Effect of repair systems on dentin bonding performance

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The purpose of this study was to investigate the influence of phosphoric acid etching, metal primer or silane coupling agent application on dentin bonding performance of a 2-step self-etch adhesive system. Human dentin surfaces were prepared and divided into four groups depending on the pre-treatment method: no pretreatment (Clearfil SE Bond 2, CONTROL); 40% phosphoric acid (K-Etchant GEL, K); metal primer (Alloy Primer, AP); or silane coupling agent (Porcelain Bond Activator, PB). The specimens were sectioned into beams, separated into 2 subgroups ($n=20$): no thermocycling or thermocycled (TC), and subjected to a μ TBS test and an acid-base challenge for SEM observation. Statistically lower results were observed between K and AP groups, PB and CONTROL, and PB with/without TC ($p<0.05$). SEM images at the dentin-adhesive interface revealed that all groups produced an acid-base resistant zone (ABRZ), with a funnel-shaped erosion under the ABRZ for the K group.

Keywords: Repair systems, Alloy primer, Silane coupling agent, ABRZ, μ TBS

INTRODUCTION

The gradual shift towards minimally invasive dentistry¹⁾ has paved the way for the approach of “repair” instead of “replacement”²⁾ of restorations, leading to the development of repair systems³⁾. That is to say, partially compromised resin restorations are now more likely to be repaired rather than replaced.

Complete removal of a composite restoration still occurs in cases where the entirety of the restoration has been compromised. That being said, it is now common practice to replace only the unsatisfactory parts of a restoration by adding new resin composite to the existing restoration⁴⁾. This can be carried out both between similar and dissimilar commercially available resin composite materials. Therefore, there is now the demand for adhesive systems capable of producing a strong chemical bond between resin composites, metal alloys and ceramics. Nevertheless, the challenge of intraoral repair is to create a strong and durable bond between the involved substrates, thus allowing for improved marginal adaptation and longevity of the repaired restoration⁵⁾. It is believed that this could be achieved through an acid-base resistant zone (ABRZ)⁶⁾. The ABRZ is an area of fortified tooth substrate thought to increase the caries resistance of composite restorations by enveloping the HAp crystals in resin. However, the ABRZ formation is dependant on the adhesive system as

well as the pre-treatment agents.

Improving the bonding strength between an already present and a newly added composite has mainly been done by increasing surface roughness, therefore promoting micro-mechanical interlocking by air abrasion with aluminum oxide particles⁷⁾. Nevertheless, the use of a silane coupling agent in addition to the bonding agent has also proved to be beneficial in maintaining higher bond strength values⁸⁾, due to the ability of the silane to improve adhesion to resin composite by interacting with silica particles in the composite⁹⁾.

Despite the initial application of mechanical treatment for increasing bonding strength of resins to metal alloys, the introduction of metal primers to the dental market has shifted the focus to chemical adhesion. Most primers contain acidic monomers capable of adhering to both the metal and the tooth substrate¹⁰⁾. However, the additional step of repair agent application could lead to unwanted contamination of the tooth substrate and therefore to a chemical interaction with the dentin/enamel or the adhesive itself, thus compromising the tooth-adhesive interface.

Extensive research has been done in order to determine the influence of repair systems on bond strength to various substrates, yet it is still unclear how their contamination to dentin affects the bonding performance to dentin. Therefore, the aim of this study was to investigate to what degree the bonding strength and quality may be influenced by the contamination of a metal primer or silane coupling agent. The null

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hypotheses are that the use of (1) silane coupling agent or (2) metal primer does not negatively influence the bonding strength to dentin.

MATERIALS AND METHODS

Materials

A two-step self-etch adhesive system (Clearfil SE Bond 2, Kuraray Noritake Dental, Tokyo, Japan; SE2) was used in this study. SE2 is composed of a self-etching primer and a bonding agent, both of which contain the functional monomer, 10-methacryloyloxydecyl dihydrogen phosphate (10-MDP).

A repair kit (Clearfil Repair Kit, Kuraray Noritake Dental), which includes 40% phosphoric acid (K-etchant GEL), a metal primer (Alloy Primer) and a silane coupling agent (Porcelain Bond Activator), was used in combination with SE2. The repair kit is designed for repair of ceramic restorations with a resin composite where the restoration has been compromised by secondary caries, or fractured. However, in this study the repair kit was used to simulate dentin contamination

during the repair procedure due to technical errors by a clinician. The bonding protocols for dentin, metal alloy and ceramic/resin composite were utilized according to the manufacturer's original instructions listed in Table 1 with the addition of active agent application.

Twenty extracted caries-free human molars were collected in accordance with the approval of the Ethical Committee at Tokyo Medical and Dental University under protocol D2013-022-02. The teeth were cleaned and stored frozen until the experiment. The teeth were randomly assigned to four experimental groups: control, acid etching pre-treatment (K group), alloy primer pre-treatment (AP group), or silane bonding agent pre-treatment (PBA group). The protocol is illustrated in Fig. 1. For the control group, SE2 primer was actively applied to the dentin surface for 20 s and air-dried, followed by the application of the SE2 adhesive, which was also air-thinned then light cured for 10 s using a LED light-curing unit VALO (Ultradent, South Jordan, UT, USA) in high-power mode (1,400 mW/cm²). For the K group, K-etchant phosphoric acid GEL was actively applied for 10 s, rinsed with air-water spray, then

Table 1 Materials used in the study

Material	LOT number	Type	Content
Alloy Primer	BE0079	Primer	Acetone >90% 6-(4-vinylbenzyl-n-propyl) amino-1,3,5-triazine-2,4-dithione (VBATDT) 10-Methacryloyloxydecyl dihydrogen phosphate (MDP)
Porcelain Bond Activator	BA0034	Silane coupling agent	3-trimethoxysilylpropyl methacrylate 40–60% Hydrophobic aromatic dimethacrylate other
K-etchant GEL	6T0064	Etching agent	Phosphoric acid Water Colloidal Silica Dye
Clearfil SE Bond 2	8S0049	Primer	2-hydroxyethyl methacrylate (HEMA) 20–40% 10-Methacryloyloxydecyl dihydrogen phosphate (MDP) Hydrophilic aliphatic dimethacrylate dl-Camphorquinone, Accelerators, H ₂ O, Dyes
Clearfil SE Bond 2	8R0072	Bonding agent	bisphenol-A-diglycidyl methacrylate (Bis-GMA) 25–45% 2-hydroxyethyl methacrylate (HEMA) 20–40% 10-Methacryloyloxydecyl dihydrogen phosphate (MDP) Hydrophobic aliphatic dimethacrylate, Colloidal silica dl-Camphorquinone, initiators, accelerators
Clearfil AP-X (A2 shade)	5D0060	Composite resin	Bisphenol-A-diglycidyl methacrylate (Bis-GMA) <12% Triethyleneglycol dimethacrylate (TEGDMA) <5% Silanated Ba glass filler, Silanated Si filler, Silanated colloidal silica dl-Camphorquinone catalysts, accelerators, pigments, other
Clearfil Majesty FLOW (A2 shade)	AD0022	Flowable composite resin	triethyleneglycol dimethacrylate (TEGDMA) <7% Hydrophobic aromatic dimethacrylate Silanated barium glass filler, Silanated colloidal silica dl-Camphorquinone, Accelerators, Pigments

Fig. 1 Bonding protocols for the four tested groups. CONTROL group: 20 s active application of the priming agent, followed by 20 s active application of the bonding agent in the SE Bond 2 set (as per the manufacturer's instruction). K group: 10 s application of K-etchant GEL, 10 s irrigation with water and air-drying; application of SE Bond 2 as per the instruction manual. AP group: 5 s application of Alloy Primer; application of SE Bond 2 as per the instruction manual. PBA group: 20 s active application of a mix of 1:1 ratio of Porcelain Bond Activator and SE Bond 2 Primer, followed by 20 s active application of SE Bond 2 Bond.

air-dried. SE2 was applied as per the manufacturer's instructions. For contamination with a metal primer (AP group), Alloy Primer, was also actively applied to the dentin surface for 5 s before being blown off with air followed by application of the SE2 adhesive system. For contamination of the silane coupling agent (PBA group), a drop of Porcelain Bond Activator was mixed with a drop of SE BOND 2 Primer and then applied to the dentin surface for 20 s using a scrubbing technique (active application). After that the surface was air dried and SE BOND 2 bonding agent was scrubbed onto the dentin, air dried and light cured for 10 s.

Microtensile bond strength (μ TBS) test

Sample preparation is shown in Fig. 2. Human molars were cut perpendicularly to the tooth axis, using a

Fig. 2 Sample preparation for the μ TBS test: (1) cutting of a dentin disc, 5 mm in thickness; (2) standardized smear layer; (3) application of test materials, adhesive system and resin composite; (4) and (5) cutting of the samples into dentin-resin beams (1×1 mm) after 24 h water storage; (6) μ TBS test.

diamond saw (ISOMET, Buehler, Lake Bluff, IL, USA) under water cooling in order to expose mid-coronal dentin. The flat dentin surfaces were then ground with 600-grit SiC paper under constant water flow for 30 s to obtain a standardized smear layer. The collected teeth were randomly assigned to one of the four test groups (5 teeth per group) and application of the materials was carried out as described above (CONTROL, K, AP and PBA). After the surface treatments were carried out, a composite block of 4 mm thickness was created (2 increments of 2 mm thickness each) using a resin composite (Clearfil AP-X in shade A2, Kuraray Noritake Dental) and light cured for 40 s. The samples were then stored in distilled water for 24 h at 37°C. The bonded assemblies were subsequently cut into resin-dentin beams of approximately 1×1 mm and randomly assigned to two subgroups ($n=20$ beams per subgroup). The first subgroup was tested immediately after 24 h storage in water (24 h), while the second subgroup was subjected to 10,000 thermal cycles (TC) between 5°C and 55°C with dwell time of 30 s. μ TBS testing was performed using a universal testing machine (EZ-SX, Shimadzu, Kyoto, Japan) at a crosshead speed of 1 mm per min, the load at bond failure was recorded then converted to MPa. Following debonding, the failure mode was observed for each specimen using a scanning electron microscope (SEM) at a magnification of 100×. The failures were classified into one of the following categories; adhesive failure at the bonded interface with dentin, cohesive failure in dentin, cohesive failure in the adhesive resin, cohesive failure in resin composite, or mixed failure.

SEM examination of ABRZ

ABRZ sample preparation, followed the method previously described in the study by Inoue *et al.*¹¹⁾ (Fig. 3). Caries-free human molars were sectioned perpendicularly to the tooth axis to obtain dentin discs of 1 mm thickness using a diamond saw (ISOMET) under water cooling. The discs were ground with #600 SiC paper to form a standardized smear layer then divided into the same four groups as for the bond test. The materials were applied as per the methods used in the bond test. Afterwards, the discs of each group were bonded together using a flowable resin composite (Clearfil Majesty Flow, Kuraray Noritake Dental) to form dentin “sandwiches” (Fig. 1). The resin composite was light cured for 40 s and stored in distilled water at 37°C for 24 h. The bonded dentin discs were removed then cut perpendicularly to the plane of the interface at the center of the specimens and embedded in epoxy resin (EpoxiCure, Buehler). After hardening, the interface of the specimens was exposed with #600-grit SiC paper and subjected to an acid-base challenge with

a demineralizing solution of pH 4.5 (2.2 mmol/L CaCl_2 , 2.2 mmol/L NaH_2PO_4 , and 50 mmol/L CH_3COOH) for 90 min and deproteinized with 6% NaOCl in an ultrasonic bath for 20 min. The demineralizing solution was used to simulate an artificial caries environment. The specimens were rinsed with water for 3 min.

In an attempt to prevent wear during polishing, the surface of the specimen was bonded with SuperBond C&B (Sunmedical, Moriyama, Japan). Following this, the specimens were cut perpendicularly to the bonded interface and polished with SiC paper up to 1500-grit and finished with diamond pastes down 0.5 μm particle size. The samples were placed in a desiccator for 24 h and subjected to an Ar-ion etching beam (EIS-200ER, Elionix, Tokyo, Japan) at 1.5 mA/cm² density in order to bring forth a sharp relief of the dentin–resin interface. Finally, the specimens were gold sputter-coated and observed SEM (JSM-IT100, JEOL, Tokyo, Japan) at a magnification of 3,500 $\times$.

Statistical analysis

The results of the μTBS test were compiled and reviewed to determine whether a normal distribution existed, after this the data were subjected to an analysis of variance (two-way ANOVA) using Bonferroni correction with the confidence interval set at 95%. Statistical analysis was performed using Statistical software (SPSS ver. 22.0 for Windows, IBM, Chicago, IL, USA).

RESULTS

μTBS and failure mode

The mean results of the μTBS test were analyzed using two-way ANOVA, and displayed in Table 2. The analysis revealed that the μTBS values were significantly affected by the type of pre-treatment method used ($p < 0.0001$), as well as by the aging of the samples in the form of thermocycling ($p = 0.048$). The interaction between the two factors was also found to be significant ($p < 0.05$).

The results for the K group (phosphoric etching pre-treatment) showed stable results regardless of thermocycling. Similar values were obtained for the AP group both before and after thermocycling. The lowest bond strength was determined for the PBA group,

Fig. 3 Sample preparation for ABRZ observation: (1) and (2) cutting two dentin discs of 1 mm thickness; (3) preparation of dentin sandwiches in each group; (4) embedding the samples into epoxy resin; (5) acid-base challenge; (6) application of SuperBond as protective layer; (7) slicing of the samples into segments; (8) Ar-ion etching.

Table 2 Microtensile bond strengths to dentin contaminated with the different combination protocols for the repair system (Mean $\pm$ SD; MPa)

GROUP	pre-thermocycling	post-thermocycling
CONTROL	64.05 $\pm$ 8.33 ^A	61.26 $\pm$ 9.72 ^B
K	60.95 $\pm$ 8.12	59.61 $\pm$ 7.27 ^C
AP	58.14 $\pm$ 4.75	60.69 $\pm$ 10.31 ^D
PBA	55.41 $\pm$ 6.37 ^{Aa}	45.68 $\pm$ 12.28 ^{aBCD}

Number of specimens ($n=20$). Within the same row, the values with the same lower-case superscript letters are statistically different ($p < 0.05$). Within the same column, the values with the same upper-case superscript letters are statistically different ($p < 0.05$).

which was significantly lower ($p < 0.05$) compared to the CONTROL in the immediately tested specimens. After thermocycling, the PBA group was the only group to show significantly lower values compared with the non-thermocycled group. In addition, the PBA group showed the lowest mean value among the groups after thermocycling, as well as being significantly lower than the other three groups ($p < 0.05$).

The failure mode in all groups was mostly cohesive failure in the bonding layer/ dentin, or was mixed failure (Fig. 4). The largest percentage of cohesive failure in the bonding layer was noted in the CONTROL group both before and after thermocycling. Slightly more cohesive failures in dentin in K group were observed. An increase in adhesive failures was observed in the AP group after thermocycling.

ABRZ

Representative images of the ABRZ for each group are shown in Fig. 5. The interface of the ABRZ was brought into relief using an argon-ion etching beam and was subsequently observed using an SEM at $\times 3,500$ magnification. The outer lesion (OL) represents the demineralized dentin depth during the acid-base challenge and was consistently 10–15 μm thick. The hybrid layer (H) was only observable in the K group where phosphoric acid etching was used, its width ranged between 3 to 4 μm . Beneath the hybrid layer a line of the same density as the dentin layer, which can be identified as the ABRZ, was visible. However, the K group was the only group which displayed signs of a funnel-shaped erosion at the interface. The relative thickness of the ABRZ was comparatively similar among the groups, with the exception of PBA, where it was noticeably thinner.

Fig. 5 Scanning electron micrographs of the ABRZ in the four test groups after an acid-base challenge.

A: CONTROL group, no pre-treatment (SE2). B: K group, phosphoric acid pre-treatment (K-etchant GEL). C: AP group, metal primer pre-treatment (Alloy Primer). D: PBA group, silane coupler pre-treatment (Porcelain Bond Activator). (R) resin composite layer, (B) bonding layer, (H) hybrid layer, (D) dentin layer, (OL) outer lesion; the arrows indicate the ABRZ, and the lightning bolt indicates an area of erosion. CONTROL group: ABRZ is visible directly beneath the bonding layer, the hybrid layer is located in between, but is not discernible at this magnification, slight slope formation can be observed at the interface. K group: visible ABRZ beneath a thick hybrid layer with signs of erosion at the margin, as well as funnel-shaped erosion at the interface. AP group: observable ABRZ, no slope formation or funnel-shaped erosion was observed. PBA group: very thin ABRZ formation, no slope formation or funnel-shaped erosion can be observed.

Fig. 4 Graphic expression of the failure mode after μTBS test (percentage).

DISCUSSION

The two-step self-etch adhesive system, Clearfil SE Bond 2 (SE2), is regarded as one of the gold standards for dentin bonding. MDP is included in both the self-etching primer and the bonding agent, which is proven to play an important role in etching, monomer penetration and chemical bonding to hydroxyapatite (HAp), rendering the apatite crystals acid-resistant¹². The ABRZ which was first reported by Tsuchiya *et al.*⁶ is also based on this concept.

The repair kit used in this study comprised a bottle of 40% phosphoric acid (K-etchant GEL), metal primer (Alloy Primer) and silane coupler (Porcelain Bond Activator), respectively. To achieve success in restoration repair, a bonding protocol for each substrate (*i.e.* metal, ceramic and/or resin composite) must be properly carried out. Nevertheless, technical errors may take place in the intraoral environment during the bonding procedure. Therefore, the effect of the repair protocol could potentially affect the bonding performance to dentin which was evaluated in this study.

In the current study, etching with phosphoric acid did not adversely affect the μ TBS results after thermocycling. That being said, the fracture mode analysis indicated that the fracture patterns in the K group were different from those of the control, suggesting that there was indeed an adverse effect to dentin bonding. The SEM observation after an acid-base challenge demonstrated a hybrid layer of 3 to 4 μ m in thickness due to the aggressive nature of the phosphoric acid etching. The hybrid layer thickness is in direct correlation to the demineralization depth, which is a function of the etch duration and acid concentration¹³. Thus, the longer the etching time, the deeper the demineralization zone. However, a reduced etching time leads to a shallower demineralization depth, which naturally has a reduced amount of exposed collagen which should allow better resin infiltration into the collagen network.

In addition to a shortened etching time, by applying the scrubbing technique (active application) not only is the primer and bonding agent continuously replenished onto to the tooth surface, it encourages deeper resin infiltration into the dentin. The active application of the primer ensures that the HEMA concentration at any given site is also constantly replenished. HEMA is a hydrophilic monomer which not only serves to keep the components of the primer and bonding agents in a homogeneous state in their respective bottles, but it is also able to coat the collagen fibrils and aid in the re-expansion of the collagen fibril network during its application (re-wetting capacity), thus allowing for increased permeation of resin monomers into the demineralized dentin surface^{14–16}. The re-expansion of the collagen network in conjunction with continuous scrubbing makes it more likely that the adhesive will reach the partially demineralized HAp crystals at the base of the demineralized zone to create an ABRZ. Incidentally, the ABRZ was observed beneath the hybrid layer (Fig. 5B), despite the previous belief that the ABRZ

could not be detected in etch-and-rinse systems due to the aggressive nature of phosphoric acid, which dissolves the mineral component of the dentin substrate and leaves no remaining apatite crystals at the etch frontier that can react with the infiltrating monomers¹¹.

The ABRZ-like structure (Fig. 5B) was characterized as thin, with marginal erosion at the top of the interface. A funnel-shaped erosion was also observed beneath. Nurrohman *et al.*¹⁷ reported that the aggressive etching of phosphoric acid leaves the HAp crystals at the bottom of the demineralized zone in a completely or partially damaged state, in an “electron-density gradient within the hybrid layer”. Despite the formation of ABRZ beneath the hybrid layer, in this case its characteristics were possibly different compared to a traditional ABRZ formed through the use of self-etch adhesives alone (*i.e.* without phosphoric acid etching pre-treatment). Firstly, the existence of a funnel-shaped erosion beneath the hybrid layer and the ABRZ confirms that even with a shorter etching time and application of the scrubbing technique, the infiltration of the resin to the very bottom of the demineralization zone might still be incomplete. Secondly, there are signs of marginal erosion of the ABRZ at the top section of the interface, which could mean either that the resin could not fully reach the underlying HAp crystals and subsequently chemically interact with them to form an ABRZ, or an ABRZ was achieved on a very superficial level rendering it suboptimal and probably prone to dissolution when exposed to acid/base process¹⁸.

Over time the hybrid layer tends to degrade, which is especially true for etch-and-rinse systems¹⁹. However, in this case, even after aging the samples through thermocycling, the bond strength of the acid treated specimen did not significantly decrease. For example, De Munck *et al.*²⁰ have found that after 4 years of water storage the bond strength of samples treated with the 3-step etch-and-rinse system, Optibond FL (Kerr, Orange, CA, USA), did not change regardless of whether the specimens were stored intact or as pre-cut sticks. Granted, it is impossible to compare two different adhesive systems both in terms of application and functional monomers. Nevertheless, it proves that durable adhesion to dentin could also be achieved using phosphoric etching and those results were repeated. In this case, it could be attributed to the scrubbing technique (active application) as well as the effectiveness of the functional monomer found in Clearfil SE Bond 2 (MDP).

The samples pre-treated with Alloy Primer showed a stable bond strength which was comparable to the control group. However, the fracture mode analysis indicated that the fracture patterns in the AP group were different from those of the control, suggesting that there was indeed some effect to the dentin adhesion. It has been proven that the use of Alloy Primer is beneficial for adhesion of resin cement to metal alloys^{21–23} when applied to a metal surface. However, the close proximity of the tooth substrate and the metal restoration subjected to repair would almost certainly lead to contamination

of the dentin with the alloy primer.

The alloy primer contains two different types of functional monomers: 6-(4-vinylbenzyl-n-propyl) amino-1,3,5-triazine-2,4-dithione (VBATDT) and MDP. VBATDT serves to chemically bond resin to metal alloys, while MDP achieves high bonding affinity to the hydroxyapatite of enamel and dentin, as well as to metal oxides of non-precious metal alloys. The fact that MDP is included in the content of the Alloy Primer might be the reason behind the stable bonding in this case. De Souza *et al.*²⁴⁾ used EDS analysis directly after Alloy Primer application, which confirmed a homogeneous distribution of carbon (MDP and VBATDT) and sulfur (VBATDT) throughout the treated surface. The VBATDT does not bond well to the tooth substrate, which could be the reason behind the increase in adhesive failure after thermocycling. It could be speculated that the VBATDT molecules located at the interface could become possible weak spots when excessive stress is applied (in this case, thermal stress). Additionally, alloy primer contains acetone as an organic solvent. Acetone has been shown to have water-chasing abilities and could help reduce remaining water on the dentin surface as well as increase the surface wettability and thus enhance monomer penetration into the underlying demineralized dentin. The comparable bond strength values (Table 2) and the formation of an ABRZ (Fig. 5C) of similar characteristics to those of the control group prove that contamination with Alloy Primer had an overall insignificant effect on the adhesion.

The only tested contaminant to produce substantial reduction in bond strength results in this study was the silane coupling agent. Previously, silane coupling agents have been shown to improve bond strength of composite to both resin and ceramics due to its γ -MPTS content^{25,26)}. During the process of composite repair, the reactive silanol groups in the silane form siloxane bonds with the hydroxyl groups of the glass fillers in the resin²⁶⁾, as well as create a chemi- and physisorbed silane layer on the surface of the filler particles²⁷⁾. Still, in order to activate the silane coupler to form the silanol groups, a low pH and hydrolyzing alkoxy groups are necessary. For the Porcelain Bond Activator this is achieved through mixing it with a drop of the priming agent. The functional monomer (MDP) then serves as an activator for the silane coupler. Furthermore, the silane coupling agent contains a high percentage of solvent, which dilutes the priming agents it is mixed with for its chemical activation. The mixture then contains equal parts of undiluted primer and silane coupler, which logically lowers the viscosity and undermines the self-etching ability of the primer due to lower MDP concentration²⁸⁾. Consequently, the adhesive layer created is also thinner compared to the one achieved through application of the usual 2-step self-etch adhesive protocol. This might also be the reason behind the visibly thinner ABRZ in the case where Porcelain Bond Activator was used (Fig. 5D).

A previous study by Chen *et al.*²⁹⁾ reported that application of a silane coupler did not affect bond strength

to dentin. However, the current results indicated that the silanization group significantly lowered the bond strength values to dentin (Table 2). The SEM observation of the interface (Fig. 5D) demonstrated a thinner hybrid layer and ABRZ compared to that of the control group, probably due to dilution of the adhesive. The low MDP concentration in addition to the fact that the silanol group does not chemically bond to dentin might then lead to more shallow demineralization and a non-uniformly etched dentin surface. This could be the reason for the lower bond strength³⁰⁾ attributed to a hybrid layer achieved through the mixture of the silane coupling agent and primer which also explains the significantly lower bond strength for the PBA group.

The current results proved that accidental contamination of the dentin during the repair protocols could lower the bond strength due to a compromise of the hybrid layer quality. Therefore, clinically it is advised to avoid these technical errors which could lead to contamination of the dentin, as well as to ensure that the step-by-step application protocol of the repair systems is followed as per the instruction manual in order to avoid much of the adverse effects observed in the study.

CONCLUSION

Within the limitations of this study, the effect of dentin contamination was simulated using agents for repair of metal and ceramic/composite structures. The results showed little adverse effects when phosphoric acid and metal primer were used. However, the silane coupling agent had a negative impact on the quality and stability of the bonding interface.

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