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Effect of Pre-heated Composites and Flowable Liners on Class II Gingival Margin Gap Formation

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Clinical Relevance

The use of reduced viscosity composites, such as flowable and pre-heated resins, as the first increment in Class II preparations, did not improve gingival margin adaptation nor did it minimize gap formation at the dentin-composite interface.

SUMMARY

Purpose: To evaluate the effect of preheated composites (PHC) and flowable liners (FL) on the gingival margin gap formation of Class II composite restorations compared to the placement of room temperature composites (RTC). Materials and Methods: Class II composite restorations were prepared on 40 extracted mandibular third molars, with the gingival margin located 1 mm below the CEJ in dentin. Optibond FL (Kerr), microhybrid Filtek Z-250 (3M ESPE) and Flow-It (Jeneric Pentron) were used to evaluate five study groups: 1) PHC, 130°F/54.4°C; 2) PHC, 155°F/68.3°C; 3) FL cured prior to the first increment composite; 4) FL cured simultaneously with the first increment composite and 5) RTC (Control). Impressions were taken with quick set polyvinyl siloxane impression material, and epoxy resin replicas were evaluated under SEM (200x). Gingival margin adaptation was quantitatively evaluated in terms of percentage of gap formation according to a modified ordinal scoring criteria. All margins were evaluated twice for reliability assessment. A non-parametric Kruskal-Wallis test was used to determine whether significant differences in gap formation existed among the study groups. Results: A high level of agreement was observed between dupli-

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cate measurements of the percentage of gap formation (intra-class correlation = 0.956, $p<0.0001$). There was no evidence of a difference among groups defined by placement technique ($p=0.82$). Overall, the mean gap-percentage for the 40 margins evaluated was 6.3 (Median=1.1; SD=14.8). Conclusions: Gingival margin adaptation was not improved relative to the control by any of the placement techniques tested. No significant differences in gap formation were found among the study groups. A high degree of intra-examiner reliability was confirmed.

INTRODUCTION

As adhesive technology continues to evolve and newer and improved adhesive and composite systems are developed, the use of posterior composites continues to gain popularity. A number of the early drawbacks of posterior composite restorations no longer represent a challenge with currently available materials. Improved dentin adhesive systems offer increased bond strengths and enhanced marginal sealing.[1] Stronger, more wear-resistant composite systems have been developed for use in stress-bearing areas. However, polymerization shrinkage remains an unavoidable problem, which may compromise the integrity and longevity of posterior restorations,[2] particularly those with margins in dentin.[3] The potential for marginal gaps and microleakage increases with cavosurface margins in dentin due to the biological variability of this tissue.[4] The presence of shrinkage-induced gaps at the composite-tooth interface may lead to post-operative complications, such as restoration fracture, leakage, sensitivity, staining and recurrent caries,[2] all of which may contribute to early failure of the restoration.

Approaches to minimize the adverse effects of polymerization shrinkage and gap formation have primarily focused on the modification of conventional placement techniques, including incremental placement,[5-6] soft-start polymerization[7-9] and the use of liners with a low modulus of elasticity as stress relievers.[10]

The use of liners with a low elastic modulus as the first increment under composite restorations has become well accepted in recent years, with the availability of materials, such as glass ionomers and flowable resins. However, the benefit of using flowable liners to reduce microleakage and improve gingival margin adaptation is still controversial, with studies showing improvement,[11-14] no effect[15-20] and even deterioration of the marginal adaptation and microleakage.[21-22]

A number of studies showing improved margin adaptation with flowable liners have attributed their results to reduced viscosity of the material, which allowed it to better wet the preparation walls.[11,23] The use of flowable liners, however, involves a restorative compromise. Their enhanced flowability may contribute to better wetting of the preparation walls, as well as providing a stress-absorbing layer during polymerization.[10] On the other hand, the reduced viscosity is achieved by lowering the filler concentration. Consequently, physical properties, such as polymerization shrinkage and strength, are negatively affected.[24-25] The thickness of the flowable resin liner and whether the liner is polymerized prior to or simultaneously with the overlaying resin have also been investigated, with the hypothesis that thinner liners may result in better margin adaptation, since less polymerization shrinkage is expected to occur in thinner increments.[11,13]

A commercially available unit (Calset, AdDent Inc, Danbury, CT, USA), which preheats resin composites prior to their application into the preparation, offers promise. By preheating the composite to one of the preset temperatures, 98°F (37°C), 130°F (54°C) or 155°F (68°C), a transient viscosity reduction comparable to that of flowable resins can be obtained.[26] A high strength, highly filled material with less shrinkage could then be used as the initial gingival increment, while still being able to take advantage of the transient viscosity reduction of the material for an enhanced wetting of the preparation walls. Preliminary studies have demonstrated improved flowability and handling characteristics of preheated resins without alteration of their physical properties.[27] A strong positive correlation between temperature and monomer conversion has also been demonstrated *in-vitro* with preheated composites requiring less light exposure to achieve higher conversion values compared to room temperature photopolymerization.[28-29] By achieving higher final monomer conversion values, the amount of residual unreacted monomer, which may potentially leach into the oral cavity, is also reduced.[28]

Limited information is available on the effect of preheated composites on the microleakage and marginal adaptation of Class II composite restorations. A laboratory study found significantly less microleakage at the cervical margin of Class II restorations with preheated composites, compared to the use of a conventional unheated hybrid or flowable liner.[30] With resin composite restorations, it has been widely assumed that microleakage and margin adaptation can be directly correlated.[31] However, this relationship may not be as clear-cut as is widely assumed.[32-33] Microgaps present at the restoration margin may leak, but this may not always be the case. Conversely, penetration of nano-size particles from the dye may be observed, irrespective of the presence of gaps at the margin. Given that microleakage and margin adaptation represent different outcome measurements, direct comparisons with other studies in the literature reporting on the effect of preheated composites on microleakage[29-30] are not appropriate. The authors are not aware of any studies reporting on the effects of preheated composites on the

gingival margin adaptation of Class II composite restorations.

The present study evaluated the effect of preheated composites (PHC) and flowable liners (FL) on the gingival margin gap formation of Class II composite restorations as compared to the conventional placement of room temperature composite (RTC) 24 hours after polymerization. Furthermore, this study aimed to evaluate the effect of two different placement techniques with flowable liners and two different temperatures of preheated composite on Class II gingival margin gap formation. The null hypothesis was that there would be no difference in gingival margin gap formation among the placement techniques.

METHODS AND MATERIALS

Forty extracted human mandibular third molars free of caries or restorations were selected, cleaned and stored in a thymol solution at room temperature (74°F/23.3°C) until needed. All preparation and restorative procedures were performed in a temperature-controlled environment (23 ± 2°C) by a single operator who rehearsed material handling a number of times prior to beginning the study.

Cavity Preparation

Standardized slot Class II composite restorations were prepared in either the mesial or distal aspect of molars with the following dimensions: 4 mm wide x 4 mm high x 2 mm deep, with the gingival margins located 1 mm below the CEJ in dentin. Either the mesial or distal surface was selected for preparation, depending on which surface was smoother. The different placement techniques were tested, with the gingival margins in dentin, as these are known to exhibit greater clinical challenges than enamel margins.[3] In order to standardize the distance from the light-curing tip to the gingival wall of the preparation, the cusps were flattened to a working distance height of 4 mm measured from the gingival margin in an occlusal direction. A diamond bur (845 KR–size 025, Brasseler, Savannah, GA, USA) in an air/water cooled high-speed turbine and a straight fissure carbide bur (#57, Brasseler) on slow speed were used for preparation and refinement of all Class II restorations. All cavosurface margins were prepared as butt-joint and all internal line angles were slightly round.

Restorative Procedures

The prepared teeth were individually fixed to a stone mold by embedding the roots in a quick-set vinyl polysiloxane impression material (Template, Clinician's Choice, New Milford, CT, USA), and a custom matrix band (AutoMatrix Retainerless Matrix System, Dentsply-Caulk, Milford, DE, USA) was adapted to the tooth. All the preparations were etched with 37.5% phosphoric acid (Gel Etchant, Kerr Corp, Orange, CA, USA) and a three-step etch-and-rinse adhesive system was applied (Optibond FL, Kerr Corp) according to the manufacturer's instructions and polymerized for 20 seconds. An LED light-curing unit (G-light, GC America, Alsip, IL, USA) was used for all procedures. An irradiance of at least 800 mW/cm^2 was ensured at all times by periodically monitoring the intensity of the light (Optilux radiometer, Kerr Corp). The 40 molars were randomly assigned to five study groups with eight specimens (N=8) per group as follows: Group 1: Preheated composite (PHC) to 130°F/54.4°C placed in 2-mm increments. Group 2: Preheated composite (PHC) to 155°F/68.3°C placed in 2-mm increments. Group 3: A 0.5- to 1-mm layer of flowable liner (FL) injected onto the gingival margin and immediately polymerized for 20 seconds; the remaining bulk of the preparation was filled with unheated resin in 2-mm increments. Group 4: A 0.5- to 1-mm layer of flowable liner (FL) injected onto the gingival margin and immediately followed by a 2-mm increment of unheated resin over the uncured liner; the two layers were polymerized simultaneously. Group 5 (Control): Room temperature composite (RTC) placed in 2-mm increments. All the increments were polymerized for 40 seconds from the occlusal aspect, except for the flowable liner in Group 3, which was polymerized for 20 seconds prior to application of the unheated resin. Groups of five specimens at a time, each corresponding to a study group, were restored. Randomization in the restorative procedures was done to avoid bias relative to sequence of the tooth restoration.

Microhybrid resin (Filtek Z-250, 3M ESPE, St Paul, MN, USA) and flowable resin (Flow-It, Pentron Clinical Technologies, Wallingford, CT, USA), both in shade A2, were used for all the restorative procedures. For groups 1 and 2, a commercially available unit (Calset, AdDent Inc) was used to preheat the resin prior to its application into the preparation. Only two of the heater's available settings were used in the current study: 130°F/54.4°C and 155°F/68.3°C. Two units were used for this purpose; each was kept at the desired temperature during the restorative procedures. An assembly of a composite compule held by a carrying gun was placed in the heating unit and left in place for five minutes to reach the desired preset temperature. A previously completed pilot study found that it takes approximately 10 minutes for the heating unit to reach the desired preset temperature from the moment it is turned on. At this time, the assembly of a composite compule held by a carrying gun is placed into the unit. The same pilot study found that it takes approximately five minutes for the composite material inside the compule to reach the desired temperature from the moment the assembly is placed into the already heated unit. Since fluctuations in flowability are expected to occur rapidly upon cooling of the resin, the same pilot study was used to

determine the cooling rate of the preheated resin. Figure 1 shows a graphic representation of the temperature change as a function of time for a resin preheated to 130°F/54.4°C. Resin preheated to 155°F/68.3°C showed the same trends. Based on the results of this pilot study, the time for placement of the first increment of resin for all the study groups was kept under 10 seconds.

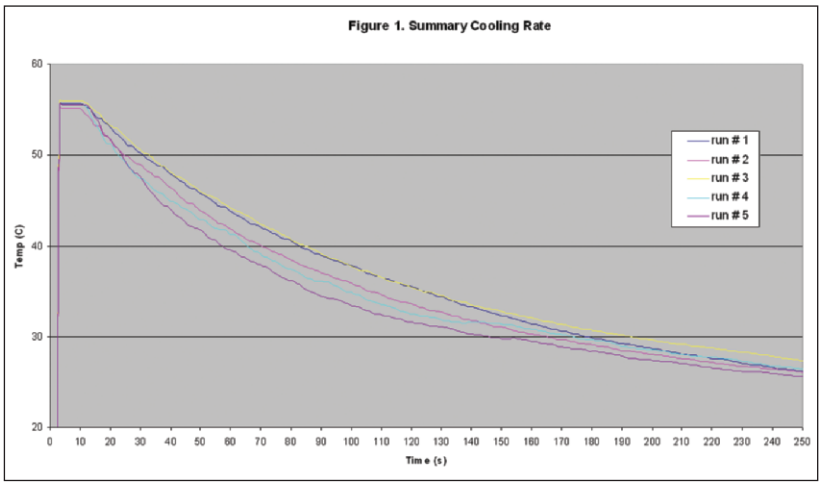

Figure 1. *Temperature change (in °C) of resin composite as a function of time (in seconds).*

Restoration Polish and Storage

Immediately after placement and polymerization of the last increment of resin, the tooth was removed from the base for finishing and polishing of the margins. A series of coarse, medium and fine finishing and polishing discs (Sof-Lex System, 3M ESPE) were used for removal of overhangs, as these could potentially interfere with an accurate reading of the preparation margins. After polishing, the specimens were rinsed under running tap water and stored in artificial saliva solution in a temperature-controlled environment (23 ± 2°C) for a minimum of 24 hours before the impression procedures. The specimens were never kept in the solution for more than 36 hours.

Replica Technique and SEM Evaluation

Prior to the impression procedure, the specimens were cleaned with 5.25% sodium hypochlorite solution (household bleach) for 30 seconds to remove contaminants and smear layer debris from the tooth-restoration interface. Immediately after cleaning, the specimens were rinsed under copious tap water and air-dried to remove excess moisture. An initial impression was made with a light body vinyl polysiloxane impression material (Extrude, Kerr Corp) to further remove any smear layer debris from the tooth-restoration interface; these impressions were discarded. A second impression with the same impression material followed immediately. These, if accurate upon visual inspection, were then stored in a hermetically-sealed plastic container at room temperature for 24 hours and poured with a low-viscosity epoxy resin (Epoxicure, Buehler Ltd, Lake Bluff, IL, USA) to produce positive replicas of the restorations. A period of at least 24 hours before pouring the impressions with epoxy resin has been recommended to avoid the incorporation of air bubbles in the epoxy replica, which may be caused by the liberation of gases during the setting reaction of the vinyl polysiloxane (personal communication with Dr Blunck). Epoxy replicas were left to set undisturbed for eight hours before gold sputter-coating for four minutes at a current of 30 milliampers.

Using eight to 10 images per replica, the entire gingival margin and at least 0.2 mm into the buccal and lingual wall margins were captured. The images were obtained with a field emission scanning electron microscope (AMRAY 1820D, Amray, Inc, Bedford, MA, USA) at a magnification of 200x. The sequence of images per replica was stitched together with computer software (Photoshop 7.0, Adobe Systems Inc, San Jose, CA, USA) (Figure 2). Cervical margin micromorphology was evaluated by a blinded evaluator who used image software (Image-Pro Plus version 5.1.0.20, BioImaging. Solutions Inc, San Diego, CA, USA) to trace the complete length of the evaluated margin and to quantitatively assess the quality of the margin. The evaluator assigned one of seven "margin quality" (MQ) scores to each of the margin sections according to the modified

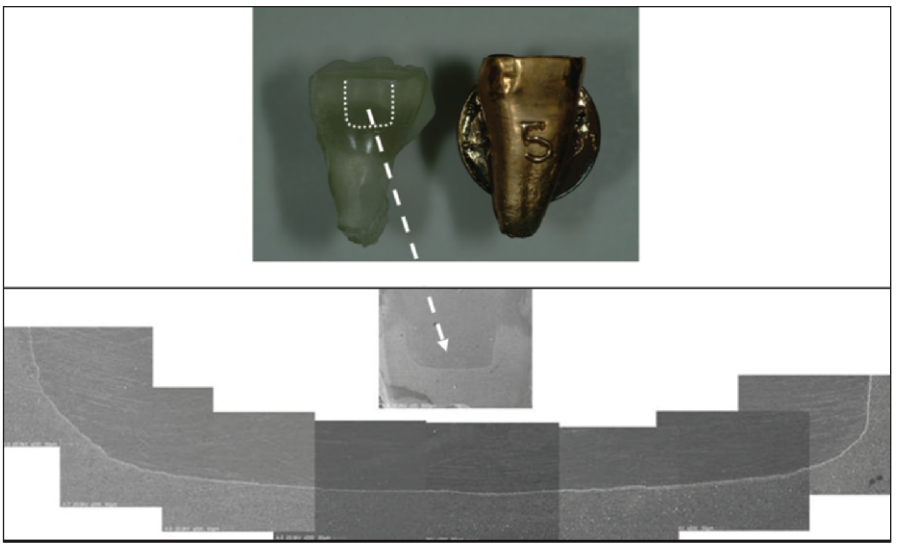

Figure 2. *Sequence of eight images of a single specimen stitched together using Photoshop 7.0.*

Table 1: *Gingival Margin Micromorphology Scoring Criteria*

Margin Quality	Description	Scoring Criteria Summarized	Score	
MQ1	Perfect margin (hardly visible)	**MQ1** + **MQ2** (Margin not or hardly visible, no or slight marginal irregularities; no gap)	Score 1	No Gap
MQ2	Margin visible, no gap			
MQ3	Margin irregularities (like bulbs, minor swelling) but no gaps	**MQ3** (No gap but severe marginal irregularities)	Score 2	
MQ4	"Hairline" crack: sharp and clear discontinuation (gap width <2 µm) at the margin without any irregularities	**MQ4** (Gap visible (hairline crack up to 2 µm wide), no marginal irregularities)	Score 3	Gap
MQ5	"Hairline" crack (gap width <2 µm) + minor margin irregularities or gap width <5 µm without any irregularities	**MQ5** + **MQ6** + **MQ7** (Severe gap (more than 2 µm wide), slight and severe marginal irregularities)	Score 4	
MQ6	Gap formation (gap width <5 µm) + heavy margin irregularities			
MQ7	Gap formation (gap width >5 µm)			

No Gap: Score 1 & 2 = MQ1 + MQ2 + MQ3; Gap: Score 3 & 4 = MQ4 + MQ5 + MQ6 + MQ7.

ordinal scoring criteria described by Blunck[34] as indicators of marginal integrity. Table 1 provides definitions for each of the original seven outcome measures (MQ1-MQ7) used for assessment of the margins *in-vitro*, as well as a description of how the data were summarized for statistical purposes into the derived measures (Score 1–Score 4). The length of the margin that was involved (had a gap) was measured and expressed as a percentage of the total evaluated margin. Repeated scores in different sections of the margin were added to determine the total percentage relative to the complete length of the evaluated margin. After preliminary assignment of the "margin quality" scores *in-vitro*, the data were summarized for statistical purposes into four "margin scores." These were further simplified into the two nominal categories of "Gap" and "No Gap" (Table 1). Results of the gingival margin gap formation were expressed as the percentage of open margins (gaps) relative to the complete length of the evaluated margin.

Statistical Analyses

All of the margins were evaluated twice by the same evaluator for reliability assessment. Duplicate measurements of the percentage of gaps relative to the complete evaluated length of the margin were analyzed to determine intra-class correlation. The percentage of gaps to the complete evaluated length of the dentin-composite interface was adjusted for artifacts (portions of the interface that could not be evaluated due to factors, such as contaminants, air bubbles or overhangs covering the margin). Ordinal data from the marginal gap formation scores was analyzed using the non-parametric Kruskal-Wallis test to assess whether significant differences in the distribution of gap formation existed among groups.

RESULTS

Intra-examiner Reliability Measurements

Intra-class correlation (ICC) coefficient results for the seven measured outcomes and five derived measures (Score 1–Score 4 and Gap) yielded a high level of agreement between duplicate measurements of percentage of gap formation relative to the complete evaluated length of the composite-dentin interface (ICC=0.956, $p<0.0001$) (Table 2).

Although all ICC scores were significant at the conventional 0.05 level, reliability was high for MQ1, MQ2, MQ3 and MQ7 (ICC of 0.947, 0.969, 0.901 and 0.979, respectively), moderately high for MQ5 (0.729) and low for MQ4 and MQ6 (0.313 and 0.364, respectively). Reproducibility was also reflected in the five derived measures, yielding exceptionally good agreement for percentage of gap formation relative to the complete evaluated length of the margin (ICC=0.956, $p<0.0001$) (Table 2).

Margin Adaptation Scores

Main margin adaptation score results for the dentin-composite interface of all specimens are provided in Figure 3 and Table 3. No significant difference was evidenced in terms of the percentage of gap formation among groups defined by the placement technique ($p=0.82$). Although the results were not statistically significant, an outlier in group 2 shifted distribution of the mean, median and standard deviation measurements

Table 2: *Intra-class Correlation Coefficients (ICC) for Both Margin Quality and Score Measurements*

Margin Quality and Score Measurements	ICC for Margin Quality	*p*-value	ICC for Scores	*p*-value
% **MQ1 (Score 1)** Perfect margin (hardly visible)	0.947	<0.0001	0.955	<0.0001
% **MQ2 (Score 1)** Margin visible, no gap	0.969	<0.0001		
% **MQ3 (Score 2)** Margin irregularities (like bulbs, minor swelling) but no gaps	0.901	<0.0001	0.901	<0.0001
% **MQ4 (Score 3)** "Hairline" crack: sharp and clear discontinuation (gap width <2 µm) at the margin without any irregularities	0.313	0.0222	0.313	0.0222
% **MQ5 (Score 4)** "Hairline" crack (gap width <2 µm) + minor margin irregularities or gap width <5 µm without any irregularities	0.729	<0.0001	0.943	<0.0001
% **MQ6 (Score 4)** Gap formation (gap width <5 µm) + heavy margin irregularities	0.364	0.0091		
% **MQ7 (Score 4)** Gap formation (gap width >5 µm)	0.979	<0.0001		
Scores 3 & 4 (GAP)	-----	-----	0.956	<0.0001

The p-value is the significance probability corresponding to the test of the null hypothesis that the intra-class coefficient is equal to zero.

to a level higher than all the other groups. For all groups, at least one specimen exhibited perfect marginal adaptation (zero percent gaps) as reflected in the column labeled "Minimum" in Table 3. Overall, the mean gap percentage for the 40 margins evaluated was 6.3, with a median of 1.1 and a standard deviation of 14.8.

The *p*-values for the Kruskal-Wallis test of the differences in distribution of a given measurement among the treatment groups is provided in Table 4. There was no evidence of treatment group differences for any of the direct (Margin Quality) or derived (Scores/Gap) measurements. The null hypothesis was supported by the results of the study.

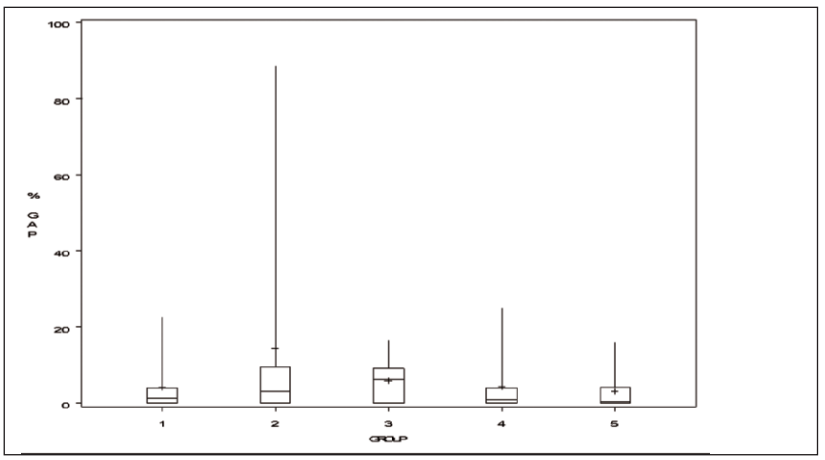

Figure 3. *Results as the amount of gap formation for the five treatment groups (1= resin pre-heated to 130°F/54.4°C; 2 = resin pre-heated to 155°F/68.3°C; 3= flowable liner cured prior to unheated resin; 4= flowable liner cured simultaneously with unheated resin; 5= room temperature composite) represented as a percentage of the complete evaluated margin length in dentin after 24 hours. The mean is represented by the small horizontal line and the median by the large horizontal line. Note the outlier in group 2 as denoted by the highest end of the vertical line (maximum value).*

DISCUSSION

In the current study, different techniques with preheated resins and flowable liners were tested to determine their effect on gingival margin gap formation as compared to the conventional placement of room temperature composite. Although no significant differences in terms of gap formation were detected, group 5 (Control) had the smallest mean value, followed by group 1 (PHC, 130°F) and group 4 (FL cured simultaneously with first increment of composite).

With a lower modulus of elasticity and better wetability, flowable resins can be expected to serve as an intermediate elastic layer between the adhesive and overlaying resin, reducing contraction stresses and improving the seal of the restoration.[23] Two different techniques involve the use of a flowable liner polymerized either prior to or simultaneously with the overlaying resin. Polymerizing the flowable liner prior to placement of the conventional hybrid resin yields a thicker layer, which may theoretically result in higher volumetric shrinkage.[23] On the other hand, a thicker flexible layer may better help to relieve polymerization contraction stresses from the overlaying resin.[35] By polymerizing both the flowable and hybrid resin simultaneously, the uncured flowable liner may be able to provide greater stress relief than the flowable liner that has been cured beforehand and already exists in a vitrified state. Also, by placing the stiffer hybrid resin onto the uncured flowable liner, most of the liner is expelled against the lateral walls, resulting in a thinner layer of flowable resin and perhaps less associated shrinkage and improved final adaptation. Excellent results have been reported in the literature with the use of this technique.[11,13] The

results of this investigation showed no significant differences in mean gap formation between the two groups of flowable liners.

Although the present study found that preheated composites did not significantly reduced gap formation at the gingival margin, their use may yield benefits in other ways. By achieving a transient viscosity reduction comparable to that of flowable resins,[29] an enhanced adaptation of the resin to all intricacies of the preparation may be obtained. At the same time, no restorative compromise was made, since a hybrid resin with high strength and high filler loading was used as the initial gingival increment. Also, an increased curing rate and degree of conversion may yield a final restoration with improved physical properties[26,29] and less unreacted monomer.[28]

Despite the findings of the current study, future research may produce different results, since the use of low viscosity materials is highly technique-sensitive and is associated with a significant learning curve. Low viscosity materials are difficult to manipulate easily, entrapping air upon removal of the syringe.[13,36] Flowable resins and preheated composites must be carefully applied to the preparation in only one direction, and removal must be done by gently wiping the compule tip against the preparation walls. In the current study, a speculation is that the operator's technique may have had an influence on the observed results.

Group 2 exhibited a single outlier specimen that shifted the entire distribution of the curve. Atypical of the overall gap occurrence, the outlier specimen displayed

Table 3: *Percentage of Gaps in Total Length of Evaluated Margin (Average of Two Measurements)*

Groups	Description	N	Mean (SD)	Median	Minimum	Maximum
1	Preheated resin to 130°F	8	4.1 (7.7)	1.2	0	22.6
2	Preheated resin to 155°F	8	14.2 (30.3)	3.2	0	88.4
3	Flowable liner cured prior to unheated resin	8	6.0 (6.0)	6.2	0	16.5
4	Flowable liner and unheated resin cured simultaneously	8	4.3 (8.5)	0.8	0	25.0
5	Room temperature composite (Control)	8	3.1 (5.7)	0.3	0	16.1
	Overall throughout all study groups	40	6.3 (14.8)	1.1	-----	-----

*No statistically significant difference in distribution of the percentage of gap formation among groups defined by placement technique was found (*p*=0.82, Kruskal-Wallis test).*

Table 4: *Differences in Distribution for Marginal Quality and Gap Formation Scores Among Treatment Groups*

	Group 1	Group 2	Group 3	Group 4	Group 5	
Measure	**Median**	**Median**	**Median**	**Median**	**Median**	***p*-value***
% **MQ1** Perfect margin	2.5	1.6	0.0	7.1	8.0	0.992
% **MQ2** Margin visible, no gap	56.4	87.0	78.6	83.0	78.2	0.669
% **MQ3** Margin irregularities but no gaps	8.9	5.0	2.9	5.5	8.0	0.678
% **MQ4** "Hairline" crack: sharp and clear discontinuation (gap width <2 μm)	0.0	0.0	0.0	0.0	0.0	0.697
% **MQ5** "Hairline" crack (gap width <2 μm) + minor margin irregularities or gap width <5 μm	0.9	2.6	4.5	0.0	0.0	0.352
% **MQ6** Gap formation (gap width < 5 μm) + heavy margin irregularities	0.0	0.0	0.0	0.0	0.0	0.545
% **MQ7** Gap formation (gap width > 5 μm)	0.0	0.0	0.0	0.0	0.0	0.715
	Median	**Median**	**Median**	**Median**	**Median**	***p*-value***
Score 1 (MQ1 + MQ2)	83.4	91.6	91.7	91.9	89.5	0.932
Score 2 (MQ3)	8.9	5.0	2.9	5.5	8.0	0.678
Score 3 (MQ4)	0.0	0.0	0.0	0.0	0.0	0.697
Score 4 (MQ5 + MQ6 + MQ7)	1.2	2.6	4.6	0.0	0.0	0.454
Gap= Scores 3 & 4 (MQ4 + MQ5 + MQ6 + MQ7)	1.2	3.2	6.2	0.8	0.3	0.825

**The p-value is the significance probability associated with the Kruskal-Wallis test of the null hypothesis that the measure of interest has the same distribution in all treatment groups. All measurements are expressed as percentage adjusted for artifact and are based upon the average of the two duplicate readings.*

not only larger gaps (MQ5, MQ6 and MQ7), but also a higher percentage of gap formation. However, these values did not remain significant. A speculation is that this outlier could have been the product of human error. Polymerizing the resin while at its maximum temperature would increase the degree of conversion,[28] thereby maximizing shrinkage stresses. Another speculation relates to the time when polymerization reaction was started relative to the cooling curve of the resin, which might have resulted in the combined shrinkage stress from both thermal contraction and polymerization shrinkage being potentially maximized in this specimen.

A material with low shrinkage, Filtek Z250,[37] was used for this study, as current techniques are moving away from high shrinkage materials. By using a low shrinkage material, the potential confounding effect of resin composite shrinkage was eliminated from the equation. This may help explain why differences among study groups were not detected.

Care should be taken not to overemphasize the results of *in-vitro* tests, since a number of *in-vivo* variables that may play a role in the margin gap formation of Class II composite restorations cannot always be accurately replicated *in-vitro*. This *in-vitro* investigation was conducted in a temperature-controlled room (23 ± 2°C). However, preheated composites applied *in-vivo* can be expected to behave differently by retaining heat longer than those applied at room temperature. Although the gingival walls on dentin are a relative contraindication for restoration with composites, the preparation margins in the present study were located 1 mm below the CEJ in dentin to provide a greater adhesive challenge. Even under these circumstances, gap formation was minimal and no significant differences were detected among groups. The rather favorable results of this investigation have to be confirmed *in-vivo*. Although most approximal margins cannot be polished *in-vivo*, all margins were finished and polished to remove overhangs that would have otherwise interfered with an accurate assessment of the margins.

The impressions of the specimens were taken after 24 hours of storage in artificial saliva. No thermocycling to simulate the long-term challenge of the interface was performed, as the purpose of this investigation was to identify gaps that may have been caused by the immediate effects of polymerization shrinkage rather than those caused from degradation of the adhesive interface over time. No prolonged water storage was performed based on the same rationale. It is well accepted that composites shrink on curing, but perhaps it is less known that they swell upon water absorption.[38] It is possible that water uptake during a longer storage period could compensate for initial polymerization shrinkage of the resin, closing microgaps or minimizing the occurrence of stresses that could induce adhesive failure.[39]

Although intra-class correlation scores were all significant at the conventional 0.05 level, reliability was high for MQ1-MQ3 and MQ7, moderate for MQ5 and poor for MQ4 and MQ6. A speculation is that the lack of descriptor with a numerical cutoff point of MQ4, MQ5 and MQ6 compared to the other categories made reproducibility of the duplicate measurements harder to achieve in this case. It seems that the replica technique used in this study can provide a reliable measurement for analysis of the margin gap formation, provided that adequate calibration of the examiner takes place prior to the beginning of the study.

CONCLUSIONS

Within the limitations of an *in-vitro* model, it can be concluded that gap formation at the gingival margin of Class II preparations was not improved relative to the control group by any of the placement methods tested in this study. A high degree of intra-examiner reliability was confirmed using duplicate measurements, indicating that the replica technique may provide an accurate method for the measurement of margin gap formation.

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