Effect of silver diammine fluoride application on dentin bonding performance

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The purpose of this study was to evaluate the effects of two different concentrations of silver diammine fluoride (SDF) on dentin bonding performance. Human mid-coronal dentin was treated with either distilled water (control), 3.8%SDF or 38%SDF for 3 min. A two-step self-etch adhesive and resin composite were applied according to manufacturer’s instructions. After thermocycling (TC) at 0, 5,000 and 10,000 cycles, microtensile bond strength (µTBS) testing and morphological assessment of resin-dentin bonding interface were performed. At 0 TC, µTBSs of 3.8% and 38%SDF were significantly reduced ($p<0.05$). At 5,000 and 10,000 TC, µTBSs of 3.8%SDF were comparable to those of the control group, whereas the µTBSs of 38%SDF were significantly lower ($p<0.05$). Acid-base resistance zone formation was observed in all groups, however, slope-shaped formation was identified only in the SDF groups. The µTBSs and interfacial morphology were influenced by concentration of SDF and also TC.

**Keywords:** Silver diammine fluoride, Acid-base resistance zone, Thermocycling, Microtensile bond strength

INTRODUCTION

Fluoride has been used in dentistry in various forms for caries prevention and remineralization of early lesions3,4. Silver compounds have also been recognized for their antimicrobial properties in both medicine and dentistry5. Therefore, silver diammine fluoride (SDF), which contains these silver and fluoride, has been introduced to arrest, inhibit and prevent dental caries3,4. Silver phosphate, which contains these silver and fluoride, has been therefore not recommended for use in deep cavities that are close to the pulp8. Moreover, in vivo studies revealed no histological changes of pulpal cells but formation of tertiary dentin was found in human primary teeth after application of SDF9. On the other hand, 3.8%SDF has been used as a root canal irrigant or inter-appointment dressing during endodontic treatment because of its ability to penetrate root dentin as well as its antimicrobial activity10.

Inadequate marginal adaptation between restorative materials and cavity wall allows fluid penetration and bacterial invasion. This may lead to recurrent caries formation which remains a major cause of direct restoration failure11. Acid-base resistance zone (ABRZ) formation around a restoration margin is important to prevent recurrent caries initiation and progression12. Although there are several studies regarding the formation of the ABRZ in intact and caries-affected dentin, the exact mechanism of ABRZ formation remains ambiguous13. Different concentrations of sodium fluoride solution were applied on bovine dentin surfaces in a previous study prior to application of a fluoride-free adhesive, and it was found to influence the microtensile bond strength ($µTBS$) and ABRZ formation14.

Many studies show that SDF is effective in preventing and treating caries in primary teeth15. It was reported that pretreatment of dentin in primary molar teeth with SDF did not affect bond strengths of composite restorations16. Likewise, a previous study showed that SDF did not adversely affect the bond strength of resin composite to non-caries dentin17. However, the evidence remains quite limited, so it is important to develop a

Dental Materials Journal 2020; : –

Color figures can be viewed in the online issue, which is available at J-STAGE.
Received Feb 28, 2019: Accepted May 29, 2019
doi:10.4012/dmj.2019-057 JOI JST.JSTAGE/dmj/2019-057
more detailed experiment to check the effects of SDF on different types of adhesives and restorations because the effect of SDF on dentin bonding performance is still unclear. While most studies focus on immediate bond strength, no studies have been conducted on the effect of different concentrations of SDF on dentin bonding durability.

Therefore, the purpose of this study is to evaluate the effect of SDF concentration on durability of the bond strength of a two-step self-etch adhesive system after thermocycling as well as to investigate the micromorphology of resin-dentin interface. The null hypothesis of this study was that the effect of SDF application does not influence the μTBS of dentin and the dentin-adhesive interfacial morphology.

**MATERIALS AND METHODS**

The materials used in this study are shown in Table 1. A fluoride free two-step self-etch adhesive system, Clearfil SE Bond (SE) and resin composite, Clearfil AP-X (Shade A2, Kuraray Noritake Dental, Tokyo, Japan) were used. Ten-methacryloyloxydecyl dihydrogen phosphate (MDP) is the main functional monomer in this bonding system.

Saforide (38%SDF; Bee Brand Medico Dental, Osaka, Japan), a caries arresting agent in primary teeth of children, and Saforide RC (3.8%SDF; Bee Brand Medico Dental) used as antimicrobial root canal irrigant or interappointment dressing during endodontic treatment were also used in this study.

**μTBS test**

This study was approved by the human research ethics committee of Tokyo Medical and Dental University (no. D2013-022). Forty-eight non-carious human extracted third molars were stored in 0.1% thymol solution kept at 4°C. All teeth were used within 6 months after extraction.

The procedures of specimen preparation are shown in Fig. 1. The crown portion was sectioned horizontally using a water-cooled using slow-speed diamond saw (Isomet 1000, Buehler, Lake Bluff, IL, USA) to obtain a superficial dentin surface from each tooth. The surfaces were finished with 600-grit SiC paper to form a standardized smear layer. The teeth were randomly divided into three groups. Groups 1, 2 and 3 were treated for 3 min with either sterile water (control), 3.8%SDF or 38%SDF respectively. The treated surfaces were rinsed with distilled water for 30 s and air dried. SE primer was applied for 20 s after which a mild air stream was applied to remove excess primer. After that, SE adhesive resin was applied to the surface and a gentle stream of air to thin the adhesive was performed then light-curing for 10 s with a halogen light-curing unit (Optilux 501, 600 mW/cm², Demetrom, Danbury, CT, USA). Following this, resin composite (Clearfil AP-X) was placed in 2 mm increments and light-cured for 40 s each time until a 5 mm thick layer was obtained. Finally, the samples were kept in 37°C distilled water for 24 h.

After 24 h water storage, the samples were sectioned in order to obtain 1×1 mm cross-sectional beams of the resin-dentin bonded tooth. Any specimen close to pulp

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**Table 1** Composition, manufacturers, Brand name of the materials and adhesive system used in this study

| Brand name  | Code  | Composition                          | pH | Manufacturer                      |
|-------------|-------|--------------------------------------|----|-----------------------------------|
| Saforide    | 38%SDF| 38% Ag(NH₃)₂F (44,800 ppmF)          | 8–9| Bee Brand Medico Dental, Osaka, Japan |
| Saforide RC | 3.8%SDF| 3.8% Ag(NH₃)₂F (4,480 ppmF)          | 8–9| Bee Brand Medico Dental           |
| Clearfil SE Bond | — | Primer: MDP; Hydrophilic dimethacrylate, CQ, N,N-Diethanol-p-toluidine, water | 2.0| Kuraray Noritake Dental, Tokyo, Japan |
| Clearfil AP-X | — | Bis-GMA, TEGDMA, Barium glass filler, Silanated silica filler, Silanated colloidal silica, CQ |  | Kuraray Noritake Dental |

Ag(NH₃)₂F: silver diammine fluoride; Bis-GMA: bisphenol A-glycidyl methacrylate; CQ: camphorquinone; DET: N, N-diethanol p-toluidine; TEGDMA: triethylene glycol dimethacrylate; HEMA: 2-hydroxyethyl methacrylate; MDP: 10-methacryloyloxydecyl dihydrogen phosphate
horns was deemed unsuitable for microtensile testing, and thus discarded. A total of 270 beams were prepared with 90 beams from each group. These were further divided into three subgroups (n=30), for thermocycling at either 0, 5,000 or 10,000 cycles between 5°C and 55°C with a dwell time of 30 s using a thermocycling device (K178-08, Tokyo, Giken, Tokyo, Japan). The thermocycled specimens were subjected to a µTBS on a universal testing device (EZ-SX machine, Shimadzu, Kyoto, Japan) at a crosshead speed of 1 mm/min.

The dentin sides of the fractured surfaces after the test were gold sputter-coated and observed under scanning electron microscopy (SEM; JSM-5310LV, JEOL, Tokyo, Japan). Failure modes were categorized into five groups according to the type and location, namely, adhesive failure at the bonded interface (A); cohesive failure in adhesive resin (B); mixed failure between resin composite and adhesive resin (C); mixed failure between adhesive resin and bonded dentin interface (D); and, cohesive failure in dentin (E).

**Statistical analysis**
The Shapiro-Wilk test was performed to confirm the normal distribution of the data before the ANOVA. The µTBSs were statistically analyzed using two-way ANOVA with pairwise comparison based on a Bonferroni correction (α=0.05). The failure mode results were analyzed using the Kruskal Wallis test to compare tested groups and TC, followed by pairwise comparison with Dunn Bonferroni. All statistical analyses were performed using SPSS IBM software (Released 2015. IBM SPSS Statistics for Windows, Version 23.0, IBM, Armonk, NY, USA).

**Specimen preparation for SEM observation of ABRZ**
Specimen preparation is illustrated in Fig. 2. Specimen preparations for SEM observation of ABRZ were done according to a previous study. Briefly, 1 mm thick dentin disks obtained from eighteen molars were ground with 600-grit SiC paper and treated with either distilled water, 3.8%SDF or 38%SDF for 3 min each, rinsed and dried. A two-step self-etch adhesive, Clearfil SE Bond, was applied on the dentin surface and light cured according to the manufacturer’s instructions. After bonding, dentin disk sandwiches were made by placing a resin composite (Clearfil AP-X) between pairs of dentin disks and light curing for 40 s at each interface with a halogen light curing unit. The specimens were stored in distilled 37°C water for 24 h, then sectioned through the center and embedded in epoxy resin (Epoxicure Resin, Buehler). The surface was ground with 2000-grit SiC paper to expose the bonded interface. Specimens were then immersed in 100 mL of a buffered demineralizing solution (2.2 mmol/L CaCl₂, 2.2 mmol/L NaH₂PO₄, 50 mmol/L acetic acid adjusted at pH 4.5) for 90 min to create artificial recurrent caries. In addition, to remove exposed dentin collagen fibrils after demineralization, the specimens were immersed in 5% NaOCl for 20 min and rinsed with running water for 30 s. The treated surfaces were covered with 4-META/MMA-TBB resin (Super Bond C&B, Sun Medical, Moriyama, Japan) to prevent the edge of the adhesive from tearing away during polishing and stored at room temperature for 24 h. Slices, approximately 2 mm thick were made perpendicular to the adhesive-dentin interface. These slices were polished with diamond pastes down to 0.25 μm grit size (Struers, Copenhagen, Denmark) then etched with an argon-ion beam (EIS-IE, Elionix, Tokyo, Japan) at 1 kV, 1.5 mA/cm² for 30 s. The resulting surfaces were sputter-coated with gold for morphological assessment at dentin-adhesive interface via SEM after acid-base challenge.

**EDS analysis of dentin surface after application of SDF**
The procedure for specimen preparation is illustrated in Fig. 3. Mid-coronal dentin surfaces were obtained by cutting human molars as described above. The dentin surfaces were sectioned to obtain 1-mm thick dentin disks with a slow-speed diamond saw under water irrigation and then serially ground with SiC papers up to 2000-grit. Distilled water, 3.8%SDF or 38%SDF were...
applied on the dentin surfaces using the same procedures described. The pretreated specimens were placed in a 2.5% glutaraldehyde solution for 2 h to fix dentin collagen then stored in phosphate buffer (PB) at 4°C overnight. After that, the specimens were dehydrated in ascending concentrations of ethanol, namely 50, 70, 80, 90, 95 and 100%. Following this, specimens were dried in desiccator for 24 h and carbon-coated. Energy dispersive X-ray spectroscopy (EDS) analysis was carried out to check the elemental depositions of calcium (Ca), phosphate (P) and silver (Ag) on the dentin surface using point analysis with SEM (H-4500, Hitachi High-Technologies, Tokyo, Japan) under an operating condition of 15 kV.

![Fig. 3 Schematic illustration of methodology of specimen preparation for EDS analysis.](image)

### RESULTS

#### µTBS and failure mode analysis

The µTBS values are shown in Table 2. In the non-thermocycled groups (TC 0), the mean µTBS value for SE was 77.5 MPa, which was significantly higher than those of the 3.8%SDF and 38%SDF groups. The µTBSs of SE after TC 5,000 and TC 10,000 were 67.9 MPa and 62.3 MPa, respectively, which were significantly different from the non-thermocycled groups ($p<0.05$). The µTBS of 3.8%SDF after 5,000 thermocycles was not significantly different from the control group ($p>0.05$), however, the µTBS of 38%SDF was significantly reduced ($p<0.05$). After 10,000 thermocycles, there was no significant difference in µTBS between the control and 3.8%SDF group ($p>0.05$), however, 38%SDF group was significantly lower ($p<0.05$).

The results of the failure mode analysis are shown in Table 3. The results for 3.8%SDF and 38%SDF showed a significant difference compared with control group at non-thermocycled group ($p<0.05$). No difference was noted between groups at TC 5,000 ($p>0.05$). For the 38%SDF groups, a significant difference compared with 3.8%SDF and control was observed for TC 10,000.

### SEM observation of ABRZ

SEM images of the adhesive-dentin interface after acid-base challenges are shown in Fig. 4. The outer lesion (OL), which is created by acid demineralization of dentin after acid-base challenge was seen in all groups. The depth of the OL ranged from 10 to 15 µm in all the SEM

#### Table 2  Effect of SDF and thermocycling on µTBS of SE to dentin

| Group     | TC 0     | TC 5,000 | TC 10,000 |
|-----------|----------|----------|-----------|
| Control   | 77.5±4.6A | 67.9±6.5B | 62.3±2.7C |
| 3.8%SDF   | 70.3±6.8A | 65.4±6.6B | 61.8±4.2C |
| 38%SDF    | 59.7±6.0A | 53.4±2.0B | 47.2±2.7C |

Values represent mean±SD, n=30 per group.
For each column, the same lowercase letters indicate no significant difference ($p>0.05$).
For each row, the same uppercase letters indicate no significant difference ($p>0.05$).

#### Table 3 Percentage (%) of failure patterns according to SEM analysis

| Group     | TC 0     | TC 5,000 | TC 10,000 |
|-----------|----------|----------|-----------|
|           | A/B/C/D/E | A/B/C/D/E | A/B/C/D/E |
| control   | 0.0/10.0/3.3/3.3/83.3Aa | 26.6/53.3/0.0/3.3/16.6B | 20.0/20.0/0.0/46.6/13.3Ab |
| 3.8%SDF   | 6.6/23.3/0.0/30.0/40.0B | 33.3/56.6/0.0/6.6/3.3 | 26.6/33.3/0.0/36.6/3.3A |
| 38%SDF    | 60.0/0.0/0.0/33.3/6.6B | 66.6/6.6/0.0/20.0/6.6 | 83.3/6.6/0.0/10.0/0.0B |

For each row, the same lowercase letters describe no significant difference ($p>0.05$).
For each column, the same uppercase letters describe no significant difference ($p>0.05$).

Adhesive failure at the bonded interface (A), cohesive failure in adhesive resin (B), mixed failures between resin composite and adhesive resin (C), mixed failures between adhesive resin and bonded interface (D), cohesive failure in dentin (E).
images. No gap or erosive lesion formation was observed at the adhesive-dentin interface in all specimens. Acid-base resistant zone (ABRZ) formation was observed in all groups, and ranged from 0.5 to 1 µm in thickness. Butt-joint formation was noted only in the control group (Figs. 4a, b, c). Slope formation was seen in both 3.8%SDF (Figs. 4d, e, f) and 38%SDF groups (Figs. 4g, h, i) even after thermocycling.

EDS analysis of dentin surface after application of SDF under SEM

SEM images of dentin surface treated with distilled water, 3.8%SDF or 38%SDF and EDS pictures are shown in Fig. 5. No crystal depositions on the dentin surface were seen in the control (distilled water) (Fig. 5a). In the EDS spectra, a silver peak (Ag) was not detected on the dentin surface in the control group (Fig. 5a). In contrast, deposition on the dentin surface of small crystals in 3.8%SDF (Fig. 5b) and many irregular-shaped crystals in 38%SDF (Fig. 5c) were observed. EDS point analysis showed a lower silver peak than the Ca and P peaks in 3.8%SDF (Fig. 5b) with higher silver peaks than Ca and P peaks for 38%SDF (Fig. 5c).

DISCUSSION

SDF is a colorless aqueous solution containing fluoride and silver ions. The 38%SDF (Saforide) contains 253,900 ppm silver (Ag) and 44,800 ppm fluoride (F), while 3.8%SDF (Saforide RC) is one tenth the concentration of Saforide according to the manufacturer’s information. The fluoride concentration of 38%SDF is the highest among fluoride-containing agents available for dental use. SDF can react with tooth hydroxyapatite and produce calcium fluoride and silver phosphate, which contributes to arrest and ‘hardening’ of dental caries. The effect of different concentrations of SDF on µTBS before application of a self-etching adhesive system showed a significant effect.

The highest µTBS was obtained in the control
Fig. 5 EDS analysis of dentin surface after application of SDF.
Left side; SEM picture for EDS analysis. White arrow shows place of point analysis for EDS. a; Control: No crystals deposition/precipitation was observed, b; 3.8%SDF: small crystals deposition/precipitation was observed, c; 38%SDF: irregular crystals deposition/precipitation was observed.
Right side; EDS charts for calcium, phosphate and silver. Ca; calcium, P; phosphate and Ag; silver. Black arrow shows Ag peak. a; Control: no detection of Ag peak. b; 3.8%SDF: Ag peak was lower than Ca and P peak. c; 38%SDF: Ag peak was higher than Ca and P peak.

group without SDF application. The two-step self-etch adhesive system (Clearfil SE Bond) contains the acidic functional monomer, 10-methacryloxydecyl dihydrogen phosphate (MDP), which improves initial bond strength to dentin due to micro-mechanical interlocking around residual hydroxyapatite crystals\textsuperscript{17,18} as well as chelation of calcium ions due to the two hydroxyl groups in MDP molecule. The mild etching is able to retain residual hydroxyapatite crystals around collagen fibrils, enhancing bond stability\textsuperscript{19-21}.

The most common evaluation methods for aging in laboratory tests for bond strength durability is thermocycling or long-term water storage. Thermocycling is a commonly used thermal fatigue method in bond strength studies\textsuperscript{22}. Increased thermocycling led to a decrease of bond strengths of the control group in this study. Accelerated chemical degradation such as the loss of hydrophilic components in an adhesive system and the weakening of collagen fibrils at the resin-dentin interface were also observed to be a result of the thermocycling process, which often seems to reduce bond strengths\textsuperscript{16,20}.

The application of SDF only on tooth surfaces results in formation of calcium fluoride and silver phosphate\textsuperscript{3,4}. On the other hand, when the surface is treated with SDF and potassium iodide together, a dense layer of silver fluoride and silver iodide precipitated on dentin surface\textsuperscript{24}. At 5,000 and 10,000 thermocycles, the $\mu$TBS of the 38%SDF group decreased substantially compared to the control and 3.8%SDF groups. This may be due to increased concentration of fluoride and silver ions of 38%SDF deposited on the dentin surface. The current EDS analysis showed deposition of Ag on the dentin surface treated with 38%SDF was higher than that with 3.8%SDF. The smear layer covered dentin surface has an increased acid resistance with the presence of additional silver precipitates. Sayed et al.\textsuperscript{25} also reported that crystal deposition from 38%SDF occluded dentinal tubule orifices. The precipitation of CaF$_2$ and Ag particles on a dentin surface can physically block monomer penetration into the underlying dentin and tubules. The pH value of the self-etching primer of SE is approximately 2.0, which is strong enough to remove the 600-grit SiC ground smear layer. However, the SE primer may not be acidic enough to remove the SDF incorporated smear layer. This remaining smear layer may hinder resin monomer infiltration and formation of a seal of the self-etch adhesive at the interface\textsuperscript{26-28}.

Nakamoto et al.\textsuperscript{14} reported that application of a high concentration (9,000 ppmF) sodium fluoride solution on dentin surfaces prior to bonding with an adhesive resulted in lower $\mu$TBSs, with adhesive failure being the predominant failure mode. This may indicate an adverse effect of high concentrations of fluoride on dentin bonding. With the X-ray absorption fine structure (XAFS) analysis, formation of CaF$_2$-like deposits were found on the dentin surfaces after a 9,000 ppmF sodium fluoride solution was applied\textsuperscript{14}. Lower fluoride concentrations, 450 and 900 ppmF sodium fluoride, did not show adverse effects on $\mu$TBS as a result of fluorapatite formation on dentin surfaces\textsuperscript{14}. It was also demonstrated that 3.8%SDF application showed no adverse effect on dentin bonding performance after TC 5,000 and 10,000, indicating that this lower concentration may have far fewer residues remaining on the dentin surface and in the underlying dentin\textsuperscript{29}.

In the present study, an ABRZ was detected in all the groups. The thickness of the ABRZ ranged from 0.5 to 1 $\mu$m, which is consistent with previous studies\textsuperscript{27,30}. The ABRZ has been reported to form after application of self-etch adhesive systems but not etch and rinse adhesive systems when applied to dentin\textsuperscript{12}. It was suggested that penetration of monomers beyond the hybrid layer and presence of chemical interaction between the functional monomer and hydroxyapatite seems to lead
to the formation of an ABRZ. This zone could not only resist acid challenge but also may provide resistance to demineralization and slow or prevent recurrent caries initiation. Formation of an ABRZ is greatly influenced by the composition of the adhesive used\(^{11,32}\).

In the present study, different morphologies of ABRZ were found at the junction between the ABRZ and outer lesion when the control and SDF-treated groups were compared regardless of the number of thermocycles. Butt-join formation was identified in the control group, whereas slope formation was observed in the 3.8% SDF and 38% SDF groups. In a previous study, slope formation of the ABRZ was created by the application of different concentrations of sodium fluoride solution on dentin surfaces before bonding with a fluoride-free adhesive. Sloped ABRZ formation was created even after application of 450 ppmF sodium fluoride solution\(^{14}\).

In the present study, slope morphologies of ABRZ did not change between the 3.8% SDF and 38% SDF groups, indicating that application of 3.8% SDF seems adequate to resist acid attack at the dentin interface even when a fluoride-free adhesive system was used. Further study should be carried out to elucidate the effect of SDF on dentin collagen at the bonded interface in details.

CONCLUSION

Within the limitations of this study, the effect of SDF on dentin bonding performance was concentration-dependent. The 3.8% SDF group showed more stable bonding performance after application of a thermal stress compared with 38% SDF group. SDF groups also showed sloped-shape ABRZ which is more resistance to acid attack than the butt-join ABRZ observed for the control group.

ACKNOWLEDGMENTS

This study was supported by a grant from the Japan Society for the promotion of Science JSPS KAKENHI Grant number JP16H05515 and JP17K17124.

CONFLICT OF INTEREST

The authors declare no conflict of interest in the present study.

REFERENCE

1) Chu C, Lo E. Promoting caries arrest in children with silver diamine fluoride: a review. Oral Health Prev Dent 2008; 6: 315-321.
2) Peng JY, Botelho M, Matinlinna J. Silver compounds used in dentistry for caries management: a review. J Dent 2012; 40: 531-541.
3) Rosenblatt A, Stamford T, Niederman R. Silver diamine fluoride: a caries "silver-fluoride bullet". J Dent Res 2009; 88: 116-125.
4) Mei M, Nudelman F, Marzec B, Walker J, Lo E, Walls A, et al. Formation of fluorohydroxyapatite with silver diamine fluoride. J Dent Res 2017; 96: 1122-1128.
5) Thanatvarakorn O, Islam MS, Nakashima S, Sadr A, Nikaido T, Tagami J. Effects of zinc fluoride on inhibiting dentin demineralization and collagen degradation in vitro; a comparison of various topical fluoride agents. Dent Mater J 2016; 35: 769-775.
6) Mei ML, Ito L, Cao Y, Li Q, Lo EC, Chu C. Inhibitory effect of silver diamine fluoride on dentine demineralisation and collagen degradation. J Dent 2013; 41: 809-817.
7) Yamaga R. Diamine silver fluoride and its clinical application. J Osaka Univ Dent Sch 1972; 12: 1-20.
8) Nishino M. Effect of topically applied ammoniacal silver fluoride on dental caries in children. J Osaka Univ Dent Sch 1969; 9: 149-155.
9) Rossi G, Squassi A, Mandalunis P, Kaplan A. Effect of silver diamine fluoride (SDF) on the dentin-pulp complex: ex vivo histological analysis on human primary teeth and rat molars. Acta Odontol Latinoam 2017; 30: 5-12.
10) Hiraishi N, Yiu CK, King NM, Tagami J, Tay FR. Antimicrobial efficacy of 3.8% silver diamine fluoride and its effect on root dentin. J Endod 2010; 36: 1026-1029.
11) Ithagarun A, Tay FR, Pashley DH, Wofel JS, Garcia-Godoy F, Wei S. Single-step, self-etch adhesives behave as permeable membranes after polymerization. Part III. Evidence from fluid conductance and artificial caries inhibition. Am J Dent 2004; 17: 394-400.
12) Inoue G, Nikaido T, Foxton RM, Tagami J. The acid-base resistant zone in three dentin bonding systems. Dent Mater J 2009; 28: 717-721.
13) Inoue G, Tsuchiya S, Nikaido T, Foxton R, Tagami J. Morphological and mechanical characterization of the acid-base resistant zone at the adhesive-dentin interface of intact and caries-affected dentin. Oper Dent 2006; 31: 466-472.
14) Nakamoto A, Ikeda M, Hiraishi N, Nikaido T, Uo M, Tagami J. Effect of fluoride mouthrinse on adhesion to bovine root dentin. Dent Mater J 2018; 37: 919-927.
15) Wu DI, Velamakanni S, Denisson J, Yaman P, Boynton JR, Papagerakis P. Effect of silver diamine fluoride (SDF) application on microtensile bonding strength of dentin in primary teeth. Pediatr Dent 2016; 38: 148-153.
16) Quock R, Barres J, Yang S, Patel S. Effect of silver diamine fluoride on microtensile bond strength to dentin. Oper Dent 2012; 37: 610-616.
17) Peumans M, De Munck J, Van Landuyt K, Van Meerbeek B. Thirteen-year randomized controlled clinical trial of a two-step self-etch adhesive in non-caries cervical lesions. Dent Mater J 2015; 31: 308-314.
18) Matsui N, Takagaki T, Sadr A, Ichinose S, Nikaido T, et al. The role of MDP in a bonding resin of a two-step self-etching adhesive system. Dent Mater J 2015; 34: 227-233.
19) Bista B, Nakashima S, Nikaido T, Sato T, Burrow MF, Palamara MJ, et al. Adsorption behavior of methacryloyloxydeoxydihydrogen phosphate on an apatite surface at neutral pH. Eur J Oral Sci 2016; 124: 195-203.
20) Fujita K, Nikaido T, Burrow MF, Iwasaki T, Tanimoto Y, Hirayama S, et al. Effect of the demineralisation efficacy of MDP utilized on the bonding performance of MDP-based all-in-one adhesives. J Dent 2018; 77: 59-65.
21) Guan R, Takagaki T, Matay N, Sato T, Burrow MF, Palamara J, et al. Dentin bonding performance using Weibull statistics and evaluation of acid-base resistant zone formation of recently introduced adhesives. Dent Mater J 2016; 35: 684-693.
22) Saboia VP, Silva FC, Nato F, Mazzoni A, Cadenaro M, Mazzotti G, et al. Analysis of differential artificial ageing of the adhesive interface produced by a two-step etch-and-rinse adhesive. Eur J Oral Sci 2009; 117: 618-624.
23) Yang B, Adelung R, Ludwig K, Böttmann K, Pashley DH, Kern M. Effect of structural change of collagen fibrils on the durability of dentin bonding. Biomaterials. 2005; 26: 5021-5031.
24) Koizumi H, Hamama HH, Burrow MF. Effect of a silver diamine fluoride and potassium iodide-based desensitizing and cavity cleaning agent on bond strength to dentine. Int J Adhes Adhes 2016; 68: 54-61.

25) Sayed M, Matsui N, Hiraishi N, Nikaido T, Burrow MF, Tagami J. Effect of glutathione bio-molecule on tooth discoloration associated with silver diammine fluoride. Int J Mol Sci 2018; 19: 1322-1333.

26) Saikaew P, Senawongse P, Chowdhury AA, Sano H, Harnirattisai C. Effect of smear layer and surface roughness on resin-dentin bond strength of self-etching adhesives. Dent Mater J 2018; 37: 973-980.

27) Nikaido T, Nurrohman H, Takagaki T, Sadr A, Ichinose S, Tagami J. Nanoleakage in hybrid layer and acid–base resistant zone at the adhesive/dentin interface. Microsc Microanal 2015; 21: 1271-1277.

28) Suyama Y, Lührs AK, De Munck J, Mine A, Poitevin A, Yamada T, et al. Potential smear layer interference with bonding of self-etching adhesives to dentin. J Adhes Dent 2013; 15: 317-324.

29) Van Meerbeek B, De Munck J, Yoshida Y, Inoue S, Vargas M, Vijay P, et al. Adhesion to enamel and dentin: current status and future challenges. Oper Dent 2003; 28: 215-235.

30) Nurrohman H, Nikaido T, Takagaki T, Sadr A, Ichinose S, Tagami J. Apatite crystal protection against acid-attack beneath resin–dentin interface with four adhesives: TEM and crystallography evidence. Dent Mater 2012; 28: e89-98.

31) Iida Y, Nikaido T, Kitayama S, Takagaki T, Inoue G, Ikoda M, et al. Evaluation of dentin bonding performance and acid-base resistance of the interface of two-step self-etching adhesive systems. Dent Mater J 2009; 28: 493-500.

32) Waidyasekera K, Nikaido T, Weerasinghe DS, Ichinose S, Tagami J. Reinforcement of dentin in self-etch adhesive technology: a new concept. J Dent 2009; 37: 604-609.