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Influence of Carisolv on resin adhesion for two different adhesive systems to sound human primary dentin and young permanent dentin

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Summary *Objective*. This study evaluated the influence of Carisolv™ (Medi Team) for resin adhesion to sound human primary and young permanent dentin.

Methods. The buccal surfaces of 28 primary molars and 64 premolars were used. Two adhesive systems and resin composites were used; SE: Clearfil SE® (Kuraray) and Clearfil APX® (Kuraray), and SB: Single Bond® (3M) and Z250® (3M). Six groups were prepared. Groups 1–2 were primary dentin and Groups 3–6 were permanent dentin. Groups 1 and 3: SE was used. Groups 2 and 4: treated with Carisolv™ and then primed, SE was used. Group 5: SB was used. Group 6: treated with Carisolv™ and then etched, SB was used. The microstructural effects of primer or etchant, and Carisolv™ plus primer or etchant applied to dentin were evaluated by SEM. In addition, the microstructure of the resin-dentin interfaces of each group was studied using SEM. Shear bond strengths (SBS) were tested, and the failed surfaces were observed using SEM. Data was statistically analyzed using ANOVA with subsequent application of Fisher's PLSD at $p<0.05$.

Results. The mean SBS (unit: MPa) of Groups 1–6 were: 27.8, 19.2, 21.3, 21.7, 6.7 and 7.6. The SBS of Group 2 was significantly lower than that of Group 1. There was no significant difference of the SBS among Groups 1 and 4, 2, 3 and 4, and 5 and 6. In SE groups, the hybrid layer for primary dentin was thicker than that for permanent dentin.

Conclusions. Carisolv™ treatment before priming significantly decreased the SBS to primary dentin in SE groups, but did not influence the SBS to permanent dentin in both SE and SB groups.

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Introduction

Conventional caries removal and cavity preparation entail a combination of the use of a turbine and a handpiece fixed with a bur. Disadvantages of this system include the perception by patients that drilling is unpleasant.[1] Local anesthetic is frequently required which is another aspect of dental treatment that renders patients particularly anxious.[2] Drilling can cause deleterious thermal[3] and pressure effects on the pulp.[4] The use of the handpiece may result in the removal of softened but uninfected dentin resulting in the excessive loss of tooth tissue.[5]

A new chemo-mechanical caries removal system, Carisolv™ (Medi Team, Gothenburg, Sweden) has recently been introduced. This system utilizes a mixture of sodium hypochlorite and three amino acids (glutamic acid, leucine and lysine) in a gel preparation and is used with previously developed hand instrument.[6] The amino acids have different charges and when chlorinated, they are supposed to interact with different moieties in the carious dentin. In addition, it contains methyl-cellulose to increase the viscosity and a dye agent.[6]

Several studies evaluating the clinical effectiveness for carious primary teeth[6-8] and permanent teeth[6,8,9] using Carsolv™ have been reported. Ericson et al.[6] reported that dentin caries was effectively removed using this system without any adverse reactions. However, Hosoya et al.[7] reported that in 63.6% of cases studied, caries was not sufficiently removed by this system and slight redness and swelling of the gingiva occurred.

A variety of in vitro studies of the effects of Carisolv™ have been reported. These studies have evaluated hardness[7,10,11] and micromorphology of carious[14-16] and sound permanent dentin,[12,13,17] rat dentin,[18] as well as resin bond strength to sound[17,19] and carious permanent dentin,[20,21] and nanoleakage of dentin adhesive to carious permanent dentin.[22] Histological changes on rat pulp tissue[23] have also been reported. From the clinical point of view, these reports suggest that Carisolv™ did not cause any disadvantage to either carious or sound dentin except for a significant decrease of the bond strength to sound primary dentin that was etched and bonded with dual-cured resin.[19]

In the operative treatment of carious lesions in dentin, the morphology and nature of the prepared dentin surface influences bonding of the adhesive restorative materials that are used to restore the tooth.[24] It has been reported that chemo-mechanically treated dentin has a higher surface energy than conventionally treated dentin. This implies that chemo-mechanically treated dentin may have a greater affinity for adhesive materials and better bonding than conventionally treated dentin.[25] Dentin topography of non-carious permanent dentin[13,19] and carious permanent dentin[14-16] after caries removal by Carisolv™ have been reported. Morphological studies have shown that Carisolv™ treatment consistently removed the smear layer and exposed the dentinal tubules of non-carious[19] and carious dentin,[15] but the surfaces of the Carisolv™ treated carious dentin were rougher than that produced by a conventional drilling method.[14] In addition, Carisolv™ treatment may have dissolved collagen fibers.[13] Tensile bond strength to sound[20] and carious[20,21] dentin bonded with Single Bond (3M ESPE, St Paul, MN, USA) showed that Carisolv™ did not influence the bond strength.

Little information for resin adhesion to primary dentin treated by Carisolv™ is available, and no information has been reported that compared differences in bonding between Carisolv™ treated primary and permanent dentin. Thus we have compared the influence of Carisolv™ for resin adhesion to human sound primary and young permanent dentin.[19] Evaluation of the influence of Carisolv™ treatment on sound dentin should provide a basis for improving our understanding of its effects during treatment of caries lesions. The result of our previous study[19] showed that the influence of Carisolv™ for resin adhesion to both primary and permanent dentin differed between the type of adhesive systems. Carisolv™ treatment before etching significantly decreased the SBS to primary dentin for Super Bond D Liner Dual® (Sun Medical Co., Moriyama, Japan), but significantly increased the SBS to permanent dentin for self-etching primer system Imperva Fluorobond™ (Shofu Inc., Kyoto, Japan).[19] More information is needed to understand the influence of Carisolv™ treatment to different adhesive resin systems both for primary and permanent dentin. Therefore, in this study, we sought to evaluate and compare the influence of Carisolv™ for resin adhesion to human sound primary and permanent dentin between self-etching priming/ bonding adhesive resin system Clearfil SE Bond (Kuraray Medical Inc., Tokyo, Japan) and wet-bonding (etching/bonding) adhesive resin system Single Bond.

Materials and methods

Buccal surfaces of 28 caries-free human primary molars and 64 human premolars that had been exfoliated or extracted for orthodontic reasons and frozen in physiologic saline soon after extraction were used. Informed consent was obtained from parents and patients for collecting the teeth. All teeth were used within 6 months of extraction. To obtain flat dentin surfaces, the buccal surfaces of all teeth were ground with a water-cooled air turbine using a 301 diamond bur (Shofu, Inc.) then abraded with 400 and 600 grit wet silicon carbide papers to expose middle dentin between the dentino-enamel junction and pulp chamber wall. After surface preparation, specimens were ultrasonically washed in de-ionized water for 1 min.

According to the previous study,[19] Carisolv™ was applied on the prepared dentin, and gently agitated using a flat-shaped hand instrument for 3 min, and then air-water rinsed and air-dried. Two combinations of adhesive systems and resin composite groups were used in this study: Clearfil SE Bond and Clearfil AP-X (SE Group, Kuraray Medical Inc.) and Single Bond and Z250 (SB group, 3M ESPE). The ingredients of Clearfil SE Bond (SE) and Single Bond (SB) adhesive systems are shown in Table 1.

The teeth were divided into 6 groups based on substrate (primary or permanent), the dentin conditioning methods, and the adhesive system. Groups 1 and 2 were primary dentin and Groups 3-6 were permanent dentin ($N=8$/group for primary dentin and $N=10$/group for permanent dentin).For Groups 1 and 3, SE was used. For Groups 2 and 4, the dentin was treated with Carisolv™ for 3 min and then SE was used. For Group 5, SB was used. For Group 6, the dentin was treated with Carisolv™ for 3 min and then SB was used. SB was used only for permanent dentin.

Table 1 Ingredients of adhesive systems used in this study.

Adhesive system	Ingredients	pH
Clearfil SE Bond (SE)		
Primer	MDP, HEMA, water, multifunctional, methacrylate, photoinitiator	2.04
Adhesive	MDP, HEMA, multifunctional, methacrylate, microfiller, photoinitiator	
Single Bond (SB)		
Etchant	35% phosphoric acid gel	0.6
Adhesive	BIS-GMA, HEMA, polyalkenoic acid copolymer, ethanol, water, photoinitiator	

Efficacy of dentin conditioning

The buccal surfaces of 6 primary molars and 12 premolars ($N=3$/condition) were used for study of the treated dentin structure by a scanning electron microscopy (SEM). The dentin surfaces treatments were SE primer for 20 s and gentle air drying for 20 s; Carisolv™ treatment for 3 min followed by SE primer for 20 s with gentle air drying for 20 s; SB etchant for 10 s; or Carisolv™ treatment for 3 min followed by SB etchant for 10 s. According to a previously described method,[26] the specimens primed with the SE primer were soaked in acetone solution for 2 min to dissolve the monomer of the primer. The specimens were serially dehydrated with 50, 70, 80, 90, 95 and 100% ethyl-alcohol and dried using 100% HMDS (hexamethyldisilazane). The dentin surfaces were observed using an Hitachi S-3500N SEM (Hitachi Inc., Tokyo, Japan) following gold coating. The dentin morphology after treatment with each solution was compared with the results of the previous study[19,27] in which Carisolv™ alone, and other etching or priming agents were used as the dentin conditioner.

Bond strength

Buccal surfaces of 16 primary molars and 40 premolars ($N=8$/group for primary dentin and $N=10$/group for permanent dentin) were used for the bond strength tests. All specimens were subjected to a single-plane shear test (SPST).[28] The sample tooth was held in plate 1 of the SPST with dental stone. Mylar tape was mounted on the dentin to mask off a circular area 3 mm in diameter. The SE and SB adhesive systems were used according to the manufacturers' instructions. In the SE groups, the primer was applied on the dentin for 20 s followed by gentle air drying for 20 s. SE Bond was then applied on the primed dentin and light cured for 10 s. In the SB groups, etchant was applied on the dentin for 10 s followed by air-water spray for 10 s and gentle air dry for 1 s. SB adhesive was then applied twice on the etched dentin and light cured for 10 s. Plate 2 of the SPST was attached to plate 1. Two layers, each 1.5 mm in thickness, of Clearfil AP-X resin composite in the SE groups and Z250 resin composite in the SB groups were placed on the bonded dentin through counter sunk hole of plate 2. Each layer was light cured for 40 s using a Visilux 2® curing light (3M ESPE). All specimens were stored wet in a box at room temperature for 24 h. The shear bond strength (SBS) was tested with an autograph DCS-500™

(Shimazu Product Inc., Kyoto, Japan) at a cross-head speed of 2.0 mm/min. All data were statistically analyzed using ANOVA subsequent to Fisher's PLSD at $p<0.05$.

Fracture mode

After the SBS test, the test surface of the dentin and resin were observed using the SEM under 25–5000× magnifications. The dentin specimens were dehydrated and dried following the same method described for the evaluation of dentin conditioning. The modes of fracture were classified as follows: dentin fracture if 100% of the bonded dentin was fractured; adhesive fracture if 100% of the bonded interface failed between the dentin and the bonding resin; cohesive resin fracture if 100% of the failure was in the resin composite; or mixed fracture if the failures were partially adhesive and partially cohesive resin fracture and/or dentin fracture. The relationships between the fracture mode and the SBS were determined according to the previously reported method.[26]

Microstructure of the resin-dentin interface

Buccal surfaces of 6 primary molars and 12 premolars (N=3/group) were used. The specimens were prepared according to the method of Groups 1–6 in which the dentin surfaces were conditioned, and bonded to the resin composite. All specimens were left in ambient air for 10 min and then immersed in distilled water at 37 °C for 24 h. All specimens were sectioned bucco-lingually in the center portion of the bonded surface with a water-cooled circular diamond blade fixed on an Isomet™ low-speed saw (Buehler Ltd, Lake Bluff, IL, USA). All sectioned surfaces were polished with 600, 800 and 1000 SiC papers followed by a 3 and 1 μm aluminum oxide polishing films. One half of the sectioned specimens of all groups was soaked in 0.5N HCl for 20 s followed by 5% NaOCl for 2 min to reveal the hybrid layer and evidence of exposed dentinal collagen. The other half of the sectioned specimens of all groups was not treated. All specimens were ultrasonically washed in distilled water for 1 min. After fixing with 2% glutaraldehyde solution for 24 h, all specimens were serially dehydrated and dried following the same method used for evaluating dentin conditioning. All bonding interfaces were coated with gold and observed by SEM under 25–5,000× magnifications.

Results

Efficacy of dentin conditioning

SEM micrographs of Fig. 1(A) and (B) are primary dentin, and Fig. 1(C)–(F) are permanent dentin. Fig. 1(A) and (C) show the dentin surfaces primed with SE primer and treated with acetone solution for 2 min. Both for primary and permanent dentin, dentinal tubules were opened but the efficacy of the SE primer for primary dentin was higher than that for permanent dentin. Arrows in Fig. 1(A) show the component of primer partially retained in the primary dentin after acetone treatment. Fig. 1(B) and (D) show the dentin surfaces treated with Carisolv™ for 3 min and then primed with SE primer for 20 s followed by acetone treatment for 2 min. Both for primary and permanent dentin, dentinal tubules in the dentin treated with both Carisolv™ and SE primer were more obvious than those in the dentin treated with SE primer alone (Fig. 1(A) and (C)). Permanent dentin treated with SB etchant for 10 s. (Fig. 1(E)) or treated with Carisolv™ for 3 min and then etched (Fig. 1(F)) showed dentinal tubules widely opened and smooth intertubular dentin.

Bond strength

The SBS testing for primary dentin and permanent dentin using SE or SB adhesive system are shown in Table 2. For primary dentin in the SE groups, the bond strength after treatment with Carisolv™ (Group 2) was significantly lower than that of Group 1. For permanent dentin, both in the SE and SB groups, previous treatment with Carisolv™ did not cause significant difference in SBS (Groups 3 vs 4, Groups 5 vs 6). No significant difference of the SBS was observed among Groups 1 and 4, and Groups 2, 3 and 4. The SBS of Group 1 was significantly higher than the remaining groups.

Fracture mode

Fracture mode after SBS test mainly showed mixed fractures that were adhesive and cohesive resin fracture for the SE groups, and adhesive fracture for the SB groups as shown in Table 2. In Group 1, two specimens showed mixed fracture that was adhesive and dentin fracture. In each of Groups 3 and 4, one specimen showed cohesive resin fracture and mixed fracture that was adhesive, dentin and cohesive resin fracture. There was no correlation between the dentin-resin fracture mode and the bond strength in any of the groups.

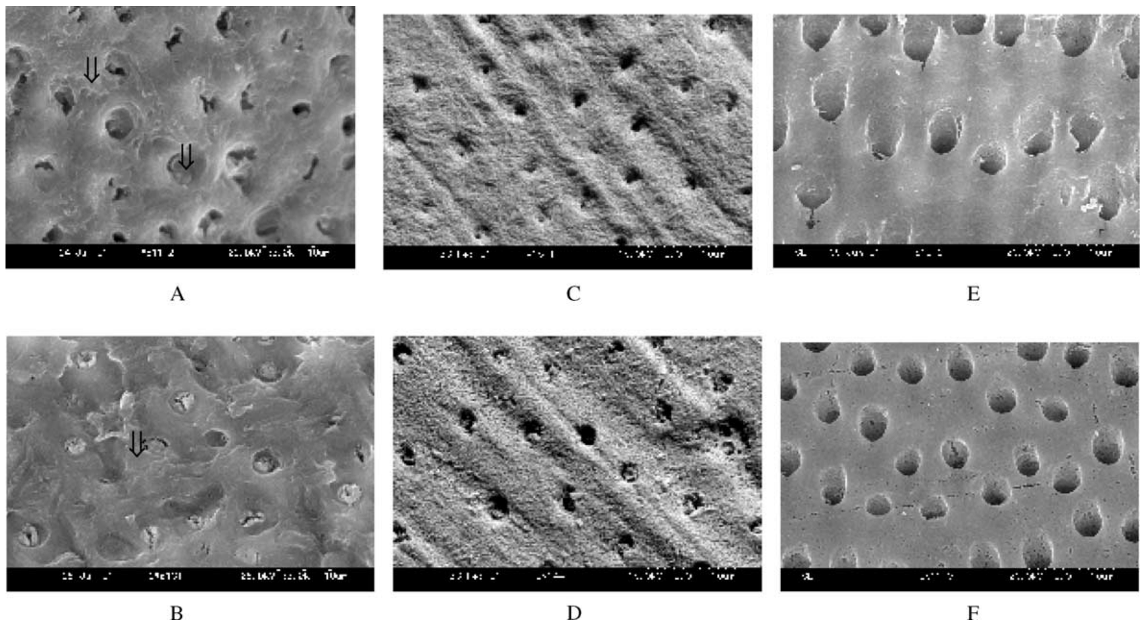

Figure 1 (A) Primary dentin primed with SE primer for 20 s and treated with acetone solution for 2 min. Component of the primer partially remained in the opened dentinal tubules and intertubular dentin (arrows). (B) Primary dentin treated with Carisolv™ for 3 min and then primed with SE primer for 20 s followed by acetone treatment for 2 min. Dentinal tubules were opened. The component of primer partially remained in the dentin (arrow). (C) Permanent dentin primed with SE primer for 20 s and treated with acetone solution for 2 min. Dentinal tubules were mildly opened and a mesh-like structure was observed in the intertubular dentin. (D) Permanent dentin treated with Carisolv™ for 3 min and then primed with SE primer for 20 s followed by acetone treatment for 2 min. Dentinal tubules were opened and mesh-like structure was observed in the intertubular dentin. (E) Permanent dentin etched with SB etchant for 10 s followed by air-water spray for 10 s. Dentinal tubules were widely opened and intertubular dentin was smooth. (F) Permanent dentin treated with Carisolv™ for 3 min and then etched with SB. Dentinal tubules were opened and intertubular dentin was smooth.

Microstructure of the resin-dentin interface

The sectioned and treated surfaces using 0.5N HCl and 5% NaOCl surfaces for each group are shown in Fig. 2(A)-(F) in the order of the Groups 1-6. In the SE groups, hybrid layer for the primary dentin (Fig. 2(A) and (B)) was thicker than that for permanent dentin (Fig. 2(C) and (D)) regardless of Carisolv™ treatment. In both the SE primary dentin and SE permanent dentin groups, more resin tags were observed in the Carisolv™ treatment groups. In the SB permanent dentin groups, a well defined hybrid layer and many long resin tags were observed regardless of the Carisolv™ treatment (Fig. 2(E) and (F)), but a gap occurred in the hybrid layer for samples pretreated with Carisolv™ (Fig. 2(F)).

Table 2 Shear bond strengths to dentin and fracture modes after shear bond strength test.

Group	Dentin	Cari-solv	Ad-hesive system	Shear bond strength Mean (SD) unit: MPa	Fracture mode (%)					No. of speci-mens
					A	A/D	A/D/Re	A/Re	Re	
1	Primary	−	SE	27.8 (8.7)^{a}	1 (12.5)	2 (25)		5 (62.5)		8
4	Permanent	+	SE	21.7 (7.0)^{a,b}	3 (30)		1 (10)	6 (60)		10
3	Permanent	−	SE	21.3 (3.6)^{b}	3 (30)			6 (60)	1 (10)	10
2	Primary	+	SE	19.2 (7.9)^{b}	2 (25)			6 (75)		8
6	Permanent	+	SB	7.6 (2.6)^{c}	10 (100)					10
5	Permanent	−	SB	6.7 (3.2)^{c}	9(90)			1 (10)		10

Values with same superscript letters indicate no significant difference at $p<0.05$. Adhesive system: SE, Clearfil SE Bond, SB, Single Bond; Fracture mode: A, adhesive fracture; D, dentin fracture, Re, cohesive resin fracture.

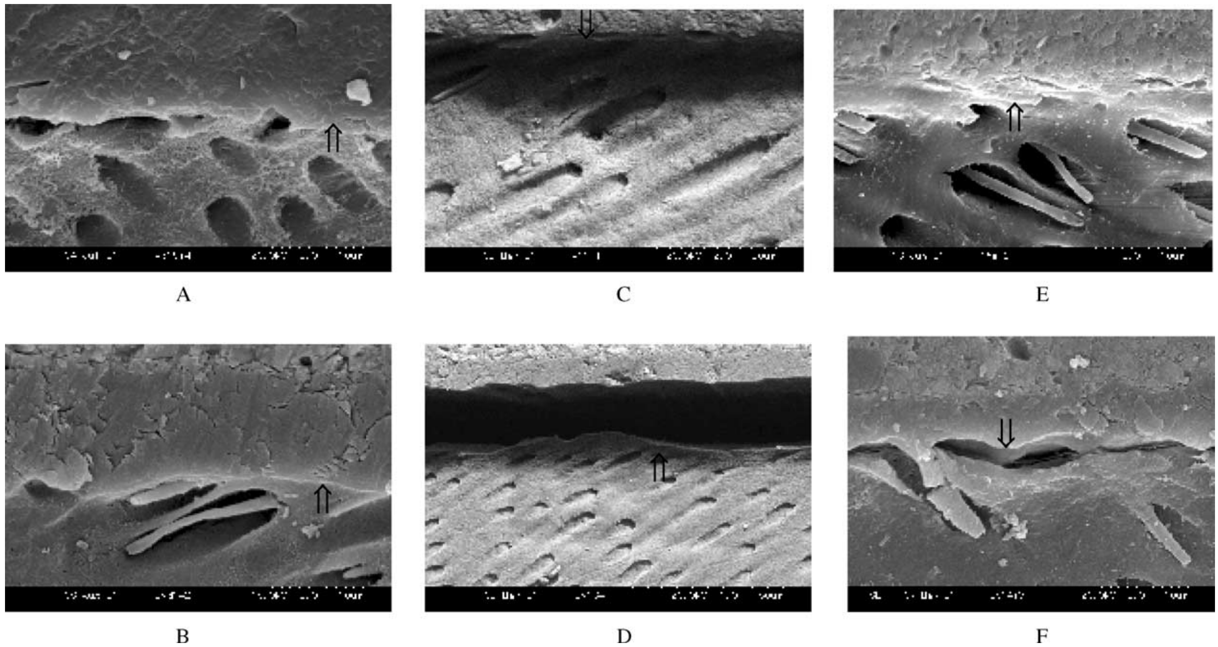

Figure 2 (A) Primary dentin primed with SE primer and bonded with SE bond. The hybrid layer (arrow) was observed. (B) Primary dentin treated with Carisolv™ and then primed with SE primer followed by bonding with SE bond. (C) Permanent dentin primed with SE primer and bonded with SE bond. Thin hybrid layer (arrow) was observed. (D) Permanent dentin treated with Carisolv™ and then primed with SE primer followed by bonding with SE bond. Thin hybrid layer (arrow) was observed. (E) Permanent dentin etched with SB etchant and bonded with SB bond. The hybrid layer (arrow) and resin tags were observed. (F) Permanent dentin treated with Carisolv™ and then etched with SB etchant followed by bonding with SB bond. Thick hybrid layer (arrow) and resin tags were observed.

Discussion

During caries removal by Carisolv™, exposed dentin adjacent to the caries lesion is also exposed to the Carisolv™. Thus understanding its effects on sound dentin is important to understand the treatment and subsequent bonding processes. Complete caries removal by Carisolv™ has been reported to require about 10 min both for primary teeth and permanent teeth,[6] and 8.5 min for primary teeth.[7] The application time of Carisolv™ in this study was 3 min and shorter than that for clinical studies.[6,7] Thus the effects of Carisolv™ in typical clinical treatments may be even more pronounced than revealed in this study.

The dentin conditioning step is fundamental for effective bonding. Cederland et al.[13] treated non-carious permanent dentin with Carisolv™ for 5 min and reported that the dentin ground with 600 grit wet abrasive paper was covered by smear layer. They also reported that the Carisolv™ and phosphoric acid-treated dentin surfaces were markedly eroded. In our previous study,[19] smear layer was partially observed on the permanent dentin treated with Carisolv™, but Carisolv™ treatment removed the smear layer and opened dentinal tubules of primary dentin. In our previous study,[19] the etching efficacy of 10–3 solution on primary dentin was considered to be better than that to permanent dentin. However, both primary and permanent dentin treated with Carisolv™ followed by 10–3 solution were well etched. In this study, the efficacies of SE primer on primary dentin, and Carisolv™ followed by SE primer (Fig. 1(A) and (B)) were better than that to permanent dentin (Fig. 1(C) and (D)). Thus primary dentin was more susceptible to both Carisolv™ and dentin conditioners (primers and etchants) than permanent dentin. The SE primer more effectively removed smear layer and primer remained even after acetone solution treatment on primary dentin suggesting that there is a greater affinity of SE bond to primary dentin than permanent dentin (Fig. 1(A)–(D)).

There are indications of some differences between primary and permanent dentin. Hardness of sound primary dentin is softer than permanent dentin.[29] Concentrations of calcium and phosphorus in both peritubular and intertubular dentin are lower in primary teeth than in permanent teeth.[30] Dentinal micromorphology also indicates potential differences between primary and permanent teeth.[31,32] These differences suggest that it is important to evaluate treatments specifically for primary dentin, since it cannot be assumed that permanent and primary dentin will respond to treatment in the same way.

For permanent dentin of this study, the dentin conditioning efficacy of SB etchant (Fig. 1(E)) was higher than that of SE primer (Fig. 1(C)). Self-etching SE primer might disclose less etching ability because of their relative high pH when compared with the pH of phosphoric acid SB etchant (Table 1) as observed previously.[33] Carisolv™ treatment before SE priming increased the dentin conditioning efficacy on permanent dentin (Fig. 1(D)) but the dentin conditioning efficacy of SB etching alone or prior Carisolv™ treatment was very similar for permanent dentin (Fig. 1(E) and (F)). In the SB groups, due to the strong demineralization effect of the phosphoric acid etchant, the smear layer and smear plugs were completely removed regardless of Carisolv™ treatment (Fig. 1(E) and (F)).

In our previous study,[19] Carisolv™ was less effective than etching for resin adhesion to primary and permanent dentin. Thus, we did not use Carisolv™ alone for dentin conditioning but applied Carisolv™ prior to dentin priming or etching. The Carisolv™ treatment before priming with SE primer significantly decreased SBS to primary dentin, but did not influence the SBS to permanent dentin (Table 2). This is in agreement with the result using 10–3 solution etching followed by Super Bond D Liner DUAL® bonding.[19] However, the results were different than those found with a different self-etching primer system (Imperva Fluorobond™: FB) that showed Carisolv™ treatment before priming significantly increased the SBS to permanent dentin, but not to primary dentin.[19] The differences in chemical reactivity between primary dentin and permanent dentin may contribute to this difference in SBS, since the efficacy of dentin conditioning of FB primer, especially for permanent dentin, is low and Carisolv™ treatment prior to FB priming produced greater dentin conditioning and led to higher SBS than dentin priming only. On the other hand, since the effect of both Carisolv™ and SE primer were greater to primary dentin than to permanent dentin (Fig. 1(A)–(D)), the 3-min Carisolv™ treatment followed by 20-s priming by SE primer caused over-conditioning and excessive demineralization, and could have denatured dentin collagen of the primary dentin inducing inferior bonding. Excessive demineralization may cause severe collapse of the dentinal collagen meshwork.[34] Primary dentin had a thicker hybrid layer than permanent dentin when SE was used. (Fig. 2(A)–(D)). This result could explain the higher susceptibility of primary dentin to both Carisolv™ and dentin conditioners.

Many studies concerning the effect of NaOCl pretreatment on dentin bonding have been reported. The results differed among the studies and some studies showed decrease but others showed increase of bond strength for same bonding materials. The difference might be caused by the different percentage and application time of NaOCl, and different test method. In general, bond strengths decreased with increasing storage time in NaOCl,[35] and depended on the adhesive system used.[36,37] The depth of dentin also might influence to the bond strength to NaOCl applied dentin.[38] The percentage of NaOCL in Carisolv™ is 0.25% after mixing of the solution A and B, and is therefore much lower than those used in the previous studies, but Carisolv™ contains other chemical components. Thus the effect of Carisolv™ on dentin bonding is not same as for the effect of NaOCl pretreatment on dentin bonding.

Several reports have compared the bond strength between primary dentin and permanent dentin using other bonding systems.[19,27,39–44] The results varied with findings indicating: no significant difference in bond strength between primary dentin and permanent dentin[38,39] significantly lower bond strengths to primary dentin;[19,40,41,43] and higher bond strengths to bovine primary dentin.[27,43] In this study, primary and permanent dentin did not differ in SBS when treated with Carisolv™ followed by SE primer, but primary dentin showed significantly higher SBS when primed with SE primer alone (Table 2). Bond strength to dentin depends on several factors: dentin hardness,[29] dentin permeability,[31] the degree of mineralization,[30,45] depth of dentin[46] and adhesive systems.[19]

The SBS of the SB groups of this study was not influenced by pretreatment with Carisolv™ treatment, and is in agreement with previous studies using Single Bond® adhesive system.[20,21] Compared to bond strength of other studies[20] in which the tensile bond strength (TBS) to sound dentin using Carisolv™ and Single Bond® adhesive system was investigated, our results gave lower values (Table 2), possibly because of the different testing procedures. In addition, the lower SBS in the SB groups might be caused by too much moisture on the samples. Nakaoki et al[47] demonstrated that the TBS to over-wet dentin (5.2 MPa) was significantly lower than those to the blot dried or 1-s dried dentin. In this study, for the SBS testing, the sectioned tooth was embedded in a plate with dental stone and then all procedures of etching, rinsing, bonding and resin composite filling were done. Although after air-water spraying, gentle air drying was done in the test surface, water absorbed in the dental stone might have caused an over-wet condition on the test surface. Adhesive fracture was mainly observed on the fractured surfaces after SBS testing in the SB groups (Table 2), suggesting that surplus water interfered with the solid adhesion between bonding resin and dentin. However, specimens for study of the resin-dentin interface were not embedded with dental stone and no influence of excess water would have been evident (Fig. 2(F)). This might explain why the dentin adhesion of Single Bond® was lower than that of Clearfil SE Bond®.

The mechanism responsible for the adhesion of newer-generation dentin adhesive systems is thought to be related on the creation of a hybrid layer.[48] Previous reports, in which the resin-dentin interfaces of primary and permanent dentin were observed in SEM, have reported that the hybrid layer of primary dentin was thicker than that of permanent dentin. It has been suggested that primary dentin is more susceptible to acid conditioning and therefore shorter application times for the dentin conditioner in primary dentin may be appropriate. This might decrease the microleakage that occurs at the bottom of the hybrid layer in primary teeth.[45,49]

In this study, 3-min treatment by Carisolv™ influenced the resin adhesion to sound primary dentin in accordance with our previous study.[19] Differences were observed between primary dentin and permanent dentin, and primary dentin was affected much more by Carisolv™ treatment than permanent dentin. The effect of Carisolv™ treatment on resin bond strength also depended on the adhesive system that was used. Shorter application time of the primer or etchant after Carisolv™ treatment might be recommended for primary dentin. Additional studies for different treatment times by Carisolv™, and the influence of Carisolv™ treatment on subsequent resin adhesion to carious dentin should be tested in future studies.

Conclusions

Effects of SE primer alone or following Carisolv™ treatment on primary dentin were different and more pronounced than on permanent dentin.

For permanent dentin, effects of SE primer alone or following Carisolv™ treatment were milder than those when SB was used.

Carisolv™ treatment before SE priming significantly decreased the SBS to primary dentin, but did not influence the SBS to permanent dentin.

Carisolv™ treatment before SB etching did not influence the SBS to permanent dentin.

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References

1. Berggren U, Meynert G. Dental fear and avoidance: causes, symptoms and consequences. *Journal of American Dental Association* 1984;**108**:247–51.
2. Green RM, Green A. Adult attitudes to dentistry among dental attenders in south Wales. *British Dental Journal* 1985;**159**:157–60.
3. Shovelton DS. The maintenance of pulp vitality. *British Dental Journal* 1972;**133**:95–101.
4. Stanley HR, Swerdlow H. Biological effects of various cutting methods in cavity preparation: the part pressure plays in pulpal response. *Journal of American Dental Association* 1960;**61**:450–6.
5. Fusayama T. Clinical guide for removing caries using a caries-detecting solution. *Quintessence International* 1988;**19**: 397–401.
6. Ericson D, Zimmerman M, Raber H, Gotrick B, Bornstein R, Thorell J. Clinical evaluation of efficacy and safety of a new method for chemo-mechanical removal of caries. *Caries Research* 1999;**33**:171–7.
7. Hosoya Y, Goto G. Effect of Carisolv™ on primary dentin Report 1. Effects on caries removal and on hardness to dentin after caries removal. *The Japanese Journal of Pediatric Dentistry* 1999;**37**:677–84.
8. Maragakis GM, Hahn P, Hellwig E. Clinical evaluation of chemomechanical caries removal in primary molars and its acceptance by patients. *Caries Research* 2001;**35**:205–10.
9. Nadanovsky P, Carneiro FC, Souza de Mello F. Removal of caries using only hand instruments: A comparison of mechanical and chemo-mechanical methods. *Caries Research* 2001;**35**:384–9.
10. Igarashi I, Hashimoto K, Tonami K, Shimizu C, Mataki S, Kurosaki N. Softening of carious dentin by Carisolv gel. *The Japanese Journal of Conservative Dentistry* 1998;**41**:704–7.
11. Hossain M, Nakamura Y, Tamaki Y, Yamada Y, Jayawardena JA, Matsumoto K. Dentinal composition and Knoop hardness measurements of cavity floor following carious dentin removal with Carisolv. *Operative Dentistry* 2003;**28**:346–51.
12. Hannig M. Effect of Carisolv™ solution on sound, demineralized and denatured dentin - an ultrastructural investigation. *Clinical Oral Investigation* 1999;**3**:155–9.
13. Cederlund A, Lindskog S, Blomlof J. Effect of a chemo-mechanical caries removal system (Carisolv™) on dentin topography of non-carious dentin. *Acta Odontologica Scandinavica* 1999;**57**:185–9.
14. Hashimoto K, Tonami K, Shimizu K, Kurosaki N. The surface of cavity floor dentin by Carisolv™. *The Japanese Journal of Conservative Dentistry* 1999;**42**:619–22.
15. Banerjee A, Kidd EAM, Watson TF. Scanning electron microscopic observations of human dentine after mechanical caries excavation. *Journal of Dentistry* 2000;**28**:179–86.
16. Yazici AR, Ozgunaltay G, Dayangac B. A scanning electron microscopic study of different caries removal techniques on human dentin. *Operative Dentistry* 2002;**27**:360–6.

17. Tonami K, Takagi T, Araki K, Mataki S, Kurosaki N. Effect of Carisolv gel on carious dentin collagen. *The Japanese Journal of Conservative Dentistry* 1999;**42**:1040–4.
18. Dammaschke T, Stratmann U, Mokrys K, Kaup M, Ott KH. Reaction of sound and demineralized dentine to Carisolv in vivo and in vitro. *Journal of Dentistry* 2002;**30**:59–65.
19. Hosoya Y, Kawashita Y, Marshall Jr GW, Goto G. Influence of Carisolv™ for resin adhesion to sound human primary dentin and young permanent dentin. *Journal of Dentistry* 2001;**29**: 163–71.
20. Suda S, Maseki T, Nara Y, Tanaka H. Effects of the chemo-mechanical caries removal system Carisolv™ on caries-affected dentin and adhesive restoration. *The Japanese Journal of Conservative Dentistry* 2000;**43**: 947–73.
21. Cehreli ZC, Yazici AR, Akca T, Ozgunaltay G. Morphological and micro-tensile bond strength evaluation of a single-bottle adhesive to caries-affected human dentine after four different caries removal techniques. *Journal of Dentistry* 2003;**31**:429–35.
22. Kubo S, Li H, Burrow MF, Tyas MJ. Nanoleakage of dentin adhesive systems bonded to Carisolv-treated dentin. *Operative Dentistry* 2002;**27**:387–95.
23. Young C, Bongenhiem U. A randomized, controlled and blinded histological and immunohistological investigation of Carisolv™ on pulp tissue. *Journal of Dentistry* 2001;**29**: 275–81.
24. Eick JD, Gwinnett AJ, Pashley DH, Rbinson SJ. Current concepts on adhesion to dentin. *Critical Reviews in Oral Biology and Medicine* 1997;**8**:306–35.
25. Emanuel R, Broom JC. Surface energy of chemo-mechanically prepared dentin. *Quintessence International* 1988;**19**: 369–72.
26. Hosoya Y, Tominaga A, Goto G. Resin adhesion to the primary dentin. Report 2.. *The Japanese Journal of Pediatric Dentistry* 1994;**32**:785–800.
27. Hosoya Y, Tominaga A, Kakazu K, Nishiguchi M, Kashiwabara Y, Goto G. A comparison of three dentin adhesives to permanent dentin in regard to those of primary dentin. *Pediatric Dental Journal* 1996;**6**:23–32.
28. Watanabe LG, Marshall Jr GW, Marshall S. Dentin shear strength: Effects of tubule orientation and intratooth location. *Dental Materials* 1996;**12**:109–15.
29. Johnsen DC. Comparison of primary and permanent teeth. In: Avery JA, editor. *Oral development and histology*. Philadelphia: B.C. Decker; 1998. p. 180–90.
30. Hirayama A. Experimental analytical electron microscopic studies on the quantitative analysis of elemental concentrations in biological thin specimens and its application to dental science. *Shikwa Gakuho* 1990;**90**:1019–36.
31. Koutsi V, Noonan RG, Horner JA, Simpson MD, Matthews WG, Pashley DH. The effect of dentin depth on the permeability and ultrastructure of primary molars. *Pediatric Dentistry* 1994;**16**:29–35.
32. Sumikawa DA, Marshall GW, Gee L, Marshall S. Microstructure of primary tooth dentin. *Pediatric Dentistry*. 1992;**21**: 439–44.
33. Oliveira SS, Pugach MK, Hilton JF, Watanabe LG, Marshall SJ, Marshall GW. The influence of the dentin smear layer on adhesion: a self-etching primer vs. a total-etch system. *Dental Materials* 2003;**19**:758–67.
34. Tam LE, Pilliar RM. Effects of dentin surface treatment on the fracture toughness and tensile bond strength of a dentin-composite adhesive interface. *Journal of Dental Research* 1994;**73**:1530–8.
35. Yamauti M, Hashimoto M, Sano H, Ohno H, Carvalho RM, Kaga M, et al. Degradation of resin-dentin bonds using NaOCl storage. *Dental Materials* 2003;**19**:399–405.
36. Prati C, Chersoni S, Pashley DH. Effect of removal of surface collagen fibrils on resin-dentin bonding. *Dental Materials* 1999;**15**:323–31.
37. Ishizuka T, Kataoka H, Yoshioka T, Suda H, Iwasaki N, Takahashi H, et al. Effect of NaClO treatment on bonding to root canal dentin using a new evaluation method. *Dental Materials* 2001;**20**:24–33.
38. Toledano M, Perdigão J, Osorio R. Influence of NaOCl deproteinization on shear bond strength in function of dentin depth. *Amerikan Journal of Dentistry* 2002;**15**:252–5.
39. Fagan TR, Crall JT, Jensen ME, Chalkley Y, Clarkson B. A comparison of two dentin bonding agents in primary and permanent teeth. *Pediatric Dentistry* 1991;**13**:163–6.
40. Salama FS, Tao L. Gluma bond strength to primary vs. permanent teeth. *Pediatric Dentistry* 1991;**13**:163–6.
41. Bordin-Aykroyd S, Sefton J, Devies EH. In vitro bond strengths of three current dentin adhesives to primary and permanent teeth. *Dental Materials* 1992;**8**:74–8.
42. Hosoya Y, Nishiguchi M, Kashiwabara Y, Horiuchi A, Goto G. Comparison of two dentin adhesives to primary vs. permanent bovine dentin. *Journal of Clinical Pediatric Dentistry* 1997;**22**:69–76.
43. El Kalla IH, Garcia-Godoy F. Bond strength and interfacial micromorphology of four adhesive systems in primary and permanent teeth. *Journal of Dentistry for Children* 1998;**65**: 169–76.
44. Hosoya Y, Kawashita Y, Yoshida M, Suefuji C, Marshall Jr GW. Fluoridated light activated bonding resin adhesion to enamel and dentin: primary vs. permanent. *Pediatric Dentistry* 1997;**19**:246–52.
45. Nör JE, Feigel RJ, Dennison JB, Edwards CA. Dentin bonding: SEM comparison of the dentin surface in primary and permanent teeth. *Pediatric Dentistry* 1997;**19**:246–52.
46. Suzuki T, Finger WJ. Dentin adhesives: Site of dentin versus bonding of composite resins. *Dental Materials* 1998;**4**: 379–83.
47. Nakaoki Y, Nikaido T, Burrow MF, Tagami J. Effect of residual water on dentin bond strength and hybridization of a one-bottle adhesive system. *Operative Dentistry* 2002;**27**:563–8.
48. Nakabayashi N, Kojima K, Masuhara E. The promotion of adhesion by the infiltration of monomers into tooth substrates. *Journal of Biomedical Material Research* 1982; **16**:265–73.
49. Olmez A, Oztos N, Basak F, Erdal S. Comparison of the resin-dentin interface in primary and permanent teeth. *The Journal of Clinical Pediatric Dentistry* 1998;**22**:293–8.