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Microleakage Resistance of Minimally Invasive Class I Flowable Composite Restorations

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Clinical Relevance

Despite recent developments in dentin-bonding systems, flowable composite resins, and restorative procedures, microleakage resistance of the restoration–tooth surface interface remains problematic. In this *in vitro* study on minimally invasive Class I restorations, the flowable composites used, with their manufacturers' bonding systems, all produced more microleakage than a conventional microhybrid composite control. Microbubbles were found within many of the flowable composite restorations; these might result in undue restoration pitting or degradation.

SUMMARY

Minimally invasive flowable composite Class I restorations are widely used. However, flowable composites are characterized by low filler contents, modified resin formulations, low moduli of elasticity, low viscosity, generally poor mechanical properties, and decreased long-term stability. The purpose of this study was to compare the microleakage resistance of a wide variety of flowable composites used with their manufacturers' recommended bonding systems to that of a long-used and widely studied microhybrid composite when placed as minimally invasive occlusal restorations. Molar teeth were prepared in a standardized manner, restored, artificially aged, stained, sectioned, evaluated, and analyzed. Microleakage varied substantially, by a whole order of magnitude, among the material groups tested. The control group, a conventional microhybrid composite material, leaked significantly less than all the flowable composite groups. Microleakage varied very slightly among measurement site locations. Tiny microscopic bubbles were seen within many of the flowable composite specimens, as were a few voids.

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INTRODUCTION

Although fluoride treatment can successfully reduce smooth surface caries, occlusal pits and fissures remain at risk.[1-3] Early diagnosis combined with conservative interceptive adhesive treatment of occlusal caries may preserve the integrity of the remaining tooth and increase its longevity.[4,5] Minimally invasive flowable composite Class I restorations have gained widespread use because of their pleasing esthetics, the belief that they require less removal of sound tooth structure than for amalgam restorations, and the perception that adhesion to enamel will reduce the risk of leakage and secondary caries.[6,7]

However, polymerization shrinkage of resinous composites can result in loss of adhesion and microgap formation.[8] Loss of adhesion and microgap formation may allow microleakage of bacteria and their toxic products; these contribute to postoperative tooth sensitivity, development of secondary caries, pulpal disease, marginal staining, and restoration failure.[9-13]

Techniques such as incremental buildup and soft-start light polymerization have been used with the aim of improving the depth of cure, reducing polymerization stress, and minimizing its unwanted developed effects.[14,15] However, other studies have not found significant differences between bulk and incremental insertion in terms of magnitude and distribution of stress at the bonded interface.[16,17]

Highly filled composites, containing proportionally less resin, likely undergo less shrinkage. However, these materials have higher elastic moduli and a lower propensity for stress relaxation, as well as are thought to be more difficult to place in conservative tooth preparations. Alternatively, it has been suggested that flowable composites with less filler and lower viscosities might be easier to place, especially in inaccessible areas, and might reduce the effects of polymerization shrinkage through increased stress relaxation.[18-21] It has been suggested that the ease of flowable composite placement facilitates superior adaptation, but supportive data are lacking. Since their introduction in the mid-1990s, flowable composites have become widely used for a broad range of restorative applications such as liners, bases, buildups, bulk restorative materials, or sealants. Flowable composites generally contain lower filler concentrations and modified resin formulations. They are characterized by low moduli of elasticity, low viscosity, generally poor mechanical properties, and decreased long-term stability.[22] Flowable resins may manifest superior notched-beam fracture toughness values in comparison to conventional microhybrid composites[23,24]; however, such findings must be tempered by their tendency toward greater deformation. Some studies have suggested that flowable composites may protect bonding agents from the effects of polymerization stress of the restorative material, thus reducing the microleakage.[18,19] However, other studies have found no significant reduction of marginal microleakage when flowable composite linings were used.[13,25]

The microleakage resistance of composites for conservative Class I restorations has rarely been evaluated. Therefore, the purpose of this study was to compare the microleakage resistance of flowable composites to that of a long-used and widely studied microhybrid composite, used with their manufacturers' recommended bonding agents, when placed as minimally invasive occlusal restorations.

METHODS AND MATERIALS

Tooth Preparation

One hundred freshly extracted human molars were stored in water at room temperature. These were mostly third molars with an even distribution of upper and lower teeth. The roots of the teeth were cleaned using periodontal curettes and then mounted in acrylic resin blocks, leaving the crowns exposed. A fissurotomy bur (Micro STF, SS White, Lakewood, NJ, USA), with flutes 0.6 mm in diameter and 1.5 mm in height, was used to make shallow preparations within the enamel of the central fossae of the molars. These minimally invasive Class I restorations were 3 mm in length from mesial to distal, 0.6 mm in width, and 1.5 mm in depth. To aid in standardizing the preparations, the handpiece (Tradition Midwest, Dentsply, York PA, USA) was mounted in a surveyor parallometer system (Ney products, Dentsply). Prepared teeth were arbitrarily assigned to one of 10 material groups (n=10) to ensure that upper and lower teeth, or larger and smaller teeth, were evenly distributed.

Restoration

Ten different flowable resin composite–bonding agent groups were included (Table 1). These included representative products from a wide range of manufacturers. Nine of these groups contained a flowable composite; one control group contained a widely used microhybrid composite as a control. Each restorative material was paired with an adhesive from, and specifically recommended for

Table 1: *Flowable Composites, Their Bonding Agents (Group Abbreviations), and Manufacturers*

(R2-OB)	Revolution 2; OptiBond SOLO; SDS Kerr, Orange, CA, USA
(VF-TQ)	Virtuoso Flowable; Tenure Quick w/FL; Den-Mat, Santa Maria, CA, USA
(UF-UB)	UniFil FLOW; UniFil Bond; GC America, Alsip, IL, USA
(HM-EX)	Heliomolar Flow; Excite; Ivoclar Vivadent, Amherst, NY, USA
(AF-OS)	Aelite Flo LV; One Step PLUS; Bisco, Schaumburg, IL, USA
(FF-SB)	Filtek Flow; Single Bond; 3M ESPE, St Paul, MN, USA
(PF-PQ)	Permaflo; PQ1; Ultradent Products, South Jordan, UT, USA
(FI-B1)	Flow-it ALC; Bond 1; PENTRON Clinical Technologies, Wallingford, CT, USA
(GD-GB)	Gradia Direct Flo; G Bond; GC America, Alsip, IL, USA
(HX-OB)	Herculite XRV; OptiBond SOLO; SDS Kerr, Orange, CA, USA

this purpose by, the same manufacturer. Conditioners, dentin bonding agents, and the flowable composite resins were applied following their manufacturer's instructions using syringes. The control material was delivered from a unidose tip directly into the preparation using a unidose gun/dispenser. The preparations were filled to the occlusal cavosurface margins. After the excess composite resin was removed with a composite metal spatula, the composites were light cured for 40 seconds at 800 mW per square centimeter (Spectrum 800, Denstsply), finished, and polished using a composite polishing kit (Diacomp, Brasseler, Savannah, GA, USA) with water spray.

Microleakage Assessment

After restoration, the teeth were stored in water at 37°C for 14 days to ensure hydration of the resinous restorations. Next, the restorations were then artificially aged by thermal cycling from 5°C to 50°C for 1000 cycles, with dwell and travel times of 20 seconds. The process of thermocycling causes differential contraction of restoration and tooth, which stresses their interface. After artificial aging, the entire surface of each tooth was coated with two layers of a clear nail polish, with the exception of 1 mm around the circumference of the restoration margins, to prevent leakage through other avenues. The restored teeth were then submerged in a 50% solution of silver nitrate for 60 minutes, rinsed with water, placed in photo developer (D76, Eastman Kodak, Rochester, NY), and exposed under a 150-W floodlamp for 30 minutes to ensure reduction and immobilization of the silver nitrate stain. The specimens were then embedded in slow-setting, low-viscosity, clear epoxy resin (Hapex 1200A/1226, Hastings Plastics, Santa Monica, CA, USA). The specimens were sectioned faciolingually through reference marks, scribed on the midfacial and midlingual aspects of the teeth using a wide diamond blade in a slow-speed saw with copious aqueous irrigation (Isomet, Buehler, Evanston, IL, USA). This provided four tooth-restoration interfaces for measurement of stain penetration on each specimen: mesiofacial (MF), mesiolingual (ML), distolingual (DL), and distofacial (DF). The sectioned samples were then re-exposed to the 150-W floodlamp for 5 minutes to ensure that all of the silver nitrate stain would turn black and be fixed.

Microleakage was recorded as a continuous parametric variable as the distance of stain penetration in millimeters, in a plane parallel to the long axis of the tooth, measured at 30× magnification using a toolmakers microscope (Unitron, Commack, NY, USA) and digital positioners calibrated to an accuracy of 0.1 μm (Boeckeler Instruments, AZ, USA; Figure 1).

Analysis

Mean microleakage means and associated standard deviations were calculated for each material group and plotted. Two-way analysis of variance was performed to evaluate the main effects of material type, measurement site, and their interaction ($p<0.05$). The Tukey multiple comparisons test was then computed to determine which materials differed from one another ($p<0.05$).

RESULTS

Microleakage varied substantially, by a whole order of magnitude, among the material groups tested (Table 2; Figure 2; $p<0.0001$). Material type accounted for almost all of the variation produced in

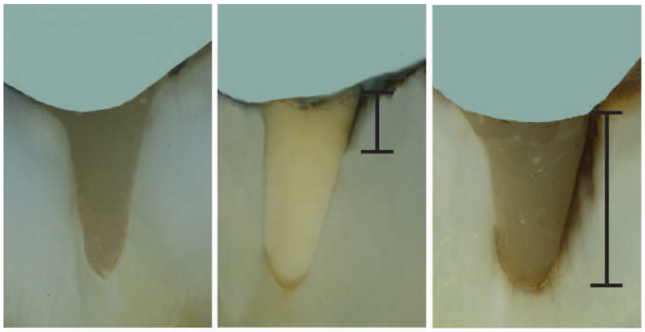

Figure 1. *Macro photographs of representative sectioned tooth specimens. Microleakage was recorded as the distance of stain penetration in millimeters, in a plane parallel to the long axis of the tooth, from the restoration margin to its most apical extent using a toolmaker's microscope and digital positioners. Microbubbles can be visualized as white spots within the bodies of all of these sectioned restorations, especially the one on the right.*

this experimental model (Table 2). Microleakage also varied among measurement site locations (Table 2; Figure 3; p=0.005). However, material type and measurement site did not interact to influence microleakage; that is, their effects were simply summative, and materials were equally affected by the measurement site locations (Table 2; p=0.1).

Almost all of the variation was attributable to the material choice (Table 2). Among the material groups, multiple comparisons testing showed that the control group, a conventional microhybrid composite with its associated bonding agent (HX-OB), leaked significantly less than all nine of the flowable composites tested. Many statistically significant differences in microleakage resistance were discerned among the nine flowable composites (Figure 2). Material choice had an enormous impact on the microleakage resistance of minimally invasive composite restorations.

Measurement site had a statistically significant, but very small, effect (Table 2; Figure 3). Multiple comparisons testing revealed that the ML/P site leaked significantly less than MF and DF there was no difference in leakage among DL,DF, and MF sites. This experimental model attributed a difference in microleakage to tooth morphology.

Defects or bubbles were seen within the bulk restorative materials in 56% of the 200 sections (Figure 1). Mostly, these bubbles were very small, approximately 50 to 100 μm in diameter, but three larger voids were seen. They often appeared as white spots on the sectioned specimens because they tended to be filled with sectioning debris. The defects had no influence on interfacial leakage. Only groups HX-OB and UF-UB were entirely without bubbles or voids. Groups R2-OB and FI-B1 had six specimens with bubbles or voids, group FF-SB had five specimens with bubbles or voids, groups AF-SB and PF-PQ had four specimens with bubbles or voids, groups VF-TQ and GD-GB had three specimens with bubbles or voids, and group HM-EX had two specimens with bubbles or voids. Because of the unexpected identification of tiny bubbles and larger voids, the flowable composites that had manifested bubbles and voids on sectioning were expressed directly onto glass slabs, polymerized, sectioned, and examined as above. For all of these materials, tiny bubbles were revealed, but larger voids were absent.

Table 2: *Two-Way Analysis of Variance for the Main Effects of Material Group and Measurement Site and Their Interaction ($p<0.05$).*

Source of Variation	Sum of Squares	Degrees of Freedom	F-Ratio	*p* Value
Material	39.9	9	865	<0.0001
Site	0.1	3	4	0.005
Interaction	0.2	27	1	0.1
Residual	1	200		
Total	41	239		

DISCUSSION

Despite a long search for materials and techniques to ensure adhesion to tooth structure so as to minimize leakage, the interface between restoration and tooth remains problematic.[26] Advances continue, but limitations persist at macro, micro, and nano levels.[27,28] In the present *in vitro* study, the inorganic compound silver nitrate was selected because it has been accepted as a suitable method for measuring both microleakage and nanoleakage.[29,30] The silver ion is very small (0.059-nm diameter) when compared with the size of a typical bacteria (0.5-1.0 μm).[31] This small size and high reactivity makes silver nitrate an appropriate agent to detect the nanoporosities.[32]

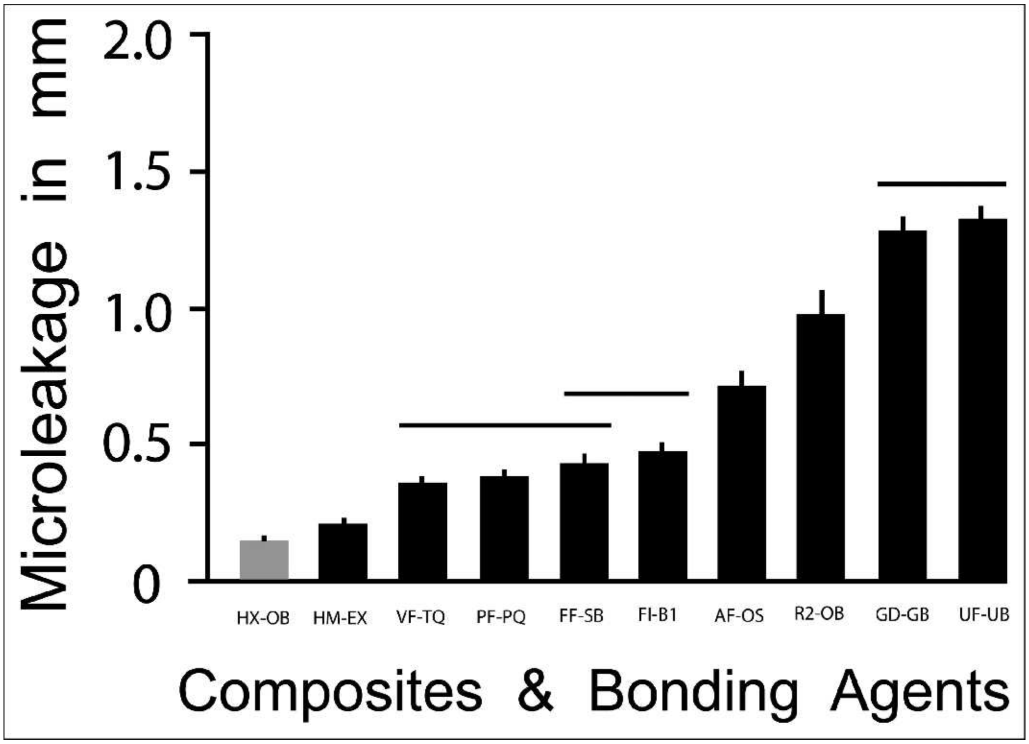

Figure 2. *Bar graph of microleakage of composite and bonding agent groups in millimeters. Means and standard deviations are displayed. Flowable composite groups are illustrated by black bars; the control microhybrid composite group is illustrated by a gray bar. Statistically similar groups are linked by horizontal lines ($p > 0.05$).*

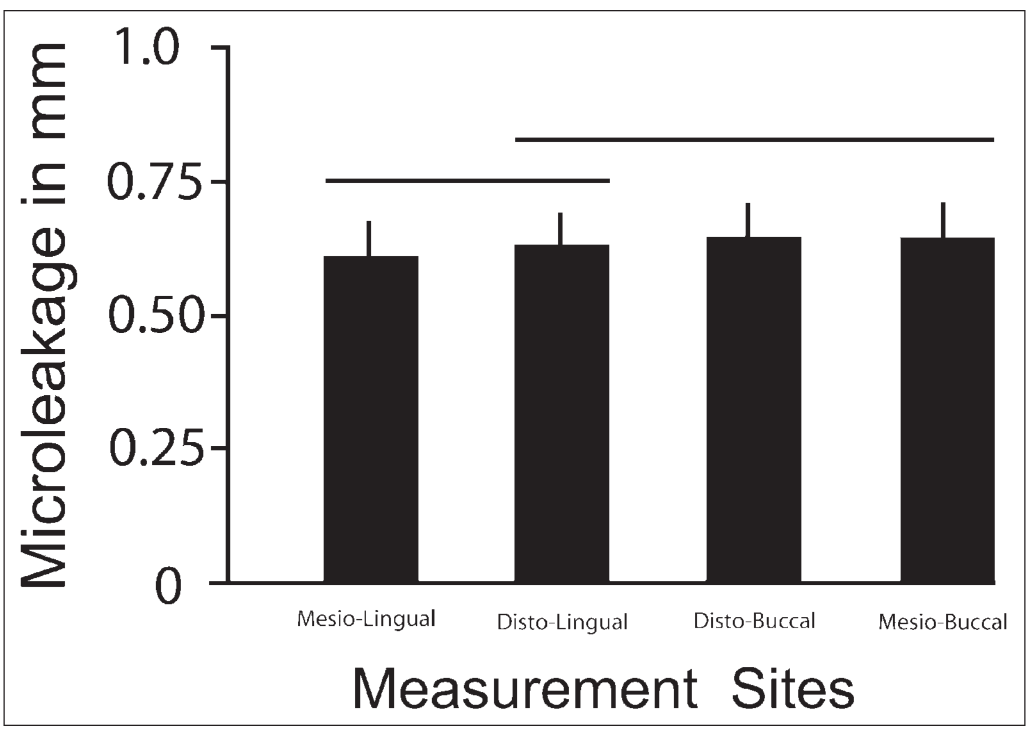

Figure 3. *Bar graph of microleakage of measurement site locations in millimeters. Means and standard deviations are displayed. Statistically similar groups are linked by horizontal lines ($p > 0.05$).*

Multiple factors may influence the microleakage resistance of minimally invasive composite restorations. These likely include polymerization shrinkage, resistance to deformation or elastic modulus, cavity configuration, the amounts of exposed enamel and dentin, and the restorative procedures themselves.[8,33-36] It has been reported that marginal gaps increase as cavity designs change from a V-shaped to box-shaped configurations.[37] The term *cavity configuration factor* (C-factor) has been used to describe differences in cavity design.[38] A high C-factor indicates a high ratio of bonded to unbonded tooth/composite surfaces, corresponding to high stress levels and increased probability of separation of the composite from the wall of the tooth preparation. This effect is caused by a reduction in unbonded surfaces, which restricts the composite's ability to flow to relieve polymerization stress. Hence, shallow cavities tend to have lower C-factors, but deep or narrow cavities tend to have higher C-factors. In this study of minimally invasive fissure preparations, the cavities were relatively shallow but proportionally very narrow. In contrast, a fissure sealant would tend to be shallower and much wider with a much more favorable configuration, whereas a conventional deeper and bulkier restoration would have a less favorable configuration.

Conflicting data on the microleakage and caries resistance of bonded flowable composites in comparison to those of conventional fissure sealants have been reported.[39,40] This may be explained by the wide variation in filler content and other properties of commercially available flowable composites.[22,24,41] This current study identified substantial differences, sixfold, in microleakage resistance among nine commercially available bonded flowable composites (Table 2; Figure 2).

In this study, the entire preparation was in enamel and had a shallow and narrow standardized conservative outline form. Because bonding to enamel is known to be very predictable, similar performances might have been expected. However, some of the differences found may be ascribed to the use of self-etching primers. The two test groups with significantly more microleakage than all others used self-etching primers. Self-etching adhesives are more effective on ground enamel than on intact enamel because self-etching materials do not create an enamel-etching pattern as well defined as those produced by a separate step 37% phosphoric acid etching.[42] Pertinently, the same bonding agent was used both with the conventional microhybrid control material (HX-OB) and with a flowable composite made by the same manufacturer (R2-OB); the flowable composite recorded five times more microleakage than the conventional microhybrid (Figure 2). It is possible that the conservative cavity preparations, without undercuts, used in this current study tended to be cut along or obliquely to rods, rather than across enamel rods, exacerbating the lesser etching ability of the self-etching adhesives.

Recently, preheating composite resin with appropriate devices such as Calset (AdDent Inc, Danbury, CT, USA) has been advocated as a method to reduce paste viscosity, to improve internal adaptation and marginal adaptation, and to shorten curing times.[43-45] Preliminary studies have demonstrated improved flowability and handling characteristics of preheated resins without alteration of their physical properties.[46] A strong positive correlation between temperature and monomer conversion has also been demonstrated *in vitro*.[47,48] However, *in vitro* testing of adaptation and microleakage resistance of preheated resins has produced mixed results.[49,50]

Identification of tiny bubbles in flowable composites that were expressed directly onto glass slabs and polymerized suggests that they were pre-existing as a result of manufacturing methods. The authors believed that the three larger voids they identified were related to the technical difficulties in placing flowable composite into narrow minimally invasive restorations. Although it is widely believed that flowable composite resins are easy to apply without voids, our results and those of others suggest that porosities remain.[25,51] Flowable composites inherently contain proportionally more resin and less filler than conventional composites. This reduces their viscosity and enhances their flowability. However, this makes them more difficult to pack into cavity preparations and increases the technical difficulty of removing microbubbles during the manufacturing process.

Anusavice, long ago, discussed criteria for the selection of restorative materials: properties vs technique sensitivity.[52] He identified the viscosity of composite resins as one of many factors influencing technique sensitivity. Both viscosity and void concentration influence rheology, or flow. However, study of the influence of rheology on technique sensitivity and clinical performance still remains in its infancy. It is also important to note that operator preference is quite a different matter than technique sensitivity or material performance.

Clinical preparation designs for minimally invasive restorations differ widely. The preparation design used in this study, created using a standard fissurotomy bur, was extremely conservative, but it was also relatively narrow and deep, having an unfavorable C-factor. Another approach was taken by Mertz-Fairhurst and others in a landmark study on ultraconservative cariostatic sealed restorations.[53] They used 45° to 60° enamel bevels at least 1 mm wide but did not excavate carious dentin. This cavity conformation likely attained a highly favorable C-factor. An autocured highly-filled hybrid composite was placed and shaped, then covered with bonded fissure sealants. These restorations, placed directly over carious dentin in frankly cavitated lesions, arrested carious progress for 10 years, despite frequent loss of marginal seal. That data indicated that shallow sealed hybrid composite restorations are capable of conserving tooth structure, preventing recurrent caries, and extending restoration survival. That data also indirectly suggested that both the use of flowable composites and narrow deep fissurotomy preparations must be critically examined, or at least compared with other preparation designs.

The authors recognize that the generally disappointing results of this current study cannot necessarily be extrapolated to clinical performance. However, the authors advocate that minimally invasive Class I composite restorations be restored using long-used and well-studied conventional microhybrid composites until flowable composites have been validated in long-term controlled clinical trials.

CONCLUSIONS

Microleakage varied substantially, by a whole order of magnitude, among the material groups tested. The control group, a conventional microhybrid composite material used with its manufacturer's recommended bonding agent, leaked significantly less than a wide variety of flowable composites used with their manufacturers' recommended bonding agents. Microleakage varied very slightly among measurement site locations. Tiny microbubbles were seen within many of the flowable composite specimens, as were a few voids.

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