Influence of Cavity Configuration on Microleakage around Class V Restorations Bonded with Seven Self-Etching Adhesives

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ABSTRACT

Purpose: The purpose of this study was to evaluate microleakage around Class V resin composite restorations with different cavity configurations, bonded with one of seven self-etching materials or with an adhesive using the total-etch technique.

Materials and Methods: Ninety-six human molars and premolars were randomly assigned to eight groups and bonded with one of seven self-etching adhesives—Prompt-L-Pop™ (3M ESPE, St. Paul, MN, USA), Adper Prompt-L-Pop™ (3M ESPE), Clearfil SE Bond® (Kuraray Medical, Okayama, Japan), Prime & Bond® NT/NRC (Dentsply DeTrey, Konstanz, Germany), Xeno® III (Dentsply DeTrey), One-Up Bond® (Tokuyama Dental, Tokuyama, Japan), AdheSE® (Ivoclar Vivadent, Schaan, Liechtenstein)—or with Prime & Bond® NT (Dentsply DeTrey) using a separate total-etch technique. Cavities were cut in both the lingual and buccal surfaces and were approximately 3 mm mesiodistally, 1.5 mm deep, and 2.0 mm occlusogingivally. Selected at random, box-shaped cavities were cut on one side and V-shaped cavities were cut on the contralateral side. After bonding, the cavities were incrementally filled with a microhybrid composite (Tetric Ceram®, Ivoclar Vivadent), cured, and immediately polished with Sof-Lex™ (3M ESPE) disks. The teeth were thermocycled, and the specimens were examined for microleakage using Procion Brilliant Red® (ICI, Slough, UK) as a marker.

Results: Comparisons of both gingival and enamel margins within each of the groups showed no significant difference owing to configuration factor (C-factor; $p > .5$ in all cases, calculated with Kruskal-Wallis nonparametric analysis of variance [ANOVA]) and Dunn's multiple comparison test). All groups showed microleakage at the gingival margins irrespective of C-factor or bonding agent (box-shaped cavities, $p = .8862$; V-shaped cavities, $p = .9623$; using the ANOVA). Microleakage was not observed at all enamel margins regardless of C-factor or bonding agent, and there were no significant differences between the groups (box-shaped cavities, $p = .9869$; V-shaped cavities, $p = .9550$; using the Kruskal-Wallis nonparametric ANOVA).

CLINICAL SIGNIFICANCE

Cavity configuration did not affect microleakage around a hybrid composite bonded with one of seven self-etching agents or an agent involving a total-etch technique. The self-etching agents used in this study were as reliable as the agent that required a separate acid-etching step.

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The most significant factor in determining resistance to recurrent caries, postoperative sensitivity, marginal staining, and pulpal damage is the ability of a restorative material/adhesive to seal the restorative interface with the adjacent tooth substrate.[1] Gap formation and the concomitant leakage of bacterial fluids, molecules, and ions are brought about by dimensional changes such as polymerization contraction,[2] thermal expansion, and incomplete hygroscopic absorption.[3]

Recent developments in dentin adhesion include the introduction of self-etching primers and adhesives that do not require rinsing. Primer and adhesive may be applied separately (Prime & Bond® NT/NRC, Dentsply DeTrey, Konstanz, Germany; Clearfil SE Bond®, Kuraray Medical, Okayama, Japan; AdheSE®, Ivoclar Vivadent, Schaan, Liechtenstein) or mixed together (Prompt-L-Pop™, 3M ESPE, St. Paul, MN, USA; Adper Prompt-L-Pop™, 3M ESPE; Xeno® lll, Dentsply DeTrey; One-Up Bond®, Tokuyama Dental, Tokuyama, Japan).

An estimated shear bond strength of 17 to 20 MPa is the critical value needed to withstand the stresses induced by polymerization contraction of composite materials.[4] Although using a 35 to 40% phosphoric acid gel when bonding to enamel is reported to be highly successful, recent reports suggest that early self-etching agents are less reliable when used on enamel without a separate acid-etching step.[5] Bonding to dentin has proven even more difficult and less predictable owing to its hydrophilic nature and histologic structure. Omission of the conventional etching step may result in the absence of the characteristic demineralization patterns of both enamel and dentin. This has been postulated to be a reason why self-etching agents have been reported to have lower bond strengths to enamel and increased microleakage compared with those obtained when a cavity is etched with phosphoric acid.[5,6]

In self-etching systems, monomer must diffuse through an altered smear layer before causing demineralization of the underlying dentin necessary for the formation of a hybrid layer, which is often cited as mandatory to produce a marginal seal.[7] However, these views have been challenged by other studies that suggest that neither the ideal etch pattern in enamel nor the classic hybrid layer with tag formation obtained after phosphoric acid etching is essential for high bond strengths,[8,9] and that the application methods and cavity design may have more significant effects on bond strengths.[10,11]

Polymerization contraction of composite materials remains the major factor in marginal gap formation. Composite strain is hindered by the confinement of material bonded to the cavity walls, and this results in stress that can rupture bonding to the tooth substrate.[12] The magnitude of the contraction stress is related to the compliance of the composite material, its degree of conversion and conversion rate, the adjacent tooth structure, and the configuration factor (C-factor) of the preparation. Several articles have recently highlighted the deleterious influence of high C-factor on bond strengths of composite specimens bonded with conventional one-bottle systems and self-etching adhesives.[13–15]

The objective of this study was to evaluate microleakage around Class V resin composite restorations in extracted human teeth when bonded with one of seven self-etching agents or a non–self-etching system as a control, and with differing C-factors. It is felt by many that stress relief should be accomplished by lowering the C-factor of the Class V cavities, and, theoretically, this should lead to a reduction in microleakage. The null hypothesis was that the lowering of C-factor in Class V cavities filled with a hybrid composite would not lead to a reduction in microleakage.

MATERIALS AND METHODS

Ninety-six intact permanent molars or premolar teeth (patient age range was 14–23 yr), extracted during the provision of routine orthodontic treatment and stored for < 3 months in 0.2% thymol solution, were selected and cleaned. Class V cavities were prepared at the cemento-enamel junction (CEJ) on both the buccal and lingual surfaces of each tooth. One half of each cavity was in enamel, occlusal to the CEJ; the other half of the cavity was in cementum/dentin, apical to the CEJ.

The cavities were made with an ISO 010-fissure diamond bur (Hi-Di®, Weybridge, Surrey, UK) in a water-cooled high-speed handpiece and were approximately 3 mm mesiodistally, 1.5 mm deep, and 2 mm occlusogingivally. On one side, selected at random, box-shaped cavities were cut; V-shaped cavities were cut on the opposite side. The base of the box-shaped cavities was approximately 2 mm. The C-factor (ratio of bonded surfaces to unbonded surfaces) for these cavities was therefore 5. The V-shaped cavities had, as the description suggests, no cavity floor, and their C-factor was 2. All preparations were without bevels, and each tooth served as its own control.

Specimens were then randomly assigned to one of eight groups ($n = 12$) and bonded using one of the self-etching dentin bonding agents or the single-bottle system using a total-etch technique with 36% phosphoric acid gel. The adhesives used in the study are listed below and were used strictly according to the manufacturers' instructions as detailed. All adhesives were cured using a light-curing unit at not less than 400 $mWcm^{-2}$ for 10 seconds.

- Group 1: Prompt-L-Pop (batch no. 127658). The mixed adhesive was applied to the prepared teeth, and the solution was rubbed on using moderate finger pressure for 15 seconds and was then dried to a thin film with a gentle stream of air. If the surface was not smooth and glossy after this procedure, an additional coat of adhesive was applied, dried, and light cured.
- Group 2: Adper Prompt-L-Pop (batch no. 138205). The mixed adhesive was applied to the prepared cavity and rubbed into the cavity walls with moderate finger pressure for 15 seconds. The adhesive was dried to a thin film with a gentle stream of air. If the surface was not smooth and glossy after this procedure, a second coat of adhesive was applied, dried, and light cured.
- Group 3: Clearfil SE Bond (batch no. 41225). The primer solution was applied to the entire cavity wall with a disposable applicator and left in place for 20 seconds, after which a mild stream of air was used to effect the evaporation of the volatile ingredients. Immediately after the bond solution was applied, it was made as uniform as possible with a gentle air stream and then light cured.
- Group 4: Prime & Bond NT/NRC (batch no. 9709000910). NRC was applied to the enamel and dentin and left without rinsing for 20 seconds. Excess NRC was gently removed using an air syringe. Immediately afterwards, an ample amount of NT was applied to the cavity and left undisturbed for 20 to 30 seconds. The solvent was removed using an air syringe, and the adhesive was light cured.
- Group 5: Xeno III (batch no. 0212000279). One drop of liquids A and B was dispensed into a dappen dish and mixed with the applicator tip. The mixed adhesive was applied to the prepared cavity, left undisturbed for 20 seconds, and spread uniformly with light air pressure for at least 2 seconds until there was no more flow. Subsequently the adhesive was light cured.
- Group 6: One-Up Bond (batch no. X4855Y2). Bonding agents A and B were mixed until the liquid turned homogeneously pink. The mixed bonding agent was then applied to the cavity surface with a disposable applicator, left for at least 20 seconds, and cured with a curing light held about 2 mm from the cavity surface.
- Group 7: AdheSE (batch no. RBJ 182/3). AdheSE primer was applied to the prepared cavity for 15 seconds and then brushed into the surface for an additional 15 seconds. It was then dispersed with a strong stream of air. AdheSE bond was then applied and dispersed with a very weak stream of air and light cured.
- Group 8: Prime & Bond NT (batch no. 970900010). Conditioner 36 gel (36% phosphoric acid) was applied to the cavity surfaces and left for at least 15 seconds on the preparation surfaces, after which it was removed using water spray for at least 15 seconds. Excess water was removed from the rinsed cavity with a gentle stream of air, leaving the surface moist and taking care not to desiccate the dentin. An ample amount of Prime & Bond NT was then

applied to the tooth surfaces and left undisturbed for 20 seconds. Solvent was removed with air gently blown from a dental syringe for at least 5 seconds. The adhesive was then light cured.

After the bonding procedure, a resin composite restoration was immediately placed using a microhybrid composite, Tetric Ceram® (Ivoclar Vivadent). The cavities were filled incrementally, first occlusally and then gingivally, and finished flush with the contour of the cavity. Each increment was cured for 20 seconds. Bonding agents and the composite restorations were cured with a Prismetics® Lite 2 (Dentsply DeTrey) light-curing unit held in contact with the surface of the material and separated by only an acetate matrix strip. The intensity of the light was monitored with a CureRite® (Dentsply/Caulk, Milford, DE, USA) light meter and was always in excess of 400 $mWcm^{-2}$.

Immediately after curing, the composite surface was polished dry with a series of Sof-Lex™ disks (3M ESPE), finishing with a fine grit. The root apices were sealed with acrylic resin, and the teeth were covered with two layers of nail varnish, except in the area of the restoration and at a l.0 mm border of tooth surrounding each cavity.

The specimens were stored in distilled water at 37°C for 24 hours prior to undergoing thermocycling.[16] The specimens were thermocycled 5,000 times between water baths held at 5°C and 55°C for 10 seconds at each temperature. After thermocycling, the specimens were immersed in a 5% solution of Procion Brilliant Red® (ICI, Slough, UK), buffered to a pH of 7 at 37°C for 24 hours, and rinsed for 15 minutes with distilled water.

The roots of the teeth were cut from the crown, which was then sectioned along the mesiodistal plane using a slow-speed saw (Isomet®, Buehler Ltd., Lake Bluff, IL, USA). Two buccolingual cuts were made through each restoration approximately 0.5 mm from the mesial and distal borders of the preparations. These cuts were at right angles to the mesiodistal plane and created four surfaces along which dye penetration could be measured. The extent of microleakage (penetration of Procion Brilliant Red) was evaluated for each section under ×10 magnification using an ocular microscope. For statistical analysis each specimen was given the highest score obtained from any of the four surfaces examined. The criteria used to score the extent of leakage around each specimen are shown in Figure 1.

To determine the significant differences between the groups, the data were analyzed using the Kruskal-Wallis nonparametric analysis of variance (ANOVA) test, corrected for ties. Intergroup comparisons were made using Dunn's multiple comparison test (95% significance levels).

RESULTS

The microleakage scores at both the gingival and enamel margins for the seven self-etching materials and the controls are shown in Tables 1 and 2. A comparison of box-shaped (C-factor 5) versus V-shaped (C-factor 2) cavities for each of groups 1 to 8 showed no significant differences in microleakage for gingival margins ($p > .5$ in every case using Dunn's multiple comparison test) and for enamel margins ($p > .05$ in every case using Dunn's multiple comparison test). Therefore, the null hypothesis that lowering the C-factor would not bring about a reduction in microleakage is upheld.

All gingival margins leaked in both the box- and V-shaped cavities

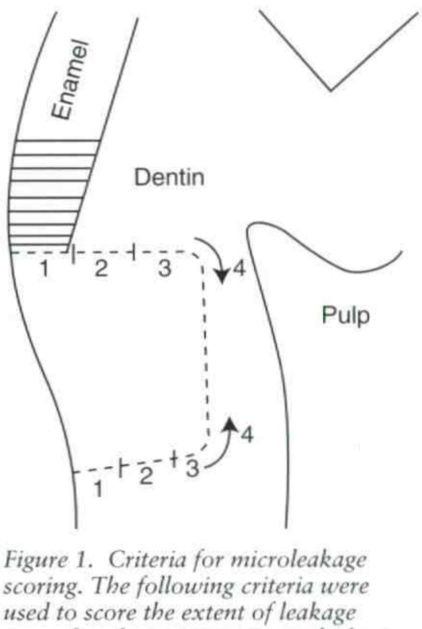

Figure 1. Criteria for microleakage scoring. The following criteria were used to score the extent of leakage around each specimen: 0 = no leakage; 1 = dye penetration up to one-third of cavity depth; 2 = dye penetration up to two-thirds of cavity depth; 3 = dye penetration to full cavity depth; 4 = dye penetration onto the axial wall of the cavity.

TABLE 1. GINGIVAL MARGINS: MICROLEAKAGE SCORES.*

Adhesive	Cavity Shape	Microleakage Scores 0	1	2	3	4	Median
Prompt-L-Pop	Box	0	3	4	4	1	3.0
	V	0	4	4	4	0	2.0
Adper Prompt-L-Pop	Box	0	3	3	6	0	3.0
	V	0	3	5	4	0	2.0
Clearfil SE	Box	0	2	4	5	1	2.0
	V	0	5	5	1	1	2.0
Prime & Bond NT/NRC	Box	0	3	5	2	2	2.0
	V	0	5	5	2	0	2.0
Xeno III	Box	0	3	6	3	0	2.0
	V	0	3	7	2	0	2.0
One-Up Bond	Box	0	3	6	3	0	2.0
	V	0	5	5	2	0	2.0
AdheSE	Box	0	4	5	3	0	2.0
	V	0	5	5	2	0	2.0
Prime & Bond NT	Box	0	4	5	1	2	2.0
	V	0	4	4	4	0	2.0

*Sample size = 12.

TABLE 2. ENAMEL MARGINS: MICROLEAKAGE SCORES.*

Adhesive	Cavity Shape	Microleakage Scores 0	1	2	3	4	Median
Prompt-L-Pop	Box	3	4	4	1	0	1.0
	V	2	4	6	0	0	1.5
Adper Prompt-L-Pop	Box	3	4	4	1	0	1.0
	V	3	6	2	1	0	1.0
Clearfil SE	Box	5	3	2	2	0	1.0
	V	4	4	2	1	1	1.0
Prime & Bond NT/NRC	Box	4	4	4	0	0	1.0
	V	4	4	2	2	0	1.0
Xeno III	Box	4	4	4	0	0	1.0
	V	3	6	2	1	0	1.0
One-Up Bond	Box	4	5	2	1	0	1.0
	V	4	5	2	1	0	1.0
AdheSE	Box	5	3	4	0	0	1.0
	V	4	4	4	0	0	1.0
Prime & Bond NT	Box	4	3	5	0	0	1.0
	V	5	4	2	1	0	1.0

*Sample size = 12.

when bonded with a self-etching agent applied as two separate solutions, a self-etching agent applied as one mixed solution, or the conventional one-bottle agent using a total-etch technique with 36% phosphoric acid. Irrespective of the adhesive used, there were no significant differences in microleakage at the gingival margins in box-shaped cavities ($p = .8862$ using the Kruskal-Wallis nonparametric ANOVA) and V-shaped cavities ($p = .9623$ using the Kruskal-Wallis nonparametric ANOVA).

Microleakage did not occur at all enamel margins in box- and V-shaped cavities when bonded either with a self-etching adhesive applied as two separate solutions, a self-etching adhesive applied as one mixed solution, or the conventional one-bottle adhesive using a total-etch technique with 36% phosphoric acid. Regardless of the adhesive used, there were no significant differences in microleakage at the enamel margins in box-shaped cavities ($p = .9869$ using the Kruskal-Wallis nonparametric ANOVA) and V-shaped cavities ($p = .9550$ using the Kruskal-Wallis nonparametric ANOVA).

DISCUSSION

The present results show that, regardless of the C-factors used, the newer self-etching agents, both those applied as an all-in-one premixed solution and those in which the primer and bonding agents are applied separately, are not significantly worse at preventing microleakage around a hybrid composite than is a conventional technique using a separate etching step.

The recommended protocol for the assessment of microleakage is to prepare control Class V cavities with butt joints in both enamel and dentin.[16] Dentin bonding is fraught with biologic, clinical, and methodological variables,[17] which it is important to control when conducting microleakage tests. Stress arising from polymerization contraction of the composite remains the critical issue; in order of importance the factors involved in shrinkage stress are cavity C-factor, cavity size, the application technique for placement of the composite, the intensity and position of the curing light, and the properties of the composite (eg, modulus of elasticity, volumetric shrinkage).[18] In the present study attempts were made to keep these variables constant whenever possible. Cavities were prepared to a standard size and varied only with respect to C-factor.

The use of one composite in the current study and the post-restoration storage in distilled water at 37°C reduced the variables associated with the resultant stress owing to polymerization contraction and water sorption. The relationship of cavity size and shape to stress are not fully known, but the literature seems to suggest that C-factor is the main issue.[2,19]

Microleakage can therefore be considered a function of the cavity C-factor and the ability of the associated bonding material to counteract the stress of polymerization contraction. In the present study microleakage around both enamel and dentin/cementum margins was not significantly affected by an increase in C-factor, as was predicted. Nor was there a significant difference in microleakage that occurred with the bonding agent using a separate acid-etch stage and any of the self-etching materials. These dynamics suggest that, in the present study, associated biologic factors such as the status of enamel and dentin substrate were more influential in marginal microleakage than were the agents used.

Enamel is a hypermineralized substrate with prism orientation varying according to the anatomic location. Optimal adhesion has been shown to occur after acid etching with phosphoric acid when the enamel rods were perpendicular to the cavity surface.[20] For this reason, beveling of enamel margins has been considered mandatory; however, recent studies have shown that enamel beveling does not significantly improve microleakage around Class V cavities when either a separate etch technique or self-etching agents are used.[21] Recent work has confirmed the importance of enamel prism orientation on bond strengths between composite restorations and enamel.[22] In Class V cavities whose enamel margins are about 1.00 mm occlusal to the CEJ, the orientation and organization of enamel rods do not aid the formation of a strong bond,[23] and their contribution to adhesion is insignificant.[6,24]

Omission of the conventional etching step with phosphoric acid gel may result in the absence of the characteristic demineralization patterns in enamel; this has been postulated as a reason why self-etching agents have been reported to have lower bond strengths to enamel compared with those obtained when the enamel is first etched with phosphoric acid.[4] However, these views have been challenged by other studies that suggest that the ideal etch pattern in enamel is not essential for high bond strengths[8] and that the application methods of the system may have more significance in this respect.[9,10]

Gingival (dentin/cementum) margins exhibited more severe microleakage than did occlusal (enamel) margins, which is in agreement with the general findings in the literature.[25–28] The quality of bond to dentin and the associated microleakage depend on a number of variables, and differences in substrate are as important as those discussed for enamel.

Dentin demineralization is related to the type of dentin, type of acid, tubular direction, and density.[29–32] Because the formation of a hybrid layer is considered mandatory for obtaining a lasting marginal seal,[29,32,33] the direction of dentinal tubules is of considerable importance. In Class V cavities, located as they are in this study at approximately 1 mm from the CEJ, dentinal tubules are oriented parallel to the cervical wall[34]; scanning electron microscopic studies have confirmed this orientation and have shown that a classic hybrid layer formation is virtually absent.[27] This absence is an important cause of leakage,[35] and it is tentatively concluded that until a no-shrinkage material is produced, polymerization shrinkage stress and the consequences of dental substrate microanatomy are the limiting factors associated with marginal microleakage.

There is, in the present study, an apparent increase in enamel margin microleakage compared with previous reports. This could be due to a decrease in bond strengths because of the reduced depth of etch, but recent studies have questioned this concept.[7] In the present study thermocycling was for 5,000 cycles, 10 times more than in some previous studies,[26–28,36] and may account for an increased thermal stress and a concomitant associated microleakage. Gale and Darvell reported that there is no standard protocol for thermocycling, specifically for the number of cycles and the temperature and liquids used within the thermocycling baths,[37] and we again call for a standard cyclic regimen to be adopted universally to facilitate comparisons of future reports.

The fluorescent chloro-*S* trianizyl dyes (Procion dyes) covalently bond to H-active functional groups in dentin and have been proved to be effective in detecting gap widths and microleakage.[38,39] The molecular mass of Procion Red is approximately 1,000.00 and, in size, is several orders of magnitude < 2 µm, the approximate size of most oral bacteria.[40] Its molecular mass allows diffusion along clinically relevant marginal gaps, where it binds to the collagen of the dentin matrix. Its homogeneous color intensity makes it readily discernible from the substrate.

Considerable debate has centered on the clinical relevance of in vitro microleakage investigations. Although Ferrari and colleagues consider that in vivo and in vitro tests give similar results,[41] Barnes and colleagues have reported that in vitro studies are more prone to high leakage scores,[42] and Abdalla and Davidson consider in vitro studies to be less sensitive to microleakage.[43]

Dentin bonding agents remain on the market for relatively brief time periods before manufacturers market "improved" versions; therefore, a rapid evaluation method is required. It is accepted that in vitro microleakage tests should be viewed to indicate no more than a theoretic level of maximum leakage.[44] The current series of investigations using in vitro testing was conducted with this proviso in mind.

CONCLUSION

Cavity configuration did not affect microleakage around a hybrid composite bonded with one of seven self-etching agents or with an agent using a total-etch technique. The self-etching agents used in this study were as reliable as the agent using a separate acid-etching step. The microleakage results obtained in the present study indicate that bonding to tooth substrate in the area of the CEJ remains problematic for clinicians.

DISCLOSURE

The authors have no financial interest in any of the companies whose products are mentioned in this article.

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