The present study aimed to evaluate the dentin bond strengths of all-in-one adhesives in combination with flowable-resin-composites of different manufacturers. The materials used in this study were two all-in-one adhesives (BeautiBond Multi, BM, and Clearfil Bond SE ONE, SE) and four flowable resin composites (Clearfil Majesty ES Flow, CME; Estelite Flow Quick, EFQ; MI Flow II, MIF; and Beautifil Flow Plus F03, BFP). By combining each all-in-one adhesive and flowable resin composite, eight experimental groups were established. The shear bond strengths (SBSs) in each group were measured, and the data were statistically analyzed using one-way analysis of variance. The SBSs of the group that used SE showed no significant differences among all flowable resin composites (p>0.05), whereas those of the group that used BM showed significant differences between BFP and CME, and CME and EFQ. The combinations showed dentin bond strength ranging approximately from 20 to 30 MPa.

**Keywords:** Flowable resin composite, All-in-one adhesive, Dentin bond strength, Different manufacturer, Compatibility

### INTRODUCTION

In general, resin composite restoration is completed by using a combination of a proprietary adhesive and an accompany resin composite. When the adhesive system of the same manufacturer is used because the similar resin monomer in bonding agent is contained in the resin composite, the bond strength of the resin composite to dentin may be reliable. The dentin bond strengths of various adhesive systems on the market are significantly varied. Recently, all-in-one adhesives became popular in clinic because of the quickness of adhesive treatment, the improvement of bond strength, and the reported clinically good performances\(^1\text{-}^6\). Nevertheless, significant differences in dentin bond strength among all-in-one adhesives on the market are also reported\(^7\text{-}^{11}\). Further, physical properties of flowable resin composites including wear resistance, compressive strength, and discoloration resistance vary\(^12\text{-}^{17}\). Therefore, to make a better restoration, clinicians sometimes accomplish resin composite restoration by using an adhesive with a different manufacturer’s resin composite.

Several previous studies reported the dentin bond strengths of various all-in-one adhesives on the market\(^7\text{-}^{11}\); however, most studies combined adhesive systems with accompanying resin composites. By contrast, the compatibility of resin composites with the different manufacturer’s adhesive systems in terms of the dentin bond strength has not reached a consensus in previous studies\(^18\text{-}^{20}\). The mechanism of adhesion between adhesives and dentin has been elucidated by the formation of a resin-impregnated layer (hybrid layer)\(^21\text{-}^{22}\). The thickness of the hybrid layer is dependent on the demineralization efficacy of the adhesive system\(^23\text{-}^{28}\). Self-etch adhesive systems exhibited a thinner hybrid layer than did etch-and-rinse adhesive systems\(^29\). Especially, the hybrid layer produced by all-in-one adhesive is considerably thin\(^30\). The difference of the hybrid layer thickness is dependent on the concomitant use of phosphoric acid solution. In self-etch adhesive system, superficial dentin is demineralized by acidic monomer solution with low pH (1–3). Adhesive monomers penetrate into the demineralized dentin surface and became the hybrid layer after photopolymerization. The superficial hybrid layer possesses unpolymerized resin layer because of contact with oxygen. The unpolymerized resin layer plays a role of adhesion between the hybrid layer and the resin composite. When they are adhering, it could be ideal if the resin monomer in the composite resin is equivalent to that in the bonding resin. The base monomer containing bonding agent may be different from that in the resin composite in case of the use of the resin composite produced by different company. The combination of different resin monomers may affect the adhesion between dentin and resin composite; however, this issue has not been elucidated sufficiently.

This study aimed to examine the effect of the combination of the all-in-one adhesive and the different manufacturer’s flowable resin composite on the bond strength to dentin. The null hypothesis was that the combination of the all-in-one adhesive and the different manufacturer’s flowable resin composite would not affect the bond strength to dentin.

### MATERIALS AND METHODS

**Materials used in the present study**

| Table 1 shows the materials used in the present study. Two all-in-one adhesives (Clearfil Bond SE ONE [SE, Kuraray Noritake Dental, Tokyo, Japan] and BeautiBond Multi [BM, Shofu, Kyoto, Japan]) and four flowable resin composites (Beautifil Flow Plus F03 [BFP, Shofu], Clearfil Majesty ES Flow [CME, Kuraray] |
Table 1  Materials used in the present study

| Material            | Abbreviation | Composition                                                                 | Lot no. | Manufacturer          |
|---------------------|--------------|------------------------------------------------------------------------------|---------|-----------------------|
| Clearfil Bond       | SE           | 10-MDP, Bis-GMA, HEMA, Hydrophilic aliphatic dimethacrylate, Hydrophobic     | 7T0053  | Kuraray Noritake Dental|
|                     |              | aliphatic methacrylate, Colloidal silica, Ethanol, Accelerators, dl-Camphorquinone, Sodium fluoride, Water |         |                       |
| BeautiBond Multi    | BM           | Bis-GMA, TEGDMA, carboxylic acid-based monomer, phosphonic acid-based      | 051329  | Shofu                 |
|                     |              | monomers, acetone, water                                                     |         |                       |
| Beautifil Flow Plus | BFP          | Bis-GMA, TEGDMA, Powdered glass, Reaction initiator, Coloring agent         | 021424  | Shofu                 |
| Plus F03 (A3)       |              |                                                                              |         |                       |
| Clearfil Majesty ES | CME          | TEGDMA, Hydrophobic aromatic dimethacrylate, Barium glass filler, Silica     | 00044A  | Kuraray Noritake Dental|
| Flow                |              | filler, dl-Camphorquinone, Photo initiator                                  |         |                       |
| Estelite Flow Quick | EFQ          | Bis-MEPP, UDMA, TEGDMA, SiO$_2$-ZrO$_2$ filler, SiO$_2$-TiO$_2$ filler,    | J258    | Tokuyama Dental       |
|                     |              | Silica filler, Photo initiator                                              |         |                       |
| MI Flow II          | MIF          | TEGDMA, UDMA, Bis-MEPP, Strontium glass filler, Silica filler, Photo         | 1406231 | GC                    |
|                     |              | initiator                                                                    |         |                       |

10-MDP: 10-Methacryloyloxydecyl dihydrogen phosphate, Bis-GMA: 2,2-bis[p-(2’-hydroxy-3’-methacryloxypropoxy) phenyl] propane, HEMA: Hydroxyethyl methacrylate, TEGDMA: Triethyleneglycol dimethacrylate, Bis-MEPP: 2, 2-bis (4-methacryloxy polyethoxy phenyl) propane, UDMA: Urethane dimethacrylate

Noritake Dental, Estelite Flow Quick [EFQ, Tokuyama Dental, Ibaraki, Japan], and MI Flow II [MIF, GC, Tokyo, Japan] were used in the present study.

**Specimen preparation**

Eighty extracted human premolars were used in the present study. The Nippon Dental University School of Dentistry at Niigata approved this study (ECNG-H-257). The premolars were cleaned and stored in 0.01% thymol solution at 4°C until use. The occlusal surfaces of the premolars were ground flat to the dentin with 120-grit silicon carbide paper (Carbimet, Buehler, Lake Bluff, IL, USA) and were finished with 600-grit paper using a polishing machine (Lewel specimen polisher, Kasai, Yokohama, Japan) under water irrigation. Then, they were randomly divided into eight groups (n=10). The premolar was embedded in the specimen holder ring using self-curing resin (Province, Shofu, Kyoto, Japan) to ensure that the flat dentin surface was parallel to and projected above the rim of the cylindrical specimen holder ring. Double-sided adhesive tape (0.12 mm thickness) with a 2.0 mm diameter opening was attached to the flat dentin surface to define the bonding areas. An acrylic tube (2.0 mm diameter, 2.0 mm height) was placed on the adhesive area, following the peeling of the laminated paper from the attached adhesive tape. Each all-in-one adhesive was applied to the dentin surface in accordance with each manufacturer’s instructions and then photopolymerized for 10 s using a light-curing unit (Candelux, Morita, Tokyo, Japan). Following adhesive polymerization, each flowable resin composite was filled into the acrylic tube and then photopolymerized for 20 s. Afterward, the translucent acrylic tube was removed, and the specimen holder rings with the adhesive specimens were stored in a thermohydrostat at 37°C and 95% humidity for 24 h. Thus, eight groups of specimens were prepared by combining BM and SE and CME, EFQ, MIF, and BFP (n=10).

**Shear bond strength (SBS) test**
The specimen holder rings were placed on a tabletop material tester (EZ Test 500N, Shimadzu, Kyoto, Japan) after the storage, and using a flat end blade, the specimens were subjected to SBS testing at a crosshead speed of 1 mm/min.

**Failure mode analysis**

Fractured surfaces of the specimens were examined with a stereomicroscope (Leica EZ4D, Leica Microsystems, Heerbrugg, Switzerland) at 35× magnification, and the fracture modes were identified. Modes of failure were classified as follows: adhesive failure, the failure occurred entirely within the adhesive area; cohesive failure in resin composite, the failure occurred exclusively within the resin composite area; cohesive failure in dentin, the failure occurred exclusively within the dentin area; and mixed failure, the failure extended from the adhesive into either the resin composite or dentin area.

**Scanning electron microscopy (SEM) observation**
Several representative specimens were selected from each group for observing morphology of the fractured surfaces thoroughly. After sputter-coating the fractured
surfaces of the resin rods with palladium and platinum, they were observed using a SEM (S-800, Hitachi, Tokyo, Japan) at an accelerating voltage of 15 kV.

**Statistical analysis**

Using one-way analysis of variance (ANOVA), followed by Tukey's post hoc test, to compare the SBS values among the flowable resin composites at each adhesive system, the data were statistically analyzed. T-test was used to analyze a significant difference in the bond strength between the two adhesives with the same flowable resin composite. Statistical analysis was conducted with BellCurve for Excel (Social Survey Research Information, Tokyo, Japan).

**RESULTS**

Table 2 summarized the means (MPa) with standard deviation of SBS of each flowable resin composite to dentin applied each all-in-one adhesive.

The results of one-way ANOVA exhibited that the SBSs of SE groups showed no significant differences among the groups ($p=0.5361$), whereas those of BM groups showed significant differences among the groups ($p<0.001$). Tukey's post hoc test detected the significant difference between BM+BFP and BM+CME ($p=0.0103$), and BM+CME and BM+EFQ ($p=0.0002$). The results of $t$-test showed that BM had a significantly higher bond strength to the flowable resin composites compared with SE ($p<0.001$), with the exception of CME. There was no significant difference on the bond strength to CME between BM and SE ($p=0.3865$).

Table 3 shows the results of failure mode analysis after SBS test. Both SE and BM groups showed that the highest rate of failure mode was mixed failure and the second one was adhesive failure. All specimens of BM+EFQ and BM+CME exhibited mixed failure. The rate of adhesive failure in the SE groups was higher than that in the BM groups. In each BM+MIF and SE+CME, only one specimen showed cohesive failure in dentin.

Figure 1 shows the representative SEM images of the fractured surface of the specimens. The specimen of SE+CME shown in Fig. 1a was determined as adhesive failure, and an adhesive resin layer was mostly observed on the surface of resin rod. The specimen of SE+MIF in Fig. 1b determined as mixed failure showed a thin detached dentin layer on the half surface of resin rod. The specimen of BM+MIF shown in Fig. 1c determined as cohesive failure in dentin showed that a thick detached dentin layer was mostly observed on the surface of resin rod.

### Table 2  Results of shear bond strength (mean±SD, MPa)

| Flowable resin composite          | Clearfil Bond SE ONE (SE) | BeautiBond Multi (BM) |
|-----------------------------------|---------------------------|-----------------------|
| Beautifil Flow Plus F03 (BFP)     | 21.58±3.73a               | 28.22±2.74b           |
| Clearfil Majesty ES Flow (CME)    | 22.56±5.86a*              | 24.41±3.04c*          |
| Estelite Flow Quick (EFQ)         | 22.55±3.59a               | 29.84±2.31b           |
| MI Flow II (MIF)                 | 20.11±3.36a               | 26.82±2.02c*          |

Values with the same superscript letters indicate no significant differences ($p>0.05$).

### Table 3  Results of failure mode analysis (%)

| All-in-one adhesive | Flowable resin composite          | Af | Cfd | Cfr | Mf |
|---------------------|-----------------------------------|----|-----|-----|----|
| Clearfil Bond SE ONE (SE) | Beautifil Flow Plus F03 (BFP)     | 20 | 0   | 0   | 80 |
|                     | Clearfil Majesty ES Flow (CME)    | 40 | 10  | 0   | 50 |
|                     | Estelite Flow Quick (EFQ)         | 40 | 0   | 0   | 60 |
|                     | MI Flow II (MIF)                  | 40 | 0   | 0   | 60 |
| BeautiBond Multi (BM)  | Beautifil Flow Plus F03 (BFP)     | 20 | 0   | 0   | 80 |
|                      | Clearfil Majesty ES Flow (CME)    | 0  | 0   | 0   | 100|
|                      | Estelite Flow Quick (EFQ)         | 0  | 0   | 0   | 100|
|                      | MI Flow II (MIF)                  | 0  | 10  | 0   | 90 |

*Af: Adhesive failure, Cfd: Cohesive failure in dentin, Cfr: Cohesive failure in resin, Mf: Mixed failure
DISCUSSION

We attempted to analyze the SBSs data using two-way ANOVA (main factors of adhesive and resin composite). However, we were not able to use two-way ANOVA because the Levine’s test for homogeneity of variance shows significant differences for all data. By contrast, the Levine’s test for homogeneity of variance shows no significant differences for each data of SE and BM. Hence, we used one-way ANOVA for analyzing the data of SE and BM, separately. The results of the present study demonstrated that the dentin bond strengths of SE exhibited no significant differences among the respective flowable resin composites; however, those of BM exhibited significant differences between BFP and CME, and CME and EFQ. We tried to analyze the significant difference of bond strength between the two adhesives with the same flowable resin composite. The homogeneity of variance test showed no significant difference, so we used a t-test to analyze the significant difference in the same. The results showed that BM had a significantly higher bond strength to the flowable resin composites compared with SE, with the exception of CME. Thus, the null hypothesis was rejected.

A few studies reported the compatibility of adhesive system and resin composite18-20. Leirskar et al. reported that the dentin bond strength of the adhesives might be dependent on the resin composites combined based on an evaluation of SBSs to dentin in which five different dentin adhesives were used in combination with two different resin composites19. As reported by Song et al., the combination of adhesive and resin composite by the same manufacturer did not always show significantly higher bond strengths than mixed manufacturer combinations19. Their results corresponded to the results of the present study, although the used materials were different from each other. In our study, the primary combination of BM and BFP as well as SE and CME did not demonstrate significantly higher dentin bond strength compared with other combinations of adhesive and resin composites by different manufacturers, except for the combination of BM and CME. This is consistent with the previous studies wherein the combinations of adhesive and resin composite from the same manufacturer failed to show higher bond strengths than those from different manufacturers. Roh and Chung elucidated that the bond strength of total-etch adhesive systems was significantly influenced by the kind of resin composite combined, whereas, in the case of the combination of two-step self-etch system and resin composite, the kind of resin composites combined did not influence the bond strength20. From these findings, including those in the present study, it appears that the combination of the products of the same manufacturer of self-etch adhesives and resin composite do not produce significantly higher bond strengths than the combination of products of different manufacturers.

After applying all-in-one adhesive to the dentin surface, resin monomers in the applied adhesive are polymerized by photo-irradiation. The superficial adhesive layer is unpolymerized because of polymerization inhibition by oxygen. Theoretically, the monomers of resin composite are copolymerized with the unpolymerized layer of the adhesive during the photopolymerization. It could be desirable that both materials comprise identical monomers to generate high bond strength by combining products of different manufacturers. Regarding the materials used in the present study, Bis-GMA is present in the all-in-one adhesives (BM and SE), but not in the resin composites except for BFP. All combinations tested demonstrated a mean bond strength of >20 MPa, although significant differences in the bond strengths among the combinations were recognized. It is speculated from this result that Bis-GMA has good compatibility with other base monomers, such as Bis-MEPP and UDMA, during copolymerization.

From the results of the failure mode analysis, the rate of mixed failure was highest among all groups. On the fractured surfaces of mixed failure specimens, fragments of detached dentin and bonding resin were observed on the resin rod. Further, the fractured surfaces
of adhesive failure specimens showed detachment between the adhesive layer and the dentin, and adhesive failure between bonding resin and resin composite was not recognized in all specimens. This SEM finding suggests that the adhesion between the respective all-in-one adhesives and flowable resin composites could be stronger than that between the adhesives and the dentin.

The dentin bond strength of all-in adhesives is also influenced by the loading stress distribution surrounding the resin–dentin interface. Irie et al. investigated the effects of finishing time on mechanical properties and marginal adaptation to a Class V cavity with eight flowable resin composites after a 24 h water-storage and found that the SBSs to enamel and dentin, the flexural strengths and the moduli of the flowable resin composites increased significantly after 24 h. From these results, they suggested that the flexural strengths and moduli of the flowable resin composites may influence the bond strength between adhesive systems and dentin. Moreover, they investigated same issues using a Class I cavity, and showed the efficacy of 24 h storage. Goracci et al. examined the influence of the physical properties of resin composites on the microtensile bond strength to dentin of all-in-one adhesives and found that the adhesive did not significantly influence the microtensile bond strength, whereas the physical properties, such as tensile strength, flexural strength, tensile elastic modulus, shear elastic modulus, and Vicker’s hardness, of resin composite were significant factors. They suggested that a favorable stress distribution in the adhesive layer is important to obtain sufficient dentin bond strength of resin composite. Chowdhury et al. evaluated the effects of a double application of self-etch adhesives on dentin bond strength and the hardness of resin–dentin interfacial structures and concluded that a double application significantly increased the bond strength and hardness of the adhesive and resin–dentin interface. They speculated that a double application improves the mechanical properties of the resin–dentin interface and stress distribution at the interface due to thicker adhesive layers. In the present study, the dentin bond strength of BM was significantly higher than that of SE, except with CME. The adhesive layer of BM may be thinner than that of SE because BM contains no fillers, whereas SE contains fillers. The results of the present study suggest an opposing theory to the previous studies.

In clinic, products of various manufacturers for both adhesive system and flowable resin composite can be combined with one another. Based on the results with the limitation of this study, it can be suggested that clinicians may combine all-in-one adhesives with flowable resin composites from different manufacturers.

The aging process of bond strength between adhesives and tooth substance is important to evaluate so we will continue to investigate the effect of the aging process on the compatibility of adhesion between the products of different manufacturers.

**CONCLUSION**

No significant difference was found on the dentin bond strength between SE and a different manufacturer’s flowable resin composite. By contrast, the combination of BM and the different manufacturer’s flowable resin composite showed significant differences in the dentin bond strength, and the dentin bond strength of BM combined with EFQ or BFP was significantly higher than that of BM combined with CME. However, all combinations showed dentin bond strength ranging approximately from 20 to 30 MPa.

**CONFLICT OF INTEREST**

The authors declare that they have no competing interests.

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