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The Influence of Elastic Modulus of Base Material on the Marginal Adaptation of Direct Composite Restoration

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Clinical Relevance

The use of RMGICs and flowable composites as base materials with the appropriate elastic modulus can reduce a marginal defect in an overlying composite restoration.

SUMMARY

This study compared the marginal adaptation of direct composites under base materials with different elastic moduli. MOD cavities were prepared in 30 teeth. The cervical margin was placed 1 mm above the cementoenamel junction (CEJ) in one side and 1 mm below the CEJ in dentin in the other. The teeth were randomly divided into the following six groups (five teeth each) according to the base materials used: No base (Group 1), experimental flowable composite (Group 2), Helioflow (Ivoclar Vivadent) (Group 3), Tetric Flow (Group 4), Heliomolar HB (Ivoclar Vivadent) (Group 5) and Fuji II LC (Group 6). In Group 1, after etching the cavity enamel with 35% phosphoric acid, the cavities were primed and bonded with AdheSE, then filled with Tetric Ceram according to the manufacturer's instructions. In the other groups, after placing the base materials (1 mm thick) into the cavity, the cavity was filled with Tetric Ceram using the same methods as in Group 1. After storing the specimens in distilled water for seven days, they were finished and polished.

Using stereomicroscopy at 150x magnification, marginal adaptation of the specimens was determined and the percentage of the imperfect margin (IM%) in the pre-loaded specimens was calculated. A mechanical load was applied using a custom-made Chewing simulator. All specimens

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were submitted to 600,000 load cycles at 49N with a frequency of 2Hz. The IM% in the post-load specimens was calculated. Repeated measured one-way ANOVA with Tukey was applied to compare the IM% in the six groups at the 95% confidence level. The results of statistical analysis indicated that the IM% was Group 3, 4, 6 ≤ 2 ≤ 5 ≤ 1.

INTRODUCTION

A composite restoration is one of the major treatments for posterior teeth. However, its inherent polymerization shrinkage and subsequent side effects, such as cuspal deflection, defects in the margin and internal surface, and resulting secondary caries, have not been solved.

To reduce the side effects caused by polymerization shrinkage stress of the composites, glass ionomer cement (GIC) or resin-modified glass ionomer cement (RMGIC) has been recommended as base materials, because they replace some of the composite volume and reduce the side effects of polymerization shrinkage.[1-5] However, this so-called sandwich technique has not been confirmed and some researchers have reported that this technique did not offer any added advantage.[6-7] Opdam and others,[8] in their recent study, indicated that a total-etch restoration with a highly filled hybrid resin composite showed higher clinical survival than a closed-sandwich restoration, and the main reason for failure in the GIC-based composite restorations was a fracture of the composites.

Filling cavities with composite restorations lined with flowable composites with a low elastic modulus is recommended, because flowable composites act as a stress-absorbing layer, reduce polymerization shrinkage stress, increase marginal adaptation and decrease the number of voids.[9-14] However, the advantage of this technique has not been demonstrated, and some researchers reported no added advantage with this technique.[15-19]

The elastic modulus of the base material might significantly affect the integrity of the overlying filling material. Krejci and others[1] reported that 5-10 GPa appeared to be the optimal range of elastic moduli for base materials and a marginal adaptation of composites was decreased in the elastic ($CA(OH)_2$) or rigid ($ZnPO_4$) base-material groups. Addison, Marquis and Fleming reported that enhancement of the ceramic strength was dependent on the elastic modulus of the luting resin.[20] Moscovich and others[21] reported that the resistance to a bulk fracture of the porcelain inlay increased when the inlay was based on composites with an elastic modulus of 26.4 GPa. This was attributed to the composite base shifting the neutral plane. In the neutral plane, opposing stresses meet and the net result is zero. It is affected by the thickness and elastic modulus of the material. Banditmahakun and others[22] recommended use of a base material with a high elastic modulus to support a ceramic inlay.

As many flowable composites, GICs (Glass Ionomer Cement) and RMGICs (Resin Modified Glass Ionomer Cement) have different elastic moduli, their effects on the overlying composites would be different when used as base materials. Their effects would be shown when a mechanical load that simulates chewing is applied to the overlying composite restorations. In addition to the argumentative advantages of RMGICs or flowable composites as a base material, such as reducing polymerization shrinkage stress or increasing marginal adaptation, their role under occlusal stress, along with their relationship with the elastic modulus, should be evaluated.

This study compared the marginal adaptation of direct composites under base materials with different elastic moduli.

The null hypothesis was that there was no difference between the marginal adaptations of composite restorations when using base materials with different elastic moduli.

METHODS AND MATERIALS

A. Cavity Preparation

Thirty caries-free, sound lower molars extracted for periodontal or orthodontic reasons within the previous three months were selected and a standard MOD cavity was prepared using a diamond bur (959 KR 018, Komet GEBR Brasseler GmbH & Co KG, Lemgo, Germany).

The cavity depth in the cental fossa area, ismuth width and gingival wall width was 3 mm, 3 mm and 2 mm, respectively. The cervical margin of the proximal side was placed in enamel 1 mm above the cementoenamel junction (CEJ) in one side, and on the other side, in dentin, 1 mm below the CEJ. The width of the gingival margin was 4.5 mm (Figures 1a and 1b).

B. Base and Composite Filling

The materials used in this study are shown in Table 1. The prepared teeth were randomly divided into six groups according to the elastic modulus of the base materials. Group 1 was the control. The enamel margins of the cavities were etched with 37% phosphoric acid (Total Etch, Ivoclar Vivadent, Schaan, Liechtenstein) for 30 seconds, irrigated with distilled water, then dried thoroughly. The dentin walls were conditioned and bonded with AdheSE (Ivoclar Vivadent) according to the manufacturer's instructions, then light cured for 20 seconds. The cavities were filled with Tetric Ceram (A3, Ivoclar Vivadent) and light cured for 40 seconds. A 2-mm thick layering

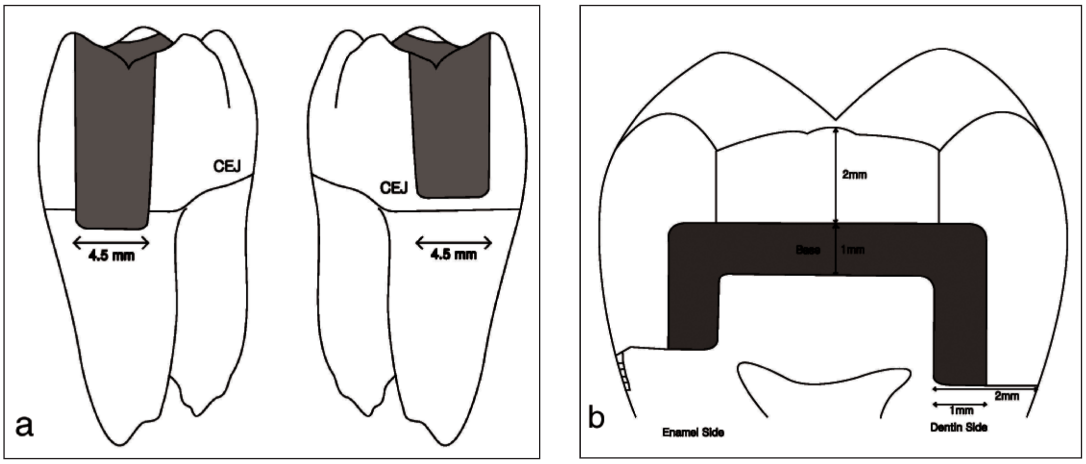

Figure 1: Schematic diagram of cavity preparation and base placement (a,b).

Table 1: *Materials Used in This Study*

Groups Material	Base	Filling Material	Flexural Modulus (GPa) Base	Filling
1	No	Tetrtic Ceram		9.4[b]
2	Experimental Flowable	Tetrtic Ceram	2.5[a]	9.4[b]
3	Heliomolar Flow	Tetrtic Ceram	4.4[b]	9.4[b]
4	Tetric Flow	Tetrtic Ceram	5.3[b]	9.4[b]
5	HeliomolarHB	Tetrtic Ceram	6.5[b]	9.4[b]
6	Fuji II LC	Tetrtic Ceram	7.9[c]	9.4[b]

a, b and c are from scientific documents released by each company, Denkist (a), Ivoclar Vivadent (b) and GC Inc (c).

technique was applied. In Groups 2, 3, 4 and 5, the exposed dentin walls were primed and bonded with AdheSE according to the manufacturer's instructions, then light cured for 20 seconds. The experimental flowable composite (Denkist, Seoul, Korea), Heliomolar Flow (Ivoclar Vivadent), Tetric Flow (Ivoclar Vivadent) and Heliomolar HB (Ivoclar Vivadent) were used as base materials in Groups 2,3,4 and 5, respectively, then light-cured for 40 seconds. The base materials and cavity walls were trimmed with a fine diamond bur (959 KR 2F018, Komet GEBR Brasseler GmbH & Co KG, Lemgo, Germany) to control the thickness of the base to 1 mm and the axial cavity wall of any dentin adhesives was cleaned. The enamel margins of the cavities were etched with 37% phosphoric acid for 30 seconds, irrigated with distilled water, then dried thoroughly. The dentin walls were conditioned with an AdheSE primer and the cavities were bonded with AdheSE adhesive. After light curing the adhesive for 20 seconds, the cavity was filled with Tetric Ceram and light-cured as reported in Group 1. In Group 6, after conditioning the cavities with a dentin conditioner (GC Cavity Conditioner, GC Inc, Japan) for 10 seconds, they were irrigated with distilled water, then dried. Fuji II LC (GC Inc, Tokyo, Japan) was placed as a base material and light-cured for 40 seconds, then the cavity walls were trimmed with a fine diamond bur to control the thickness of the base to 1 mm and the axial cavity wall was cleaned of any Fuji II LC debris. The enamel margins of the cavities were etched with 37% phosphoric acid for 30 seconds, irrigated with distilled water and dried thoroughly. The procedures for priming, adhesive application and composite filling were the same as was reported for the other groups. Figure 1 shows a schematic diagram of the cavity preparation and base filling design.

C. Marginal Adaptation Analysis (Pre-mechanical loading)

The cavity margins were categorized as the occlusal enamel margin (EO); vertical enamel margin of the proximal surface, where a cervical margin was placed in the enamel (EV); cervical enamel margin (EC); vertical enamel margin of the proximal surface, where the cervical margin was placed in dentin (EVD) and the cervical dentin margin (DC). Using a stereomicroscope under 150x magnification, the cavity margins of a specimen were examined along the entire cavity margin. Images of the magnified marginal area were captured as a graphic file and stored in a computer. An entire graphic image of a specimen was assembled using a special graphics program (i-Solution ver 7.3, IMT i-Solution Inc, Conquitlam, Canada). Both the length of the perfect margin (PM) and imperfect margin (IM) were measured in a computer program (LAS version 3.3.0, Leica Microsystems Limited, Switzerland) using the assembled image. Cavity margins that showed gaps, enamel chipping, dentin or composites and cracks were included in the IM. The % ratio of IM (IM%) was defined as:

$$IM/(PM + IM) \times 100$$

The IM was calculated in the whole cavity margin (WM) and in the EO, EV, EC, EVD and DC.

D. Mechanical Loading

The specimens were placed in the mold and fixed in position using acrylic resin. The specimen in the mold was mounted in the custom-made chewing simulator, in which an occlusal load of 49N with a 2Hz frequency was applied to the specimen 600,000 times.

During this procedure, the specimen was dwelled in water to prevent drying.

E. Marginal Adaptation Analysis (Post-mechanical Loading)

After the mechanical loading process, the specimens were demounted from the molds, and the cavity margin was analyzed in the same manner as in the pre-thermo-mechanical load.

F. Statistical Analysis

The IM% of each group in the WM was compared using repeated measured one-way ANOVA with post-hoc Tukey test at the 95% confidence level. For each group, the IM% of EC, EV, EO, DC and EVD was compared using a Kruskal Wallis test and Mann Whitney U-test at the 95% confidence level and the pre- and post-mechanical loading data was compared using a Wilcoxon signed rank test at the 95% confidence level.

RESULTS

Before thermo-mechanical loading, the IM% in the WM in Groups 1, 2, 3, 4, 5 and 6 was 4.9, 2.6, 1.9, 4.2, 7.3 and 2.5%, respectively. After mechanical loading, they were 21.3, 10.3, 7.2, 6.6, 16.0 and 7.2%, respectively (Table 2, Figure 2). Repeated measured one-way ANOVA revealed a difference in the IM% between the pre- and post-mechanical load ($p<0.05$) and there was an interaction between the groups and repeated factor (pre- and post-mechanical loading) ($p<0.05$) (Table 3). There was a difference in the IM% among the six groups ($p<0.05$), and the results of the post-hoc test showed the following: Groups 3, 4, 6 ≤ 2 ≤ 5 ≤ 1 ($p<0.05$).

Table 4 shows the IM% of EC, EV, EO, DC and EVD in each group.

There was a difference in IM% between tooth areas in all groups, but the patterns were different. There was a difference in IM% between the pre- and post-mechanical loading in all areas except for Group 6 (EO) and Group 3 (EVD).

DISCUSSION

The use of low modulus composite base materials could reduce the IM%, considering that the IM% of Groups 2 through 5 were lower than Group 1. However, there were also differences in their effects on the IM%, depending on their elastic modulus. The IM% of group 1 was the highest, followed by Group 5, in which a rel-

Table 2: *The % Ratio of Imperfect Margin IM% in the Whole Cavity Margin (WM)*

Group	Before Loading	After Loading
1	4.9 (3.2)	21.3 (8.2)
2	2.6 (1.0)	10.3 (1.8)
3	1.9 (1.1)	7.2 (3.3)
4	4.2 (2.5)	6.6 (1.6)
5	7.3 (3.8)	16.0 (4.2)
6	2.5 (1.6)	7.2 (3.5)

Table 3: *Results of Repeated Measured One-way ANOVA*

Source	Sum of Square	df	Mean Square	F	*p*-value
Intra-group Analysis					
Repeat factor	854.079	1	854.079	122.072	.000
Repeat factor*group	295.513	5	59.103	8.447	.000
Error (repeat factor)	167.916	24	6.997		
Inter-group Analysis					
Slice	3529.246	1	3529.246	197.525	.000
Group	694.876	5	138.975	7.778	.000
Error	428.817	24	17.867		

Table 4: *The % Ratio of Imperfect Margin (IM%) in Each Tooth Area*

		EC	EV	EO	DC	EVD
Group 1	BL	2.3a	1.2a	7.0b	5.3a	4.0a
2		0.0a	5.4b	2.9a	0.9a	1.8a
3		8.2c	1.4a	2.5b	0.6a	1.9a
4		0.0a	1.4a	4.3b	0.0a	1.0a
5		1.0a	4.4a	15.8b	0.0a	0.0a
6		0.0a	0.0a	10.3b	1.1a	0.5a
Group 1	AL	37.8c*	19.6b*	23.8b*	23.1 b*	14.1a*
2		8.2a*	20.1b*	9.2a*	7.8 a*	7.7a*
3		23.8b*	8.1a*	6.5a*	5.3 a*	2.2a
4		10.0a*	4.0a*	7.6a*	16.0 c*	3.9a*
5		12.0a*	10.0a*	20.2b*	7.4 a*	24.4b*
6		9.8b*	2.1a*	10.5b	4.1 a*	2.6a*

In each group, different letters indicate different IM% at p=0.05 level.
**indicates significant difference in IM% at p=0.05 level between each group's before-mechanical loading (BL) and after-mechanical loading (AL) data in each area.*

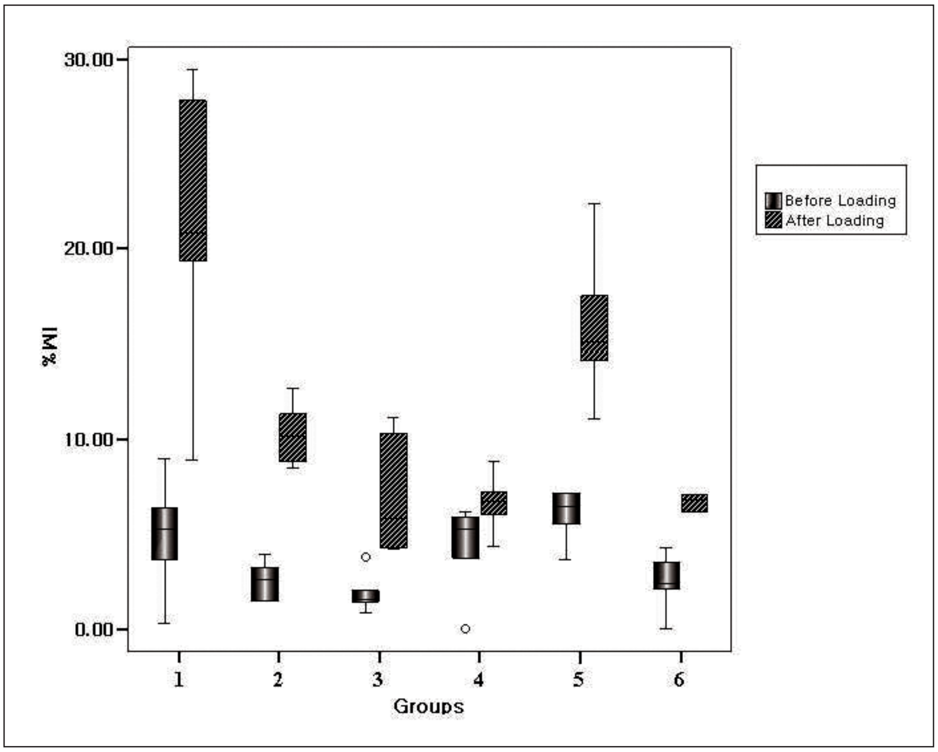

Figure 2: *IM% of the whole margin(WM) before and after loading.*

atively high modulus (6.5GPa) base material had been used. The relatively higher modulus of Heliomolar HB compared to other flowable composites might have affected the results. The IM% of Group 2, in which the base material of the lowest elastic modulus (2.5 GPa) was used, had the next highest IM%. The elastic modulus might be too low for it to be suitable as an optimum base material. Compared to Groups 3 and 4, which had elastic moduli of 4.4 and 5.5, respectively, the base material of Group 2 may provide unfavorable conditions for the marginal quality of composite restorations under a mechanical load, because it might be too elastic and might not support the restoration properly. This result is consistent with previous studies which indicate that a base material with too low an elastic modulus hinders the marginal quality of the restoration.[1]

Considering that the IM% of Groups 3 and 4 had the lowest IM% in the current study, there appears to be some optimal range of elastic moduli in flowable composites as base materials (4-6 GPa) within which the base can effectively buffer the occlusal stress.

Cattani-Lorente and others[23] reported that the elastic modulus of Fuji II LC (GC, Tokyo, Japan) ranged from 6.2-10.8 GPa after 24 hours of light curing under different storage conditions. The elastic modulus was 10.8 GPa under wet and dry conditions, as in the current study. The IM% of Group 6 was one of the lowest, even though its elastic modulus was higher than the other composite-base materials. A comparison with results from Group 5 suggested that the IM% did not depend completely on the elastic modulus of the base material. The polymerization shrinkage stress of RMGIC is much lower than that of the composites,[4] and the RMGIC under the composites reduced the level of polymerization shrinkage of the composites.[24] Cuspal deflection was also lower in the MOD cavity when RMGIC was used as a base material than that in the cavity restored with the composite only.[3] The reduced polymerization shrinkage stress of RMGIC on the cavity margin might explain the lowest IM% in Group 6.

Opdam and others[8] reported that the long-term failure rate was higher in posterior composite restorations when they were lined with Vitrabond (3M ESPE, St Paul, MN, USA) and GC Lining Cement (GC) than with composite restorations without a GIC lining. Opdam and others concluded that the total-etch restoration with a highly filled hybrid resin composite showed a higher survival rate than closed-sandwich restorations due to the lower fracture rate. In their study, most failures in GIC-lined composite restorations were composite fractures. The elastic modulus in the Vitrabond and GC Lining Cement were 1.1GPa[25] and 2.9GPa,[26] respectively, and their flexural strength was also very low compared to Fuji II LC (GC). A possible disadvantage of too low a modulus lining or base under composite restorations might be the weakening effect on the strength of the overlying resin composite, which would concentrate a high force on a low modulus lining material between the high modulus composite and the tooth. Therefore, materials with too low a modulus might deteriorate adhesion of the restorations in the long-term. Considering the results of the current study, composites with high E-modulus RMGICs, such as Fuji II LC (GC), would show more favorable results after a longer-term clinical study. Another point that should be considered in RMGIC-based composites may be retention of the restoration. When composite restorations are lined with RMGICs, there is a loss of retention, because the bond strength between the composite and RMGIC is much lower than what would be between the composite and tooth.[27] Therefore, it is important in RMGIC-lined composite restorations that tooth surfaces other than a GIC-lined surface should provide sufficient adhesive retention for composite restorations. If not, the long-term failure rate would be higher than that of composite restorations without a RMGIC or GIC lining. In the current study, the MOD cavity in Group 6 might provide sufficient adhesive surface for retention, even though there was some loss in the RMGIC-lined surface, which may result in the lowest IM%.

These results showed that flowable composites or RMGIC-base materials with an adequate modulus can provide better marginal adaptation than the control group. In small cavities that do not extend to a depth of 3 mm, flowable composites would be more suitable as a lining material than RMGIC or GIC, because they would not decrease retention. In large and deep cavities, RMGIC or GIC would be more preferable, because it could reduce polymerization shrinkage stress and its associated complications.

It was interesting that the IM% of EVD was relatively lower than the other areas after mechanical loading. Only one exception was found in Group 5. In the current study, a mechanical occlusal load was applied to the occlusal surface and the dentin cervical wall possibly provided a more effective occlusal stress relieving surface for the vertical enamel wall than the enamel cervical wall. However, considering the deviation of the data, considerably more samples should have been included in order to clarify the effect of the E-modulus of the base material on the marginal quality of each tooth region.

In the current study, both the flowable composite surface and cavity wall were trimmed with a fine diamond bur to control the thickness of the composites and clean the exposed cavity wall after lining the cavity wall with flowable composites followed by light curing. However, in clinical situations, the restorative composites are usually placed over the flowable composite lining material without trimming. In this *in vitro* study, the oxygen inhibition layer of the flowable composite surface might be removed during the trimming process. Dall'Oca and others[28] reported that the oxygen inhibition layer was not essential for a chemical reaction to occur between the previously cured composite and new composites. Dall'Oca and others reported that the unreacted free radicals in the precured composites might promote a chemical reaction in the absence of an oxygen inhibition layer and the half-life of free radicals might be the limiting factor. In the current study, a restorative composite and bonding agent was applied immediately after trimming the flowable composites, which may not have damaged the chemical reaction between the trimmed flowable and restorative composite.

One limitation of the current study was that composite materials with a different matrix, fillers and photoactivation system were used. Although all the composites, except for Group 2, were obtained from one company to reduce this problem, there were also some differences. A comparison of the same composites with the difference in the elastic modulus would be more desirable for a future study. More precise correlations between the elastic modulus in a restorative composite and base materials would be possible.

CONCLUSIONS

The elastic modulus of the base material affected the marginal quality of the composite restoration. The use of flowable composites and RMGICs as base materials can reduce the marginal defects of composite restorations.

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