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Microleakage Evaluation of a New Low-shrinkage Composite Restorative Material

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Clinical Relevance

Incremental placement remains the preferred restorative technique for direct composites. To reduce the effects of polymerization shrinkage on marginal quality, the low-shrink Hermes system might become a good alternative in clinical practice.

SUMMARY

Purpose: This study compared the microleakage of an experimental low-shrinkage resin composite (Hermes), a nanofilled resin composite material (Filtek Supreme) and a hybrid resin composite (Tetric Ceram) using a dye penetration method. Methods and Materials: Class I cavities prepared in 60 human molars were randomly divided into 3 groups according to the restorative material used. The preparations were restored using a bulk or an incremental technique. Half of the specimens from each group were subjected to 200,000 cycles of loading at 50 N, while the other half were stored in distilled water for 24 hours at 37°C. All specimens were immersed in 1% methylene blue (pH = 7.0) for 24 hours and sectioned into 3 slabs. The margins were evaluated for microleakage using an ordinal scoring system (0-4) under a stereomicroscope at 40x magnification. Data were subjected to the non-parametric Kruskal-Wallis analysis of variance and Mann-Whitney test (*p*<0.05). Data were expressed as median leakage scores and mean ranks.

Results: All of the restorative systems had microleakage, regardless of the insertion technique and mechanical load cycling. Incremental placement significantly reduced microleakage as compared to the bulk technique, regardless of the restorative system used. Load cycling significantly affected incrementally placed restorations, except for the Hermes system.

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INTRODUCTION

Resin composite materials have improved greatly since their introduction more than 40 years ago.[1] Although composites are now the material of choice for most restorations,[2] their polymerization shrinkage remains a problem.[3-4] The contraction stress associated with this shrinkage can cause debonding at the composite/tooth interface and can contribute to post-operative sensitivity, enamel fracture, recurrent caries, marginal staining and eventual failure of the restoration.[4-5] Although little or no clinical evidence sustains the hypothesis that composite materials with greater polymerization shrinkage have poorer clinical performance, laboratory data from several studies support this belief.[4,6-8]

Several restorative techniques have been proposed to minimize polymerization shrinkage. One involves the application of an intermediate low-modulus liner between the prepared tooth structure and the resin composite, which would contribute to a homogenous distribution of stress over the adhesive interface.[7] Another approach is to reduce the polymerization rate by using an initial low-intensity curing light exposure,[4,8] which would allow deformation to occur during the polymerization process and, consequently, decrease the tensile forces exerted by the hardening material.[7-9] A third approach is incremental placement of the restorative material. It has been suggested that an oblique incremental restorative technique could limit the effects of polymerization shrinkage at the cavosurface margins.[7] The rationale for this concept is that marginal integrity would be improved regardless of the light-curing method or rate, because the occlusal-most layer would never be tied simultaneously to both facial and lingual enamel margins. Small increments with greater free surfaces in lieu of bonded ones would compensate for polymerization stresses rendering a better integration between the composite and tooth structure, thus resulting in a better-sealed restoration.[10-11]

Other factors also can be considered. One example is the cavity configuration factor (C-factor), which describes the ratio of bonded surfaces to unbonded surfaces in a restoration.[8] With the use of bonded shrinking polymeric materials,[10,12] high C-factors are accompanied by greater internal stresses. Recently, Choi and others[13] demonstrated that thicker layers of a low-modulus adhesive system can decrease contraction stress of the associated resin composite material and enhance the marginal seal.

The clinical methods used to avoid polymerization shrinkage can be time-consuming, and some of the procedures remain unproven or controversial.[6,14] There are other approaches to overcome polymerization shrinkage that involve modifications of formulation of the material, such as an increase in the filler content, an increase in molecular weight per reactive group and the use of ring opening monomers, which are known for their low polymerization shrinkage.[15-16]

For dental purposes, Siloranes, a new class of ring-opening monomers, were synthesized to overcome the problems related to polymerization shrinkage.[15] This new type of monomer can be described as an arrangement of siloxanes and oxiranes, combining the properties of both, such as biocompatibility, hydrophobicity, high reactivity and low shrinkage.[15-16] Using the Archimedes method,[16] the volumetric shrinkage of a silorane-based composite was determined to be 0.99 vol%.

Weakening of the adhesive resin due to mechanical loading is an important issue in restorative dentistry. Studies suggest that occlusal mechanical cycling could accelerate deterioration of the dentin/restoration interface.[17-20] In many experimental protocols, the evaluation of sealing ability has included mechanical load cycling.[18-19,21]

Therefore, this research compared the microleakage of a low-shrinkage resin composite (experimental restorative material Hermes, 3M ESPE, Seefeld, Germany), a nanofilled resin composite (Filtek Supreme, 3M ESPE, St Paul, MN, USA) and a hybrid resin composite (Tetric Ceram, Ivoclar Vivadent, Schaan, Lietchtenstein) by means of dye penetration. This study evaluated 3 independent variables: type of composite, insertion method and load cycling.

METHODS AND MATERIALS

The occlusal surfaces of extracted human molars (n=60) were ground with 320-grit silicon carbide paper under running water to produce a flat surface perpendicular to the long axis of the tooth but without removing all of the occlusal enamel. Class I cavity preparations, approximately 6-mm in length, 4-mm in width and 3-mm in depth, were prepared using a 245 carbide bur. The cavosurface margins were prepared at 90°. The teeth were randomly divided into 3 groups according to the restorative material used:

(A) Experimental Hermes resin composite with Hermes Bond self-etch adhesive system (3M ESPE). The adhesive was applied using a microbrush with agitation for 15 seconds, gently air-dried, then a second coat was applied followed by a gentle stream of air. The adhesive was light-cured for 10 seconds.

(B) Filtek Supreme resin composite with Single Bond adhesive system (3M ESPE). A 35% phosphoric acid gel was applied for 15 seconds and rinsed for 10 seconds. The tooth was blot-dried, leaving a moist structure. Two consecutive coats of Single Bond adhesive system were applied and gently dried for 2 to 5 seconds. The adhesive was light-cured for 10 seconds.

(C) Tetric Ceram with AdheSE self-etching adhesive system (Ivoclar Vivadent). The AdheSE primer was vigorously scrubbed onto the tooth surface for 15 seconds, and the excess primer was dispersed with a long stream of air. AdheSE bonding agent was applied and dispersed with a weak stream of air followed by polymerization for 10 seconds.

All adhesive systems were light-cured using an Elipar Freelight 2 light-curing unit (3M ESPE).

The teeth were restored using 2 different techniques:

Technique 1—Bulk technique (Figure 1 A): A single 3-mm-thick composite increment was placed in bulk, contacting all cavosurface margins. This single increment was light-cured according to the manufacturer's instructions at a power density of approximately 1000 mW/cm² using an Elipar Freelight 2 light-curing unit to allow maximum stress development. After 1 minute, the restoration was polished using Sof-Lex brushes (3M ESPE).

Technique 2—Oblique incremental technique (Figure 1C): The first 1-mm composite increment was placed on the pulpal floor and was light activated according to the manufacturer's instructions at a power density of 1000 mW/cm². A 2-mm thick composite increment was placed obliquely from the occlusal-facial line angle to the lingual-pulpal angle and was light-cured at a power density of 1000 mW/cm². A second oblique 2-mm composite increment was placed to complete the restoration and was light-cured, similar to the previous increments. All increments were light-cured using an Elipar Freelight 2 light-curing unit. After 1 minute, the restoration was polished as previously described.

The experimental design is summarized in Table 1. Half of the specimens restored with each technique were subjected to mechanical load cycling using a Leinfelder Wear Test Apparatus modified for loading tests (Figures 1B and 1D). The apparatus consisted of 4 stainless steel pistons in which a polyacetal cylinder tip was attached to the end. The specimens were mounted in acrylic resin and kept wet by immersion in distilled water. The polyacetal tips were placed in contact with the restorations. The loading device delivered an intermittent axial force of 50 N for 200,000 cycles.

Microleakage Evaluation

For microleakage evaluation, the root apices were sealed with wax, and the root and crown surfaces of the teeth were sealed with 2 coats of nail varnish except for 1 mm around the restoration margin. The teeth were then immersed in 1% methylene blue (pH=7) for 24 hours, washed and dried. Next, the teeth were sectioned in a sagittal plane into 3 slabs using a slow-speed diamond saw (Isomet, Buehler Ltd, Lake Bluff, IL, USA). Four sites per slab (cavosurface angle to pulpal wall from facial and lingual walls) were examined under an optical stereomicroscope at 40x magnification and dye penetration was scored as described in Table 2.

A total of 6 measurements per margin (facial and lingual) were made. The median of the scores was sub-

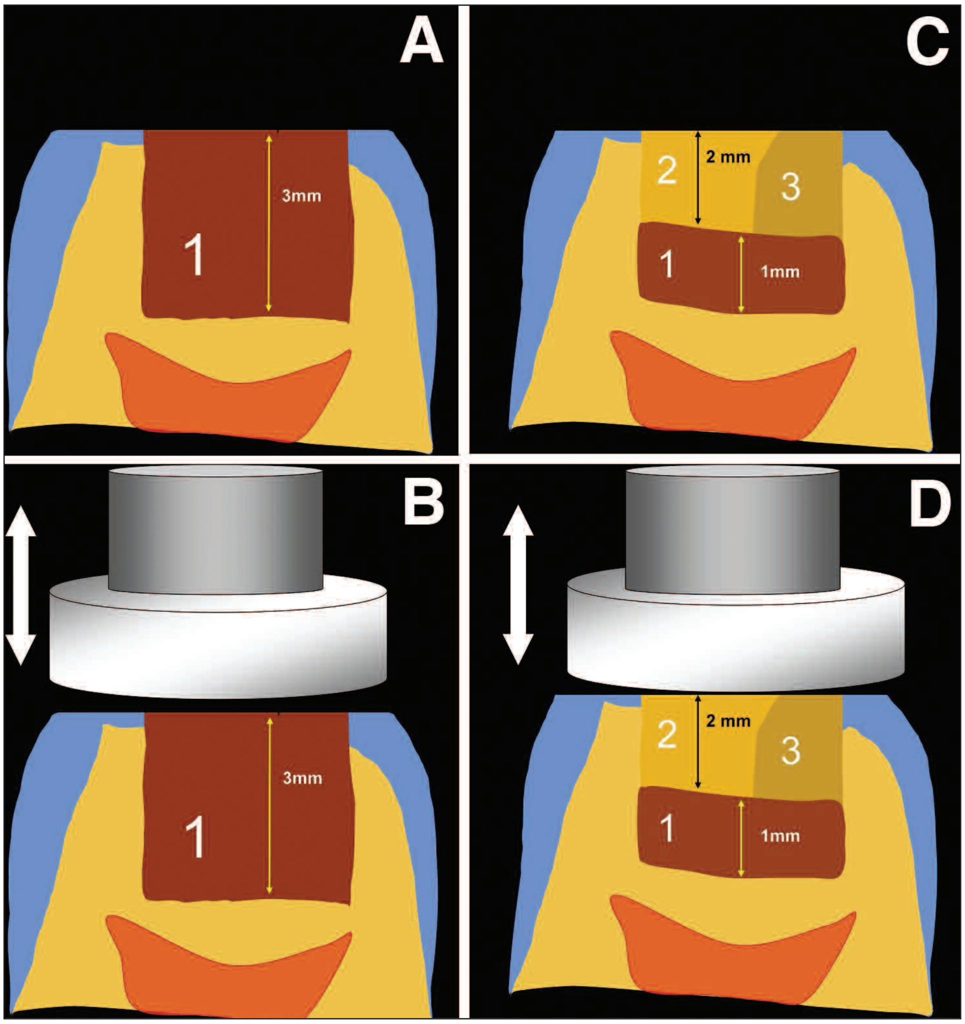

Figure 1: *Scheme of the incremental technique used in this study. A–Bulk Technique. The resin-based composite was placed in 1 increment and cured while in contact with all cavosurface margins. B–Bulk Technique + Application of Loading. Polyacetal tips were placed in contact with the restoration at 50N for 200,000 cycles. C–Oblique incremental technique. The resin-based composite was placed in 3 increments, and the last 2 increments (2 and 3) were cured separately onto the opposing buccal and lingual enamel cavosurface margins. D–Oblique Incremental Technique + Application of Loading. Polyacetal tips were placed in contact with the restoration at 50N for 200,000 cycles.*

jected to statistical analysis using the non-parametric Kruskal-Wallis analysis of variance test and the Mann-Whitney test (p<0.05)

RESULTS

Median leakage scores and mean ranks for each group are listed in Table 3, and images illustrating the different microleakage scores (see Table 2) are shown in Figure 2. The Kruskal-Wallis test indicated significant differences between groups (p<0.05).

When specimens were not subjected to loading, the incremental insertion technique resulted in significantly lower microleakage than the bulk insertion technique for each of the 3 materials tested. Also, the microleakage of each system was similar when the same placement technique was used.

However, mechanical loading significantly increased leakage for Single Bond/Supreme and AdheSE/Tetric Ceram systems, but not for Hermes, which was placed using the incremental technique. Loading did not increase leakage of bulk-filled restorations.

Regardless of the insertion technique used, specimens restored with the Hermes system had a higher incidence of internal gaps (Figure 2C) as compared to the Single Bond/Supreme system. The internal gaps did not affect microleakage values when the restoration margins were adequately sealed. This study did not specifically look for internal gaps; rather, these gaps were observed incidentally during microleakage evaluation under the microscope.

Table 1: *Summary of Experimental Design*

Group	Material	Insertion Technique	Mechanical Load Cycling
1	Hermes System	Bulk	0
2	Hermes System	Bulk	200,000
3	Hermes System	Incremental	0
4	Hermes System	Incremental	200,000
5	Filtek Supreme	Bulk	0
6	Filtek Supreme	Bulk	200,000
7	Filtek Supreme	Incremental	0
8	Filtek Supreme	Incremental	200,00
9	Tetric Ceram	Bulk	0
10	Tetric Ceram	Bulk	200,000
11	Tetric Ceram	Incremental	0
12	Tetric Ceram	Incremental	200,000

Table 2: *Dye Penetration Score Criteria Used in This Study*

Score	Criteria
0	No evidence of dye penetration at the tooth/restoration interface.
1	Dye penetration along the cavity wall up to one-third of the cavity depth.
2	Penetration greater than one-third, but less than two-thirds of the cavity depth.
3	Penetration greater than two-thirds of the cavity depth, but not along the dentinal tubules.
4	Penetration to the cavity depth, and along the dentinal tubules.

DISCUSSION

Resin composites have become the material of choice in restorative dentistry, especially due to their esthetic properties, the adhesive concept and patient demand. Even though modern composites have better mechanical and physical properties[14] than earlier methacrylate-based composite materials, polymerization shrinkage remains a major problem, and many efforts have been made to reduce it, either by changing material formulations or by using different clinical techniques.[6,8,15] According to Ferracane,[6] the polymerization shrinkage

Table 3: *Median Leakage Scores and Mean Ranks of the Groups Tested*

Materials	Insertion Technique	Microleakage Scores			
		No Loading		Loading	
		Median	Mean Rank	Median	Mean Rank
Hermes System	Bulk	1.75	77.30[b,c]	1	58.75[a,b]
	Incremental	1	38.05[a]	1	29.75[a]
Single Bond/Supreme	Bulk	2	75.60[b,c]	2.5	90.20[c]
	Incremental	1	30.40[a]	1.25	71.60[b,c]
AdheSE/Tetric Ceram	Bulk	1	71.60[b,c]	1.5	74.30[b,c]
	Incremental	1	42.45[a]	1	66.00[b,c]

Same superscript letter indicates no statistically significant difference between groups.

of dental composites is on the order of 1.5-5%, enough to result in the development of internal stresses that might reduce the service life of a composite restoration. A new resin composite material, Experimental Hermes system, was developed to overcome this issue.[15-16] The results of this study showed that the new low-shrink composite restorative material had significantly less microleakage after mechanical load cycling than Single Bond/Supreme and AdheSE/Tetric Ceram, especially when the materials were used with the oblique incremental technique.

This study compared the microleakage of a new low-shrinkage resin composite to a nanofilled composite restorative material and a hybrid resin composite. All 3 resin composite materials used in this study had some degree of leakage. Microleakage evaluation is the most common method of assessing the sealing efficiency of a restorative material.[22] There is no gold standard for this method, and the authors used 1% methylene blue for 24 hours as was previously used in the literature.[22-23] Class I cavities were used due to the high C-factor ratio that causes greater polymerization stresses[10] as a result of restrained contraction by the bonded surfaces.

When the same insertion technique was used, there was no significant difference in leakage between composite materials without mechanical load cycling. On the other hand, there was a statistically significant difference between bulk and incremental filling techniques, with the latter resulting in less microleakage. These findings are in accordance with other studies in which use of the incremental placement technique resulted in less microleakage for Class II resin-based composite restorations.[24-26] An incremental filling technique has been widely used by many clinicians, and it is believed to reduce stress in the restoration interface, even though a theoretical study using finite element analysis by Versluis and others[26] showed that the oblique incremental technique could produce higher polymerization shrinkage values than the bulk technique.[27] The bulk application of resin composite might not allow for complete polymerization of the light-curing material,[2] and it might increase internal stresses,[10-11] resulting in partial debonding of the restoration on areas where the bond strength of the adhesive is lower than the tensile forces generated by resin-based composite shrinkage.[2,8]

The best method of simulating *in vivo* conditions with laboratory techniques is yet to be determined.[14] In this study, the application of mechanical loading using modified Leinfelder wear test apparatus was performed. The force of 50 N was chosen to represent a medium-low force during mastication, which, when employed with a high number of cycles, such as 200,000, can promote a continuous stroke aimed to fatigue primarily the restoration interface.[19-20]

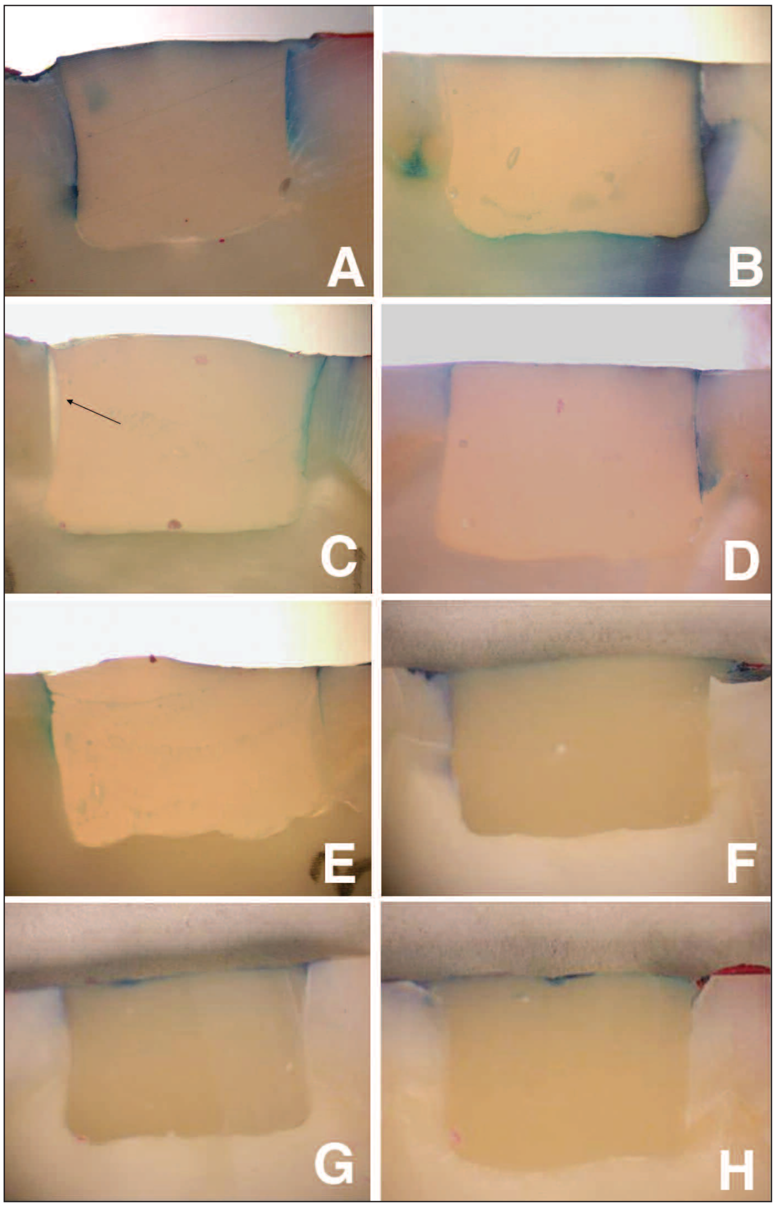

Figure 2: *Representative photomicrographs of the microleakage scores used in this study. A–Hermes System bulk technique. Dye penetration score 3 (left margin) and score 2 (right margin). B–Single Bond/Supreme bulk technique. Dye penetration score 0 (left margin) and 4 (right margin). C–Hermes System bulk technique. Dye penetration score 0 (left) and 3 (right). Black arrow = internal gap. D–Single Bond/Supreme incremental technique. Dye penetration score 1 (left) and 3 (right). E–Hermes System incremental technique. Dye penetration score 2 (left) and 2 (right). F–AdheSE/Tetric Ceram bulk technique. Dye penetration score 3 (left) and 0 (right). G–AdheSE/Tetric Ceram incremental technique. Dye penetration score 1 (left) and 1 (right). H—AdheSE/Tetric Ceram bulk technique. Dye penetration score 1 (left margin) and 1 (right margin).*

The application of loading significantly affected the results of the incrementally placed nanofilled and hybrid composite restorative materials. This was probably due to masticatory forces which can be detrimental to the long-term durability and adaptation of composite restorations, thus, being of considerable value in *in vitro* studies.[28] It is also hypothesized that, since silorane technology provides lower polymerization shrinkage and related polymerization stress than methacrylate-based composite materials,[16] it should be able to withstand fatigue at the interface better than the nanofilled and micro-hybrid composites tested in this study.

Loading did not affect microleakage results when the bulk filling technique was used. This may be observed, because the internal stresses developed when the composite material is placed in bulk are already high, thus the fatigue applied in the restoration interface did not cause a higher degree of leakage.

One group (Single Bond/Supreme) used a total-etch adhesive system, and this type of bonding procedure should more likely reduce leakage at enamel margins.[29] However, that was not the case in this study.

The Hermes system had a greater incidence of internal gaps, but these gaps did not affect microleakage values when the margins were adequately sealed. The authors believe that the formation of internal gaps occurred during placement of the resin composite, probably because the viscosity of the material compromised adaptation to the cavity walls. Internal gaps were more common in the bulk insertion technique. Even though a study by Weinmann and others has shown that silorane technology provides better mechanical properties than methacrylate-based composite materials,[16] the effect of these internal gaps should be further investigated.

Both shrinkage and elastic modulus increase with time; thus, internal stresses increase in an incremental manner.[6] As resin composites still undergo contraction stress over time and damage of marginal sealing after water storage,[14] long-term data are still necessary. In addition, it has been demonstrated that the association of mechanical loading with thermal cycling may significantly increase leakage values.[22,29] Thus, further studies evaluating the influence of storage and thermal cycling on microleakage are required.

CONCLUSIONS

Within the limitations of this study, the authors concluded that:

- None of the restorative systems and insertion techniques tested totally prevented microleakage.
- The use of an incremental technique resulted in significantly less microleakage than use of a bulk technique, regardless of the restorative system employed. For Class I cavities, the incremental technique should be the elective restorative technique.
- Mechanical load cycling significantly increased microleakage when the Single Bond/Supreme and AdheSE/Tetric Ceram restorative systems were placed incrementally.
- When the Hermes system was used, mechanical load cycling did not significantly affect microleakage, regardless of the insertion technique.
- The low-shrink Hermes system had significantly less microleakage after mechanical load cycling than Single Bond/Supreme and AdheSE/Tetric Ceram, especially when the materials were used with the incremental technique.

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