The effects of filling techniques and a low-viscosity composite liner on bond strength to class II cavities

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KEYWORDS
Dentin bonding; Microtensile testing; Low-viscosity composite; C-factor

Summary
Objective. The aim of this study was to test the hypothesis that the effects of filling technique, cavity configuration and use of a low-viscosity composite liner influence resin bond strength to the dentin of class II cavities gingival floor; and analyze the failure modes of fractured specimens.

Methods. Standardized class II cavities were prepared in the proximal surfaces of freshly extracted third molars, which were randomly assigned to 10 experimental groups. All prepared surfaces were acid-etched, bonded with Single Bond adhesive system and restored with TPH composite, according to each technique: G1 and G2-horizontal layering, G3 and G4-faciolingual layering, G5 and G6-oblique layering, G7 and G8-bulk filling, G9 and G10-control (flat dentin surfaces). Groups were tested, with or without a low-viscosity composite liner (Tetric Flow Chroma). After storage in water for 24 h, teeth were vertically serially sectioned to yield a series of 0.8 mm thick slabs. Each slab was trimmed into an hourglass shape of approximately 0.8 mm² area at the gingival resin–dentin interface. Specimens were tested in tension at 0.5 mm/min until failure. Fractured specimens were analyzed in an SEM to determine the failure modes.

Results. No significant difference was found between groups restored with and without a low-viscosity composite liner (p > 0.05). Among filling techniques, the bulk filling groups presented the lowest bond strength values (p < 0.05), while incremental filling groups did not differ from control (flat dentin surfaces). Failure modes varied significantly among groups restored with and without the low-viscosity composite liner.

Significance. Bond strengths were not improved when a low-viscosity composite liner was applied, but it remarkably influenced the failure modes. Incremental techniques improved bond strength.

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Introduction
The conditions in which bond tests are normally performed are far removed from real clinical
conditions. While the use of abrasive papers is convenient in the laboratory, clinically, dentin is never prepared with abrasive paper. Moreover, flat dentin surfaces are not subjected to the same polymerization contraction stresses faced on three-dimensional cavities. The cavity configuration factor, C-factor, is the ratio of the restorations bonded to unbonded surfaces area. Only a few studies have assessed bond strength to complex cavity walls. However, tests realized under clinically relevant conditions might better predict restorations behavior in the oral environment.

Quality bonding to dentin depends on proper infiltration of the adhesive system into demineralized dentin matrix in order to create a micromechanical interlocking between collagen and adhesive resin, and form a hybrid layer. Several studies have shown that adhesion is affected by differences in dentin location and changes in the different areas of a tooth. With the introduction of the microtensile test by Sano et al., the determination of specimens bond strengths using small surface areas for bonding has been possible. This test method has facilitated the study of regional bond strengths, providing more information regarding adhesion within clinically relevant cavity preparations.

Low-viscosity or flowable composites have been advised for deep parts of class II cavities under hybrid or packable composites to act as a stress-absorbing layer between the hybrid layer, the adhesive resin and the shrinkage of the resin composite, by partially relieving the polymerization contraction stress. Their low moduli of elasticity and increased flow capacity might provide more contraction stress relaxation, and could reduce the frequency of marginal microleakage and possible debonding.

Restoration placement techniques are widely recognized as a major factor in the modification of shrinkage stresses. Thus, the purpose of this study was to evaluate the effects of four different filling techniques, placed with and without a low-viscosity composite liner on cavities with different C-factor values, on bond strength to the dentin of class II cavities gingival floor; and analyze the failure modes of fractured specimens.

Materials and methods

Cavity preparation

Freshly extracted sound third molars (stored in 0.05% thymol) were used in this study. The teeth were obtained by protocols (136/2001) that were analyzed and approved by the Ethical Committee in Research at the Piracicaba School of Dentistry/UNICAMP. After being cleaned and pumiced, teeth had their roots apical third included in polystyrene resin cylinders to facilitate handling. Standardized uniform box-shaped class II cavities were prepared with a precision cavity preparation device on either the mesial or distal surface, depending on which surface would provide the most ideal preparation. Occlusal enamel was abraded with 600-grit SiC paper to obtain an occlusal height of 5 mm with the gingival margin located 1 mm below the cemento–enamel junction, and the proximal surface was slightly abraded to remove any irregularities. The preparations were outlined with coarse diamond burs #3145 (KG Sorensen, Barueri, SP, Brazil) operated in a high-speed hand-piece using copious air-water spray. The bucco-lingual width of the preparations was 4 mm and the axial wall was prepared to a depth of 2 mm, with the axial wall parallel to the long axis of the tooth (Fig. 1(A)). Control groups (corresponding flat dentin surfaces) were prepared the same way, but cavities were enlarged after preparation. The precision cavity preparation device was adjusted to remove all surrounding dental structures and leave a flat dentin surface on the corresponding gingival floor with the same texture for the bonding procedures (Fig. 1(B)).

Restorative procedures

Cavities were acid-etched with 35% phosphoric acid (3M Scotchbond Etchant) for 15 s, rinsed for 20 s and gently air-dried to keep the dentinal surfaces visibly moist. Single Bond adhesive system was applied according to the manufacturer instructions on all dentin surfaces, which were checked for a shiny surface. The adhesive resin was thinned with a directed low-pressure air stream and light-cured for 20 s using an XL 3000 light curing unit (3M ESPE, St Paul, MN, USA). A polyester matrix band was fixed around the tooth and it was restored according to one of the four filling techniques: groups 1 and 2-horizonal layering (Fig. 1(C)); groups 3 and 4-faciallingual layering (Fig. 1(D)); groups 5 and 6-oblique layering (Fig. 1(E)); groups 7 and 8-bulk filling (Fig. 1(F)); groups 9 and 10-a 5 × 2 × 4 mm³ composite resin block was built in three increments on the corresponding flat dentin surface (Fig. 1(G)). Each increment was light cured for 40 s.

On groups 2, 4, 6, 8 and 10, a 0.5 mm layer of a low-viscosity composite (Tetric Flow Chroma) was placed and light cured for 40 s before the insertion of Spectrum TPH hybrid composite resin. Materials,
manufacturers, composition and batch numbers are listed in Table 1.

Microtensile testing

After 24 h of storage in water at 37 °C, the specimens were mesio-distally sectioned into 0.8 mm thick slabs for micro-tensile testing using a diamond impregnated saw (Isomet, Buehler Ltd, Lake Bluff, IL, USA) (Fig. 1(H)). Three slabs were obtained from each tooth (Figs. 1(I)). Each slab was trimmed to an hourglass shape, yielding bonded surface areas of approximately 0.8 mm² (Fig. 1(J) and (K)). The slabs were attached to the flat grips of a microtensile testing device with cyanoacrylate glue (Zapit, DVA, Corona, CA, USA) and tested in tension in a Universal Testing Machine (Instron CO., Canton, MA, USA) with a cross-head speed of 0.5 mm/min until failure (Fig. 1(L)). After testing, the specimens were carefully removed from the fixtures with a scalpel blade and the cross-sectional area at the site of fracture measured to the nearest 0.01 mm with a digital caliper (Starret 727-6/150, Starret, SP, Brazil) to calculate the ultimate tensile bond strength and express results in MPa. Differences in microtensile bond strengths were evaluated for statistical significance using a two-way analysis of variance ANOVA, and Student–Newman–Keuls at the 0.05 level of significance. All statistical analysis was done using SAS for the personal computer (SAS Institute, Cary, NC, USA).

SEM observations

After testing, the dentin sides of fractured specimens were mounted on an aluminum stub, gold-sputter coated (MED 010, Balzers Union, Balzers, Liechtenstein) and observed with a scanning electron microscope (LEO 435 VP, LEO Electron Microscopy Ltd, Cambridge, United Kingdom) at

Figure 1  Schematic representation of specimen preparation. (A) Class II cavity; (B) control groups cavity design (after 1A was prepared, surrounding walls were removed with the cavity preparation device); (C) horizontally filled group; (D) faciolingually filled group; (E) obliquely filled group; (F) bulk filled group; (G) control group after restoration (note that the gingival floor is the only bonded wall); (H) sectioned specimen; (I) three slabs were obtained from each tooth; (J) 0.8 mm thick slab; (K) specimen trimming; (L) microtensile testing.
200 × or higher magnification for determination of the mode of fracture. Failure mode was classified into one of four types:

Type 1, adhesive failure between adhesive resin and dentin, and partial cohesive failure in adhesive resin;
Type 2, total cohesive failure in the adhesive resin;
Type 3, partial cohesive failure in dentin;
Type 4, partial cohesive failure in the low-viscosity composite layer, or failure between the low-viscosity composite and composite resin.

The frequency of fracture modes was analyzed by Kruskal–Wallis test at the 0.05 level of significance.

In order to observe composite adaptation, hybrid layer formation and tubule orientation on cavity bonded walls, additional specimens were similarly prepared and filled as in test groups to permit SEM examination. They were sectioned perpendicular to the bonded surfaces with a low speed wheel saw under water. Each interface was finished with a 1000-grit SiC paper under water and then polished with 6, 3, 1 and 0.25 μm diamond paste using a polish cloth. Afterwards, specimens were demineralised with 37% phosphoric acid for 8 s. After each step, specimens were rinsed, and debris were ultrasonically removed for 10 min. In order to observe the fractured interface of a specimen that failed cohesively in composite resin (group 8), the fractured specimen was diamond polished as mentioned above, and both sides of the slab were fixed together on a stub.

For examination of the site available for bonding, two additional specimens were similarly prepared as in test groups, but were not restored. Cavity walls were removed, and the gingival floor was lightly wet abraded with 1000-grit SiC paper, etched with 37% phosphoric acid for 15 s, washed and allowed to air dry.

Each specimen was sputter-coated with gold (MED 010) and observed under an SEM (LEO 435 VP). Representative areas of the interfaces and of the available site for bonding were photographed at 3000 × magnification. The fractured interface was photographed at 500 ×.

**Results**

Mean bond strength values obtained with combinations of cavity filling techniques and the low viscosity composite resin are displayed in Table 2. There was no statistically significant difference within groups restored with or without a flowable

<table>
<thead>
<tr>
<th>Techniques</th>
<th>Composite</th>
<th>Composite + flowable</th>
<th>SNK</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>21.3 (5.5) 12</td>
<td>NS</td>
<td>24.4 (7.7) 11</td>
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<tr>
<td>Horizontal</td>
<td>22.5 (9.1) 10</td>
<td>NS</td>
<td>19.1 (5.0) 9</td>
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<tr>
<td>Faciallingual</td>
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<td>NS</td>
<td>19.4 (8.3) 12</td>
</tr>
<tr>
<td>Oblique</td>
<td>17.5 (4.3) 9</td>
<td>NS</td>
<td>18.3 (7.6) 12</td>
</tr>
<tr>
<td>Bulk</td>
<td>14.5 (5.2) 8</td>
<td>NS</td>
<td>15.2 (5.0) 9</td>
</tr>
</tbody>
</table>

Means marked with different letters are statistically different by Student–Newman–Keuls test (p < 0.05). NS-no statistical significant difference.
composite liner (p > 0.05). Student-Newman-Keuls test revealed significant differences among filling techniques (p < 0.05). Bulk filling groups presented the lowest bond strength means, however, they were not significantly different from the oblique layering technique. All incremental filling groups presented bond strength means statistically similar to control groups, which represent a flat dentin surface. Bond strength values obtained on flat dentin surfaces (C-factor below one) were only statistically different from the bulk filling groups.

**SEM observations**

Illustrative SEM of the cavity gingival floor is shown in Fig. 2. A characteristic middle to deep dentin is noted, with high tubule density and low amount of intertubular area for hybrid layer formation. Fig. 3 is a representative micrograph of the bonded interface. Tubules are oriented obliquely to the surface. Hybrid layer and resin tags can be observed along the axial and gingival walls.

Failure mode observations showed considerable variation among groups restored with and without the low-viscosity composite liner (Table 3). A great number of type 4 failures was observed on groups restored with the low-viscosity composite resin. A fracture between flow composite and a bulk-filled restoration can be observed on Fig. 5. Type 1 failure was the most predominant failure pattern on groups restored without the low-viscosity composite resin.

**Discussion**

Direction of curing shrinkage, depth of cure and polymerization contraction stresses are some of the shortcomings of the curing pattern of light-cured resin composites, which may compromise the achievement of a perfect seal at the cavity wall. The polymerization shrinkage of a resin composite can create contraction forces that may disrupt the bond to cavity walls. This competition between the mechanical stress in polymerizing resin composites and the bonds of adhesive resins to the walls of restorations is one of the main causes of marginal failure and subsequent microleakage observed with composite restorations. Several researchers have sought for techniques and materials to overcome composites undesirable curing effects. The introduction of the microtensile technique has permitted the evaluation of regional bond strengths in complex cavity restorations, allowing a better comprehension of the bonding mechanism.

In this study, test groups exhibited relatively low bond strength means, ranging from 14.5 to 24.4 MPa. These low values can be attributed to the availability of solid dentin for hybrid layer formation at the site of bonding. Fig. 2 is a representative photomicrograph of the site available for bonding at the gingival floor of the cavity. Besides the great tubule density and small area of solid dentin, tubules are not oriented perpendicular to the bonding area as in most bond strength tests (Fig. 3).

Flowable composites were created by retaining the same small particle size of traditional hybrid composites, but reducing the filler content and consequently, reducing their viscosity. Low-viscosity composites are intended to act as stress-absorbers by partially relieving the polymerization contraction stress. In the present investigation, results exhibited no significant differences between bond strength values of groups restored...
with and without a low-viscosity liner, showing that low-viscosity composites had no effect on bond strength. However, analysis of failure modes revealed that the use of a low-viscosity composite liner might improve the marginal seal of the dentin tubules, because a great number of type 4 failures was observed. The type 4 failure is characterized by a partial or total failure within the flowable composite, or between the flowable composite and the composite resin (Figs. 4 and 5). Our findings corroborate with the study performed by Montes et al.\textsuperscript{15} which showed that a low-viscosity resin had no effect on tensile bond strength, even though it influenced failure modes.

Studies have found an improvement in marginal sealing with the use of a flowable composite as the first increment in class II cavities.\textsuperscript{20,27} A reduction in the number of voids has also been demonstrated when a low-viscosity composite was used as a liner in class II cavities.\textsuperscript{28} The low-viscosity composite liner may act as a stress-absorbing layer due to its lower elastic modulus, and avoid disruption of the bond promoted by the adhesive resin during polymerization shrinkage; or, in the case it is disrupted, there is a great chance that dentin tubules will be kept sealed, as seen in the failure mode analysis (Fig. 4). Flowable composites have also been suggested to be used as filled adhesives.\textsuperscript{26}

<table>
<thead>
<tr>
<th>Groups</th>
<th>Type 2\textsuperscript{a}</th>
<th>Type 2\textsuperscript{b}</th>
<th>Type 3\textsuperscript{c}</th>
<th>Type 4\textsuperscript{d}</th>
<th>Grouping</th>
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<td>0</td>
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<td>C</td>
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<td>3</td>
<td>na\textsuperscript{e}</td>
<td>BC</td>
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<tr>
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<td>0</td>
<td>1</td>
<td>na\textsuperscript{e}</td>
<td>C</td>
</tr>
<tr>
<td>Bulk</td>
<td>6</td>
<td>2</td>
<td>0</td>
<td>na\textsuperscript{e}</td>
<td>BC</td>
</tr>
<tr>
<td>Control + flow</td>
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<td>0</td>
<td>1</td>
<td>5</td>
<td>AB</td>
</tr>
<tr>
<td>Horizontal + flow</td>
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<td>0</td>
<td>1</td>
<td>2</td>
<td>BC</td>
</tr>
<tr>
<td>Faciolingual + flow</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>8</td>
<td>A</td>
</tr>
<tr>
<td>Oblique + flow</td>
<td>6</td>
<td>0</td>
<td>0</td>
<td>6</td>
<td>AB</td>
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<tr>
<td>Bulk + flow</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>6</td>
<td>AB</td>
</tr>
</tbody>
</table>

\textsuperscript{a} Type 1: adhesive failure between adhesive resin and dentin, and partial cohesive failure in adhesive resin.
\textsuperscript{b} Type 2: total cohesive failure in adhesive resin.
\textsuperscript{c} Type 3: partial cohesive failure in dentin.
\textsuperscript{d} Type 4: partial cohesive failure in the low-viscosity composite layer, or failure between the low-viscosity composite and composite resin.
\textsuperscript{e} na: not available.

Figure 4  (A) SEM photomicrograph illustrating a Type 4 failure, showing that fracture partially occurred within the flowable composite (FC), partially within the adhesive resin (AR) and between the adhesive resin and dentin (D). Fracture occurred at either the bottom (left) or at the top (right) of the hybrid layer. Note the irregular surface produced by the diamond bur during cavity preparation. Original magnification \( \times 220 \). (B) Close-up of the transition zone of the fracture between the adhesive resin (AR) and the hybrid layer (HL). Original magnification \( \times 10,700 \).
however, in a recent study, Frankenberger et al.\textsuperscript{29} stated that low-viscosity composites should not be used to replace bonding agents.

Another approach to minimize the effects of curing shrinkage is the insertion of the composite resin in increments. The use of incremental techniques has been extensively studied,\textsuperscript{30–33} however, there is not a common agreement among authors.\textsuperscript{16} Our findings showed that the use of reduced amounts of resin to be polymerized at each increment helped achieving bond strength values similar to flat dentin groups (control), which presented a C-factor below one. Even though the C-factor of each increment was higher than the one found in flat surfaces, incremental filling assures uniform and maximum polymerization of the composite resin.\textsuperscript{34}

Two factors may have contributed for the low bond strength values at the bulk filling groups: polymerization contraction stresses created during light curing of a great volume of composite resin;\textsuperscript{35} or decreased effectiveness of polymerization at the bottom of the cavity.\textsuperscript{34} Fig. 5 depicts a situation in which fracture occurred between composite resin and flowable composite. This is a strong evidence that deficient polymerization may occur at the deepest part of thick composite increments, leading to premature failure of bulky filled restorations. In this situation, the use of a flow composite liner contributed to keep the seal of dentin tubules at the gingival floor.

In the current study, the class II configuration factor was not of a high magnitude, about 1.7, but sufficient to affect the bonded interfaces. It was estimated that by filling the class II cavities incrementally, the C-factor would have been reduced to about 1.3. However, the assurance of uniform and maximum polymerization in this type of cavity, provided by incremental filling techniques, was probably more important than the C-factor reduction. Among the incremental filling techniques, oblique layering provided the smallest bond strength values, and although it was statistically similar to control groups, it did not differ statistically from the bulk filling groups. Although incremental filling decreases shrinkage stresses due to minimal contact with the cavity walls during polymerization as well as to the reduced shrinkage produced by a small volume material, this is valid for each individual increment. Finite element analysis and photoelastic models have shown that the total shrinkage and its stress field are a result of the combined effect of the contraction of all the incremental layers of a restoration.\textsuperscript{16,32} The oblique layering technique comprised the insertion of four composite increments, whereas three increments were inserted to fill the cavity in the horizontal and faciolingual layering techniques. The bonded interface was probably more challenged in the oblique than in the other incremental techniques.

Results of this study indicate that the use of a low-viscosity composite liner had no effect on bond strength of composite resin to dentin of a complex cavity design. However, it significantly influenced failure modes. The lower elastic modulus of the flowable composite may help relieve the stresses produced during polymerization shrinkage in a cavity preparation. Bond strengths obtained on flat dentin surfaces created with abrasive paper may overestimate adhesive systems performance. Additional research is required to determine optimal procedures for bonding to cavities prepared and restored under clinical relevant conditions. The bulk filling groups presented the lowest bond strength values, however, bond strengths reached values similar to those obtained on flat dentin surfaces by incrementally filling the cavities.

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References


