Marginal gap repair with flowable resin-based composites

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This study was designed to test the hypothesis that the flowable/dentin interface has the weakest bond and highest frequency of failure when a resin-based composite is repaired using a flowable composite.

Comparing three specific groups—dentin, flowable composite, and hybrid composite—under the Kruskal-Wallis test showed that the mean bond strength values at the flowable/dentin interface and within the dentin were significantly lower than those at the hybrid/flowable interface and within the flowable resin. Dentin near the pulp chamber yielded consistently lower bond strength values than dentin located at the dentino-enamel junction. Bonding at the flowable resin/dentin interface showed the weakest bond and highest frequency of failure.

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Directly applied tooth-colored restorations are used widely for the restoration of defective and carious teeth.1 Due to some inherent limitations of these technique-sensitive materials, the restorations often require replacement after seven or eight years.2 Many resin-based restorations are replaced due to the clinical diagnosis of secondary caries, an ill-defined and subjective diagnosis that invariably leads to the replacement of the entire restoration.3,4 Defects usually are found gingivally to the restoration.4

Previous in vitro studies have shown that replacing resin-based composite restorations increases the size of the cavity preparation regardless of where the failure is located; that is, the preparation extends to areas remote from the defect.5 The cervical margin of a restoration is the most critical area, as it often is associated with a localized defect at the dentinal margin. To enhance the longevity of resin-based composite restorations, alternate replacement methods are necessary.

Repairing defective resin-based composite restorations is an alternative to replacing the entire restoration. This approach will preserve healthy tooth structure; in addition, repairing resin-based composite restorations is cost-effective and may reduce pulpal trauma. Indications for repair include localized defects such as marginal fracture, marginal discoloration, and secondary caries of an otherwise clinically sound restoration.

Several in vitro studies have tested repairs utilizing resin-based composite materials and reported acceptable shear bond strength values; some studies reported that bond strength following repair was as much as 80% of the cohesive strength of the resin-based composite material.11-20 Although repairing a partly lost fissure sealant is an established technique, the clinical repair of composite restorations is not well-received; a 2003 survey reported that 30% of North American dental schools do not teach repair.21-23 These schools do not recognize repairing resin-based composite restorations as an acceptable procedure. Despite studies that have reported high repair strength, the bond between existing and repair material is raised as a concern.11-20,24

The clinical repair of defective restorations often calls for an exploratory preparation into the composite at the tooth/restoration interface until a sound dentin wall is exposed and the absence of caries is confirmed at the defective site. Composite repair often occurs within a deep and narrow gap, presenting a space constraint that optimally may be restored by using a low viscosity resin-based composite. The use of low viscosity (that is, flowable) resins to repair previous resin-based composite restorations has not received adequate attention. Flowable resin-based composite has been used clinically for small conservative restorations.

Whenever clinical repairs are performed, two different interfaces must be bonded simultaneously: the reparative resin must be bonded to the tooth structure (which is mostly dentin) and also to the existing composite material. This condition presents a unique three-element adhesion challenge. Simulating the elements that are involved in the repair bonding is fundamental to understanding the bonding at the clinical setting.

This in vitro study was designed to replicate the three-element adhesion model of a clinical composite repair and identify the weakest bond and the interface that provide the highest frequency of failure. The authors hypothesize that the weakest bond and highest frequency of failure of a repaired marginal gap of a RBC is at the flowable/dentin interface.

Materials and methods

Eight caries-free extracted molars were embedded in gypsum and ground flat along the long axis of the tooth with 320 grit silicon carbide paper (Mark V Laboratory, East Granby, CT; 800.243.9776); this grit was chosen to simulate a 15 μm diamond stone.

Eight blocks (5.0 mm x 8.0 mm x 5.0 mm) were built using hybrid Filtek Z250 resin-based composite (3M/ESPE, St. Paul, MN; 888.364.3577). The blocks were prepared in 1.5 mm increments and each was polymerized with a photocuring unit (Optilux, Kerr Demetron, Orange, CA; 800.537.7123) for 40 seconds. The resin-based composite blocks were placed in distilled water (37°C) for 48 hours and finished with 320 grit silicon carbide paper.

A U-shaped die-stone spacer (1.1 mm thick) was constructed and glued to...
the exposed dentin, forming a space that simulated a marginal gap (Fig. 1). The resin-based composite block was stacked against the die-stone spacer; after acid etching with 35% phosphoric acid for 15 seconds and bonding (Single Bond, 3M ESPE), the 1.1 mm gap was restored using Heliomolar Flow (Ivoclar Vivadent, Inc., Amherst, NY; 800.533.6825) in two increments (Fig. 2).

The specimens were stored in distilled water for one week at 37°C and sectioned into microtensile test specimens, using a slow-speed diamond saw under water-cooling. Each specimen bar (approximately 0.9 mm × 0.9 mm × 14 mm) consisted of dentin, flowable composite, and hybrid composite in series (Fig. 3).

A total of 83 specimen bars were obtained. Specimen locations were designated (that is, in the outer, middle, or inner third of dentin) to reflect the location of bonding with respect to the dentin depth toward the pulp chamber.

The specimens were subjected to a tensile force using an Instron Model 1125 testing machine (Instron Corp., Canton, MA; 800.564.8378) with a crosshead speed of 0.5 mm/min. To determine bond strength value, the load required to fracture the specimen was divided by its cross-sectional area. The failure mode of fractured surface by the location was examined using a light microscope (40x magnification). The location of failure includes five zones: within the hybrid composite, the hybrid/flowable interface, within the flowable composite, the flowable/dentin interface, and within the dentin structure.

The frequency of failure by location was calculated. Because the number of fractured specimens in each failure mode was not expected to be the same and the strength value distribution normality was not known, the Kruskal-Wallis one-way ANOVA was used to detect differences in the mean bond strength value among various modes of failure. The Kruskal-Wallis test also was used with the flowable/dentin interface failure group to determine the effect of dentin depth on the bond strength values.

Results
Table 1 shows the location of failures following surface examination with a light microscope and mean bond strength values. Four of the 66 specimens that fractured at the flowable/dentin interface failed before test and were included in the analysis with strength values of zero. No failure occurred within the hybrid resin. The Kruskal-Wallis test showed significant differences among the four modes of failure ($p = 0.0018$). Comparison of specific groups under the Kruskal-Wallis test showed that the mean bond strength value both within dentin and at the flowable/dentin interface were significantly lower than those that failed at the hybrid/flowable interface or within the flowable composite (see Table 1). There was no significant difference between the mean bond strength value of the flowable/dentin interface group and the mean value of the within dentin group.

Table 2 shows the distribution of bonding sites, separated by dentin depth, for the specimens that failed at...
the flowable/dentin interface and their respective bond strength values. The Kruskal-Wallis test shows that there was significant difference among the three groups (\( p = 0.0008 \)). A comparison of specific groups showed that the inner third dentin group yielded significantly lower mean strength value than the middle and outer third dentin groups.

**Discussion**

Successful resin repair requires an adequate interfacial bond between the surfaces involved in the repair. The wettability of the different substrates plays an important role in the bonding. The bonding between the flowable composite and the two surfaces involved in the repair (the dentin and the hybrid composite) is micromechanical; however, the flowable resin might wet the surface of the old composite better that it would wet the dentin substrate. This phenomenon may depend on the treatment of the composite surface. Bonding to a resin-based composite was enhanced when a flowable composite was applied following treatment with phosphoric/maleic acids and air abrasion.\(^ {25,26} \) Similar enhancement is expected with the application of hydrofluoric acid and silane.\(^ {27} \) Although one 1984 study reported that uncut resin-based composite surfaces provided a better substrate for bonding than ground surfaces, roughening the surface of the composite that is to be bonded increases the bonding surface area between the parts involved.\(^ {19} \) This increase in surface area is important for mechanical bonding.

In addition to a significant low bond strength value, the high frequency of failure (approximately 80%) was an important element to support the authors’ hypothesis that the flowable/dentin interface is the most critical area in a three-element adhesion model of a clinical composite repair.

The two surfaces involved in the repair, the dentin and the hybrid composite, were separated by a rigid spacer in the selected study design (Fig. 1). The flowable composite was placed between these two substrates, where it acted as a repair material. The flowable composite is rich in unfilled resin and will contract significantly; Bowen et al demonstrated in 1983 that significant tensile stresses develop during hardening of composite resins when they bond to the cavity walls.\(^ {28} \) The contraction during the polymerization of the flowable composite undoubtedly would generate more stresses at the two interfaces and further stress the bond at the weaker of the two interfaces as a result. When the specimen was submitted to tensile strength testing, the dentin/flowable interface and the dentin substrate showed lower bond values than the other groups; however, the dentin/flowable interface was the most critical and weakest area of this three-element adhesion model regarding the frequency of failure.

There are numerous means for enhancing the bond between composite resins but the need to improve the bond to dentin has not received adequate attention regarding the repair of restorations. The dentin substrate is rich in

### Table 1. Frequency of failure modes and mean microtensile bond strengths with standard deviations (SD); group mean values with the same letter are not statistically different (\( \alpha = 0.05 \)).

<table>
<thead>
<tr>
<th>Failure mode</th>
<th>No. of specimens</th>
<th>% of specimens</th>
<th>Mean microtensile bond strength (MPa)</th>
<th>SD</th>
<th>Statistical grouping</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hybrid/flowable interface</td>
<td>6</td>
<td>7.0</td>
<td>25.6</td>
<td>6.0</td>
<td>A</td>
</tr>
<tr>
<td>Within flowable composite</td>
<td>7</td>
<td>8.0</td>
<td>20.3</td>
<td>8.0</td>
<td>A</td>
</tr>
<tr>
<td>Within dentin</td>
<td>4</td>
<td>5.0</td>
<td>13.7</td>
<td>17.4</td>
<td>A,B</td>
</tr>
<tr>
<td>Flowable/dentin interface</td>
<td>66</td>
<td>80.0</td>
<td>12.9</td>
<td>8.8</td>
<td>B</td>
</tr>
<tr>
<td>Within hybrid composite</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td></td>
</tr>
</tbody>
</table>

### Table 2. Mean microtensile bond strengths with standard deviations (SD) of specimens that fractured at the flowable/dentin interface as a function of the dentin depth; group mean values with the same letter are not statistically different (\( \alpha = 0.05 \)).

<table>
<thead>
<tr>
<th>Dentin depth</th>
<th>No. of specimens</th>
<th>Mean microtensile bond strength (MPa)</th>
<th>SD</th>
<th>Statistical grouping</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outer</td>
<td>20</td>
<td>17.9</td>
<td>12.1</td>
<td>A</td>
</tr>
<tr>
<td>Middle</td>
<td>16</td>
<td>14.6</td>
<td>6.8</td>
<td>A</td>
</tr>
<tr>
<td>Inner</td>
<td>30</td>
<td>8.6</td>
<td>3.8</td>
<td>B</td>
</tr>
</tbody>
</table>
water, which can be controlled to a certain degree by the hydroxyethyl methacrylate (HEMA) in the bonding agent. The unfilled resin's hydrophilic property could result in a better environment for bonding to dentin; however, bonding to dentin still may produce inconsistent results when compared with bonding to composite. Studies also indicate that covalent bonds are formed between the methacrylate groups of the bonding agent and the matrix of the composite substrate. The resin-based composite blocks were left in water for 48 hours prior to bonding. This would have reduced the number of free methacrylate groups capable of reacting with the bonding agent; as a result, this bonding mechanism appears to be the least important factor. No significant differences were found among the specimens, which had been stored for either 1 or 60 days prior to repair.

According to the results of the current study, the composite surface is more favorable for bonding than the dentin surface. Previous literature concerning the adhesion of a two-component system has reported that composite-to-composite bonding generally is higher than composite-to-dentin substrate bonding. The present experimental design made it possible to assess the bonding position of the specimens (that is, outer, middle, or inner dentin), which reflects the location of the bond in relation to the pulp chamber. It is interesting to note that the findings confirm that dentin nearest the pulp chamber consistently yielded lower bond strength values. Dental tubules close to the pulp chamber are larger in number, diameter, and dentin permeability; consequently, the water content also varies according to the different dentin depth. Other differences may have affected the strength results, such as dentin morphology and dentin age.

Some studies have shown that bonding parallel to the dentinal tubules leads to lower bond strength results than bonding perpendicular to the dentinal tubules. Bonding perpendicular to the dentinal tubules probably would result in a bond to a higher zone of collagen fibers, which could enhance bond strength results. Some of the concerns addressed regarding the repair strength of resin-based composite materials are not validated by the current study. The current study shows that bonding to dentin, rather than composite repair, remains a problematic area.

Summary
The study indicated that the weakest bond occurred at the flowable/dentin interface and within the dentin substrate. The highest frequency of failure occurred at the flowable/dentin interface; as a result, the hypothesis of the study was accepted.

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References


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