application of the self-etching primer, the adhesive of SE was applied and light-cured using the same light curing unit for 10 s according to manufacturer’s instructions. After light-curing the adhesives, a resin composite, Clearfil AP-X (Shade-A2, Kuraray Noritake Dental) was built-up incrementally to a height of 5.0 mm to ensure sufficient bulk for the µTBS test. Each increment was a height of 2.0

| Material                        | pH  | Composition                                                                 | Manufacturer’s instruction |
|--------------------------------|-----|-----------------------------------------------------------------------------|----------------------------|
| Clearfil Universal Bond Quick   | 2.3 | 10-MDP, Bis-GMA, HEMA, Hydrophilic amide monomer, Colloidal silica, Ethanol, dl-Camphorquinone, Accelerators, Water, Sodium fluoride | 1. Apply BOND (Waiting time 0 s) 2. Dry with mild pressure air flow 3. Light-cure for 10 s |
| Experimental One-Step Self-etch Adhesive (UBQ<sub>exp</sub>) | 2.1 | 10-MDP, Bis-GMA, HEMA, Colloidal silica, Ethanol, dl-Camphorquinone, Accelerators, Water, Sodium fluoride | (N/A) |
| Clearfil SE ONE (SO)            | 2.3 | PRIMER: 10-MDP, HEMA, Hydrophilic aliphatic dimethacrylate, Hydrophobic aliphatic methacrylate, Colloidal silica, Ethanol, dl-Camphorquinone, Accelerators, Water, Sodium fluoride | 1. Apply BOND (Waiting time 10 s) 2. Dry with mild pressure air flow 3. Light-cure for 10 s |
| Clearfil SE BOND (SE)           | 2.1 | BOND: MDP, Bis-GMA, HEMA, Colloidal silica, Ethanol, dl-Camphorquinone, Accelerators, Water, Sodium fluoride | 1. Apply PRIMER (Waiting time 20 s) 2. Dry with mild air flow 3. Apply BOND 4. Distribute evenly with mile air flow 5. Light-cure for 10 s |
| Clearfil AP-X                   | —   | Bis-GMA, TEGDMA, Camphorquinone, Photo initiators, Pigments, Silanated barium glass, Silanated silica | Light cure for 40 s |

HEMA, 2-hydroxyethyl methacrylate; Bis-GMA, 2,2 bis[4-(2-hydroxy-3-methacryloyloxy-propoxy)-phenyl] propane; CQ, camphoroquinone; 10-MDP, 10-methacyrloyloxydecyl dihydrogen phosphate; TEGDMA, triethyleneglycol dimethacrylate
mm and light-cured for 40 s. After storage in 37°C water for 24 h, all the bonded teeth were sectioned into beams (surface area: 1.0×1.0 mm) using a low-speed diamond saw (Isomet, Buehler, Lake Bluff, IL, USA) under water spray coolant. Five beams were taken from the center of each tooth making a total 25 beams for each experimental group, were individually bonded to a tensile testing jig using cyanoacrylate adhesive (Model Repair II Blue, Dentsply- Sankin, Tokyo, Japan) mounted in a tabletop testing machine (EZ-SX, Shimadzu, Kyoto, Japan) and subjected to the μTBS test at a crosshead speed of 1.0 mm/min (Fig. 1). After the microtensile bond test, the fractured specimens were observed using a scanning electron microscopy (SEM; JSM-5310, JEOL, Tokyo, Japan) to characterize their failure modes. To analyze the failure mode, fractured specimens were classified as either: (1) C-D; cohesive failure in dentin (80–100% of the failure occurred in the underlying dentin), (2) I-F; interfacial failure (80–100% of the failure occurred between dentin and resin and (3) C-R; cohesive failure in resin (80–100% of the failure occurred in the underlying resin) or 4) Mix; mixed failure (interfacial failure and cohesive failure in the adhesive resin and/or dentin).

**Water sorption test**

One step self-etch adhesives (UBQ, UBQ<sub>exp</sub> and SO) and the bonding agent of the two-step self-etch (SE) were poured into round silicone molds (6.0 mm in diameter and 1.0 mm in thick) and covered by a transparent thin plastic strip. In the case of the one step self-etch adhesives, the solvents of each adhesive were firstly evaporated using a 3-in-one dental air-syringe for 3 min at a distance of 15 cm at an air pressure of 3.8 kgf/cm² in subdued light before light curing. The adhesives in these molds were irradiated for 90 s with a LED light-curing unit (VALO, Ultradent Products, light output>600 mW/cm²) and polymerized resin disks were fabricated for water sorption (n=3). The thickness and diameter of the specimens were measured using a digital caliper, rounded to the nearest 0.01 mm, and these measurements were used to calculate the volume (V) of each specimen. Water sorption was determined according to the ISO specification 4049 (2000)<sup>19</sup>, except for the specimens’ dimensions, shape and period of water immersion.

Immediately after polymerization, the specimens were placed in a container filled with anhydrous calcium sulphate (CaSO₄) to ensure dryness at 37°C. The specimens were repeatedly weighed after intervals of 24 h until a constant mass was obtained. The thickness and diameter of the specimens were measured using a digital caliper (ABS Solar Digimatic Caliper, Mitutoyo, Kanagawa, Japan) rounded to the nearest 0.01 mm, and these measurements were used to calculate the volume (V) of each specimen (in mm³). They were individually immersed in distilled water at 37°C for the water sorption and solubility test. After intervals of 24 h, the resin disks were gently wiped with absorbent paper, weighed, and stored in distilled water (Fig. 2). This regime was continued until a constant mass (M₁) was obtained. Then, the resin disks were stored in a dry state, and weighed daily until a constant dry mass (M₂) was obtained. Water sorption (WS) was calculated using the following formula:

\[
WS = \frac{M_1 - M_2}{V}
\]

where M₁ is the wet constant mass (μg) after water storage; M₂ is the dry constant mass after desiccation and V is the volume of the specimen in mm³.

**Ultimate tensile strength (UTS) test**

Beam shaped specimens (1.0×1.0×10.0 mm³) were prepared from the bonding agents of SE, UBQ, UBQ<sub>exp</sub> and SO by pouring into beam shape silicone molds and covering with transparent plastic strips. For UBQ, UBQ<sub>exp</sub> and SO, the solvents were evaporated using the
same procedure for the water sorption test and then all the specimens were irradiated with a LED light-curing unit for 10 s. After light curing, all the specimens were dried for 24 h in the desiccator. Half of the specimens, 12 randomly-selected beams, were individually bonded to a tensile testing jig using cyanoacrylate adhesive (Model Repair II Blue, Dentsply-Sankin) mounted in a tabletop testing machine (EZ-SX, Shimadzu) and subjected to the μTBS test at a crosshead speed of 1.0 mm/min ($n=12$, Immediate). The other half of the specimens from each adhesive system were stored in 37°C water for 24 h, followed by the μTBS test in the same manner (24 h water storage) (Fig. 3).

**Statistical analyses**

Microtensile bond strength data and UTSs data were analyzed using a two-way ANOVA ($\alpha=0.05$) and the $t$-test with Bonferroni corrections. Water sorption data...
were analyzed using \( t \)-test with Bonferroni corrections.

**RESULTS**

**Microtensile bond strengths and failure modes**

The microtensile bond strength data and failure modes were shown in Table 2. There were no pretest failures during specimen preparation for \( \mu \)TBS testing. Two-way ANOVA revealed that the \( \mu \)TBSs were significantly affected by the adhesive systems \( (p<0.001) \) and the application time \( (p<0.001) \), and that there was a significant interaction between the adhesive systems and the application time \( (p<0.001) \). UBQ showed higher \( \mu \)TBS than UBQ\(_{exp} \) at all the application times \( (p<0.001) \). For UBQ, there were no significant differences between the 0 s and 10 s group \( (p>0.05) \), and among 10 s, 20 s, and 40 s \( (p>0.05) \). For UBQ\(_{exp} \), SO and SE, there were significant differences in \( \mu \)TBS between the 0 s and 10 s groups \( (UBQ_{exp}: p=0.01, SO: p<0.001, SE: p<0.001, \) respectively). UBQ at 0 s application time, and SE at 20 s and 40 s application time showed the highest \( \mu \)TBS among the materials.

None interfacial failure was seen in the UBQ specimens at all the application times, while some specimens of UBQ\(_{exp} \) showed interfacial failure at all the application times. More cohesive failures in resin/dentin in the specimens bonded with UBQ and SE were observed compared to UBQ\(_{exp} \) and SO at all the application times. Irrespective of the adhesives, as the application time was shortened, interfacial failure and mixed failure increased.

**Water sorption**

The water sorption values \( (\text{Wsp}) \) are summarized in Table 3. The highest Wsp values were in the order of UBQ\(_{exp}>SO>UBQ=SE \).

**UTSs**

The UTS values are summarized in Table 4. Two-way ANOVA revealed that the UTS were significantly affected by the material \( (p<0.001) \) and the storage period \( (p<0.001) \), and that there was a significant interaction between materials and storage period \( (p<0.001) \). Water storage for 24 h significantly decreased the UTS of

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**Table 2** Microtensile bond strengths of tested in this study [MPa]

| Adhesives | Application time |
|-----------|------------------|
|           | 0 s   | 10 s   | 20 s   | 40 s   |
| UBQ       | 76.0 (5.7)\(^{ab}\) | 78.9 (5.6)\(^{ab}\) | 81.4 (6.3)\(^{ab}\) | 81.6 (6.7)\(^{ab}\) |
| UBQ\(_{exp}\) | 61.4 (5.7)\(^{ab}\) | 66.6 (7.2)\(^{ab}\) | 69.1 (6.2)\(^{ab}\) | 70.1 (7.3)\(^{ab}\) |
| SO        | 55.7 (3.8)\(^{ab}\) | 63.9 (5.2)\(^{ab}\) | 64.6 (4.0)\(^{ab}\) | 65.4 (4.2)\(^{ab}\) |
| SE        | 69.1 (6.2)\(^{ab}\) | 81.9 (6.1)\(^{ab}\) | 86.7 (5.5)\(^{ab}\) | 87.1 (5.7)\(^{ab}\) |

Values are mean (S.D.) \((n=25)\). Same superscript letters indicate statistically no significant difference \( (p>0.05) \). Upper case letters refer to column, and lower case letters refer to row. Failure mode: [cohesive failure in dentin/interfacial failure/mix failure/cohesive failure in resin]. Cohesive failure in dentin=80–100% of the failure occurred in the underlying dentin. Interfacial failure=80–100% of the failure occurred between dentin and resin. Cohesive failure in resin=80–100% of the failure occurred in the resin. Mix failure=interfacial failure and cohesive failure in the adhesive dentin and/or dentin.

**Table 3** Water sorption values in this study

| Adhesives | Water sorption [μg/mm\(^3\)] |
|-----------|-----------------------------|
| UBQ       | 65.2 (0.9)\(^{a}\)         |
| UBQ\(_{exp}\) | 176.7 (9.9)\(^{b}\)   |
| SO        | 103.1 (8.7)\(^{c}\)       |
| SE        | 65.8 (2.4)\(^{a}\)        |

Values are mean (S.D.) \((n=3)\). Different letters show significant differences \( (p<0.05) \).

**Table 4** Ultimate tensile bond strengths of polymerized adhesives tested in this study

| Adhesives | Dry [MPa] | Water storage 24 h [MPa] |
|-----------|-----------|-------------------------|
| UBQ       | 46.0 (6.6)\(^{ab}\) | 42.9 (4.7)\(^{ab}\)   |
| UBQ\(_{exp}\) | 41.7 (3.1)\(^{ab}\) | 25.8 (4.3)\(^{ab}\) |
| SO        | 40.4 (9.5)\(^{ab}\) | 27.3 (3.7)\(^{ab}\) |
| SE        | 48.4 (6.4)\(^{ab}\) | 44.4 (4.4)\(^{ab}\) |

Values are mean (S.D.) \((n=12)\). Same superscript letters indicate statistically no significant difference \( (p>0.05) \). Upper case letters refer to column, and lower case letters refer to row.
UBQexp and SO, however it did not significantly decrease the UTS of UBQ and SE. After 24 h water-storage, there are no significant differences between UBQ and SE and between UBQexp and SO, and the UTS of UBQ and SE were significantly higher than that of UBQexp and SO.

**DISCUSSION**

In this study, we investigated the influence of 2 factors, the type of adhesive system and the application time on the μTBS to dentin. According to the results of this study, the application time had a significant effect on the bond strengths (p<0.05). Therefore, the null hypothesis that the application time does not affect the microtensile bond strengths of self-etch adhesive systems was rejected.

The etching process of the smear layer and the underlying dentin would be influenced by the type of functional acidic monomer, acidity of the adhesives and the nature of the smear layer\(^{19-20}\), depending upon the application time. The adhesive systems tested in this study, contain the same functional acidic monomer (10-MDP) with similar pH values of 2.1–2.3, which are categorized as “mild” self-etch adhesive systems\(^{24}\). Presumably, the etching effect on smear-layer-covered dentin at the same application time would not have been largely different between SO, SE and UBQ. When the application time was prolonged from 0 s to 10 s, SO and SE showed dramatically increased the μTBS (p<0.05). These results agree with the previous studies, which reported that extending the application increased dentin bond strengths compared to 0 s application\(^{13,15}\). This could have been attributed to insufficient etching of the smear layer because remnants of the smear layer could interrupt the infiltration of resin monomers. However, the μTBS of UBQ did not significantly change in (p>0.05) when the application time was extended from 0 s to 10 s (p>0.05), maintaining the relatively higher μTBSs (76.0 and 78.9 MPa, respectively). Additionally, for the failure mode analysis of the 0 s application time group, there was no interfacial failure in the case of UBQ, while for SO and SE, some specimens failed at the interface. The infiltration process into the underlying dentine through the smear layer would be influenced by components of the hydrophilic and/or hydrophobic resin monomers, depending upon the application time. Therefore, it is speculated that there might be different infiltration mechanisms of the resin monomers between UBQ and either of SO and SE.

SO and SE contain the hydrophilic monomer, HEMA, while UBQ contains a multifunctional hydrophilic monomer and HEMA. The hydrophilic monomer, HEMA plays an important role in promoting resin penetration into the demineralized dentin\(^{25}\). However, the mechanical properties of HEMA are relatively low even after polymerization and the water sorption leads to a further reduction in the mechanical properties\(^{7}\). Therefore, infiltration of hydrophobic resin monomers which contribute to higher mechanical properties of the adhesive layer as well as the hybrid layer would be required to create a highly-strengthened resin-dentin interface\(^{26}\). It is anticipated that it would take more time for hydrophobic monomers to infiltrate into dentin compared to hydrophilic monomers.

We prepared the experimental 1-SEA (UBQexp), which has the same composition as UBQ but the multifunctional amide monomer was replaced with HEMA, to evaluate the effect of incorporating an amide monomer into 1-SEA on resin-dentin bond strengths. Regarding the bond strengths, when the application time was extended from 0 s to 10 s, the μTBS of UBQexp significantly increased (p<0.05) unlike UBQ. This indicates that the μTBS of UBQexp without the hydrophilic amide monomer is more time-dependent than the μTBS of UBQ. The multifunctional hydrophilic amide monomer contained in UBQ has a lower octanol/water partition coefficient; logP\(_{ow}\) (~0.7) (supplied information by the manufacturer\(^{27}\)) than HEMA (logP\(_{ow}\)=0.3), indicating more hydrophilicity before polymerization. Therefore, it is suggested that the incorporation of a hydrophilic amide monomer into a 1-SEA contributes to minimizing the time-dependency on μTBS. As can be seen from the water sorption test and UTS test performed in this study, polymerized adhesives of UBQ showed less Wsp and higher UTS after water storage for 24 h, compared to those of UBQexp. This may explain why UBQ showed significantly higher bond strength with both more cohesive failures in resin and more cohesive failures in dentin compared to UBQexp irrespective of the application time. Thus, the other null hypothesis tested in this study, i.e., that the amide monomer does not affect the microtensile bond strengths of one-step self-etch adhesive systems to dentin was rejected. Interestingly, the UTS and Wsp of UBQ were similar to those of the polymers of the adhesive agent of SE (p>0.05) which is relatively hydrophobic\(^{6}\). The similar properties of the multifunctional hydrophilic amide monomer-containing UBQ after polymerization to the adhesive agent of SE could be due to creation of a three-dimensional polymer network. The resin-dentin bond is susceptible to hydrolytic degradation of collagen matrix and/or bonding resin within a bond structure\(^{29-30}\), and chemical degradation at the border between the adhesive layer and resin composite because of the oxygen-inhibition layer especially with 1-SEAs\(^{31}\). Therefore, UBQ showing less water sorption and higher mechanical properties is expected to contribute to a strong and durable adhesive layer and a hybrid layer less susceptible to water absorption, leading to better bonding performance and durability\(^{32}\).

At 0 s application time, in other words, in the case of no-waiting time, UBQ showed the highest bond strength among all the adhesives tested. It is speculated that incorporation of the amide monomer into 1-SEA may enhance wetting of the dentine subsurface, possibly contributing to better infiltration of hydrophobic resin monomers into demineralized dentin, enabling a shortened application time. However, with 20 s, or 40 s application, the μTBSs of UBQ showed significantly lower μTBS than the 2-SEA, SE. Although UBQ improved the μTBS compared to SO, the lower μTBS of
the 1-SEAs may be associated with phase separation and a competitive and differential diffusion of hydrophilic and hydrophobic monomers into dentin, resulting in heterogeneous hybrid layers and an adhesive layer with limited thickness\(^{21,38}\), which may also magnify the oxygen inhibition effect on adhesive polymerization\(^{31,34,35}\). These complex blends contain high concentrations of solvents that are not thoroughly evaporated, affecting resin polymerization and lowering the strength of the resin-dentin bonds\(^{37}\). Another explanation why the 2-SEA performed better than the 1-SEAs can be attributed to the application of the mild self-etching primer of SE separated from the application of the adhesive agent that leads to a negligible dissolution of the smear plugs, facilitating penetration, entanglement and polymerization of monomers with the underlying dentin to form accurate hybrid layers\(^{36,37}\), which following the application of the self-etching primer, secures polymerization of adhesive layer\(^{37}\).

In this study, we prepared the dentin surfaces using 600-grit SiC papers to create flat surfaces and standardize the smear layer. Clinically, the dentin surfaces are generally bur-cut and prepared prior to adhesive application. Compared to the dentin surface prepared using SiC papers, the bur-cut dentin surfaces could create thicker and more compact smear layers\(^{21,38}\), requiring more time for the functional resin monomers to demineralize and infiltrate the smear layer\(^{14}\). Moreover, it is expected that mild self-etch adhesive systems can be affected by dense smear layers. In fact, the µTBS of 1-SEAs to the dentin surface prepared with SiC papers was significantly higher than that to the bur-cut dentin\(^{14,21}\). This may be regarded as a limitation of the present study. Therefore, it is speculated that the application time should be more extended or the scrubbing technique\(^{39}\) should be performed in order to obtain stronger bond strengths to bur cut dentin in the clinical situation. The findings of the current study suggest that UBQ may demonstrate their potential at the clinical situation. The findings of the current study to obtain stronger bond strengths to bur cut dentin in dentin bonds\(^{17}\). Another explanation why the 2-SEA performed better than the 1-SEAs can be attributed to demineralization and infiltration of the smear layer\(^{14}\). Moreover, it is expected that mild self-etch adhesive systems can be affected by dense smear layers. In fact, the µTBS of 1-SEAs to the dentin surface prepared with SiC papers was significantly higher than that to the bur-cut dentin\(^{14,21}\). This may be regarded as a limitation of the present study. Therefore, it is speculated that the application time should be more extended or the scrubbing technique\(^{39}\) should be performed in order to obtain stronger bond strengths to bur cut dentin in the clinical situation. The findings of the current study suggest that UBQ may demonstrate their potential at the clinical situation. The findings of the current study to obtain stronger bond strengths to bur cut dentin in dentin bonds\(^{17}\).

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CONCLUSION
Within the limitations of this study, it is concluded that the extended application time significantly increased the µTBSs of 1-step and 2-step self-etch adhesive systems, and that the hydrophilic amide monomer incorporated into 1-SEA increased the bond strength with a reduction in water sorption and an increase in the mechanical properties of the polymerized adhesive and may enable a “zero” application time.

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