Effect of Cyclic Loading on Marginal Adaptation and Bond Strength in Direct vs Indirect Class II MO Composite Restorations

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Clinical Relevance
Indirect composite restorations have better marginal adaptation than direct composite restorations, and cyclic loading has a more deteriorating effect on the marginal adaptation and microtensile bond strength of direct composite restorations than indirect composite restorations.

SUMMARY
This study evaluated the effect of cyclic loading on the marginal adaptation and microtensile bond strength of direct vs indirect Class II composite restorations in an in-vitro model. Forty Class II cavities were prepared on the mesial surface of extracted human maxillary first premolars and divided into two groups: Group I—direct composite restorations and Group II—indirect composite restorations. Groups I and II were further divided into subgroups: A (without cyclic loading) and B (with cyclic loading of 150,000 cycles at 60N). The gingival margin of the proximal box was evaluated at 200x magnification for marginal adaptation in a low vacuum scanning electron microscope. The restorations were sectioned perpendicular to the bonded surface into 1 mm thick slabs. The slabs were further trimmed at the interface to produce a cross-sectional surface area of approximately 1 mm². All specimens were subjected to microtensile bond strength testing. The marginal adaptation was analyzed using descriptive studies and bond strength data were analyzed by one-way ANOVA test. The indirect composite restorations performed better under cyclic loading.
INTRODUCTION

The use of resin composites as a material for restoring posterior teeth has greatly increased in recent years. Despite reports of good clinical longevity, there are some inherent problems with composite restorations, including polymerization shrinkage and lower wear resistance.\(^1\) Polymerization shrinkage appears to be the most significant problem with composite restorations, as it has the potential to initiate gap formation at the tooth-composite interface,\(^6\) which can lead to microleakage,\(^7\) marginal discoloration,\(^8\) secondary caries\(^9\) and eventual failure of the bond.\(^10\) Posterior resin composites can be processed by two methods,\(^11\) either by directly placing the composite in increments, then curing each increment or by indirectly preparing an inlay from the composite, curing it outside the oral cavity and luting it into the cavity with the help of dual cure resin-based cement.

The bond strength between the restorative material and dentin plays an important role in the success of a restoration. Tensile bond strength is influenced by many factors, including physical and mechanical properties of the restorative material, the intra-oral environment and occlusal stresses.\(^12\)-\(^14\)

In the past, research has been dedicated to bond strength, microleakage, survival rates, post-operative sensitivity and marginal adaptation of composite restorations, giving conflicting results. Wendt and Leinfelder\(^15\) showed that heat-treated inlays showed significantly (\(p<0.05\)) less microleakage than direct composite restorations. Liberman and others\(^16\) studied the effect of thermal stresses and cyclic loading on the marginal seal of composite inlays. They showed that all indirectly fabricated restorations resulted in improved marginal sealing compared to conventional direct restorations. However, Hasanreisoglu and others\(^17\) found no significant difference between direct and indirect fabrications. Bedran and others\(^18\) studied the effect of thermal and mechanical load cycling on microleakage and shear bond strength and found no statistically significant influence of thermocycling, mechanical load cycling or the combination on microleakage and shear bond strength. Few studies have included cyclic loading as a parameter and a simultaneous evaluation of marginal adaptation and tensile bond strength. Thus, the current study was undertaken to evaluate the marginal adaptation and microtensile bond strength of direct vs indirect composite restorations before and after cyclic loading. Marginal adaptation was evaluated using a low vacuum Scanning Electron Microscope and microtensile bond strength by a Universal Instron testing machine.

METHODS AND MATERIALS

Forty freshly extracted, caries free human permanent maxillary first premolars (having approximately the same width and length) were collected. The teeth were cleaned of debris and stored in normal saline for up to one month. The samples were distributed into two experimental groups, each consisting of 20 samples. Class II MO cavities of standard dimensions were prepared in all 40 premolars. The occlusal portion of the preparation had a facio-lingual width of 1.5 mm and a depth of 1.8 \(\pm\) 0.25 mm. The isthmus was prepared up to one-third of the facio-lingual width of the tooth. The gingival floor of the proximal box was kept 0.8-1.0 mm below the pulpal floor but above the CEJ to keep the gingival margins in enamel. All the cavities were restored as follows.

Group I: Direct composite restorations with SR Adoro (Ivoclar Vivadent, Schaan, Liechtenstein) and directly cured with QTH curing light after acid etching and dentin bonding, per the manufacturer’s instructions.

Group II: Indirect composite restorations with SR Adoro (Ivoclar Vivadent) composite restorative material, as per the manufacturer’s instructions. Two coats of glycerin were applied on all the preparation walls and margins as a lubricant and separating medium and they were left for three minutes for complete drying. A clear plastic matrix strip was placed. The desired amount of ready-to-use paste-type liner (050–500 SR Adoro) was extruded from the syringe and spread on the mixing pad, using a disposable brush. The liner was applied to the cavity walls and floor in a thin coat, and each segment was cured for 20 seconds using a QTH light-curing unit. A small increment of SR Adoro Dentin (110-140, A2 shade) was firmly packed into the cavity over the cured liner and was cured for 20 seconds. Subsequently, the whole of the cavity was built-up using SR Adoro Dentin (110-140, A2 shade). The matrix was removed and the restoration was teased out of the cavity using a fine probe. SR Gel (SR Adoro) was applied to the entire surface (to prevent formation of the oxygen-inhibiting layer), ensuring that all areas were fully covered and the layer was not too thick. After application of the SR Gel, the restorations were mounted onto an object holder and placed in the Lumamat 100 furnace. The P3 program, which includes four stages: Stage I—preheating with the heater off for 10 minutes; Stage II—gradual heating up to 104°C in three minutes; Stage III—tempering with light and heat at 104°C for seven minutes; Stage IV—cooling for five minutes. The SR Gel (SR Adoro) was removed from the inlay surface under running water. The inlays were finished and polished using diamond stones and a composite polishing kit (Shofu Inc, Kyoto, Japan). The intaglio surface of the inlays was air abraded with 50 \(\mu\)m SiO\(_2\) particles. The inlays were luted with dual cure cement (Rely X ARC, 3M ESPE, St Paul, MN, USA) after application of a layer of bonding agent (Single Bond 3M ESPE).
Groups I and II were further divided into subgroups A and B as follows:

Subgroup A—Without cyclic loading.
Subgroup B—With cyclic loading of 150,000 cycles on the restored marginal ridge at 60N (simulating six months of oral masticatory stresses) using a cylindrical stylus.

Preparation of the Specimens for Evaluation of Marginal Adaptation in a Scanning Electron Microscope (SEM)

The gingival margins were cleaned with the help of 10% ortho-phosphoric acid for five seconds to remove the debris over the margin. The samples were placed on standard half-inch pin-type aluminum stubs with the help of a carbon conductive double-sided adhesive tape (SPI Supplies, West Chester, PA, USA). The stubs were placed in a specimen chamber mounting table of SEM (LEO VP 435 [Carl-Zeiss NTS Gmbh, Oberochen, Germany]). The gingival margin of the proximal box was evaluated at 200x magnification for marginal adaptation. The overall margin was investigated and the maximum marginal gap was measured. The margins were given scores on the basis of the following criteria.

- Score 0: No marginal gap formation.
- Score 1: Maximum marginal gap <30 µm.
- Score 2: Maximum marginal gap >30 µm.

These findings were recorded onto a Microsoft Excel sheet (Microsoft Office Excel 2003).

Preparation of the Specimens and Evaluation of the Microtensile Bond Strength (µTBS) Measurement in a Universal Instron Machine

The samples were serially sectioned perpendicular to the bonded surface with the help of diamond disks (Horico H557F220, Hopf, Ringleb & Co GmbH & Cie, Berlin, Germany) in a straight air motor handpiece, creating approximately 1 mm thick slabs, under copious water irrigation. The specimens were trimmed into an hour-glass shape, with the narrowest portion (approximately 1 mm²) located at the resin-dentin interface, with the help of diamond points (#204, ISO 160013 Shofu Inc) and copious water spray. The trimmed specimens were mounted onto a Universal Instron testing machine (Zwick testing instrument, Zwick GmbH and Co, Ulm, Germany) with the help of a cyanoacrylate adhesive. The samples were stressed to failure at a crosshead speed of 0.5 mm/minute. The tensile bond strength was calculated as the load at failure divided by the bonded area (1 mm²). The findings were recorded onto a Microsoft Excel sheet for statistical evaluation using SPSS 11.5 for Windows (SPSS Inc, Chicago, IL, USA).

RESULTS

A descriptive analysis of the microtensile bond strength was conducted for each of the variables of the four groups (Table 1). The results are presented as Minimum, Maximum and Mean ± Standard deviation. Since the variables in this study were following the normal criteria, one-way Analysis of Variance (ANOVA) was used for comparing these variables among the four groups. The significance between the individual groups was calculated using a Post Hoc ANOVA test (Table 2).

A descriptive analysis of marginal adaptation values was done for each of the variables of the four groups (Table 3). Since the values for marginal adaptation were described as categorical variables, categorical two-way tables using proportions were used to compare the variables among the four groups.

Descriptive Statistics for Microtensile Bond Strength (µTBS) of the Four Groups

The µTBS of direct and indirect restorations without cyclic loading was similar, 19.998 ± 1.45399 and 19.9680 ± 1.69036, respectively, and were statistically insignificant (p=1). The µTBS of the direct composite restorations after cyclic loading was 12.9860 ± 1.54976 MPa; whereas, the µTBS of the indirect composite restorations after cyclic loading was 15.3070 ± 1.288. One-way Analysis of Variance showed that the effect of cyclic loading was more pronounced in direct composite restorations, as the mean µTBS reduced by 7.012 MPa; whereas, in the case of the indirect restorations, the reduction in mean µTBS after cyclic loading was 4.661 MPa. The difference in the reduction of µTBS of both the direct and indirect composite restorations was -2.321 MPa and was moderately significant (p=0.009).

Descriptive Statistics for Marginal Adaptation Scores of the Four Groups

Since the data had categorical variables, the groups were compared using the proportions of samples with

<table>
<thead>
<tr>
<th>µTBS (MPa)</th>
<th>Group I</th>
<th>Group II</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Subgroup A</td>
<td>Subgroup B</td>
</tr>
<tr>
<td>Minimum</td>
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</tr>
<tr>
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<td>21.76</td>
<td>16.23</td>
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<tr>
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<td>19.998</td>
<td>12.9860</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>1.45399</td>
<td>1.54976</td>
</tr>
</tbody>
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Table 1: Microtensile Bond Strength (µTBS) Values of All Four Groups
a particular score in each group. Cyclic loading deteriorated the marginal adaptation of both direct and indirect composite restorations. In direct composite restorations, 50% of the samples had no marginal gap, but the number decreased to 10% after cyclic loading. Moreover, there was an increase of 10% in the samples with a marginal gap of <30 µm and a 30% increase in samples with a marginal gap of >30 µm. Similarly, in indirect composite restorations, there was a decrease of 20% in samples with no marginal gap. Also, there was an increase of 10% in samples with a marginal gap of <30 µm and a 10% increase in samples with a marginal gap of >30 µm. Hence, it was observed that cyclic loading created marginal gaps in additional samples where none existed, and cyclic loading increased the number of gaps as well as widened the existing gaps after loading.

**DISCUSSION**

The search for an ideal esthetic material for restoring teeth has resulted in significant improvements in both the material aspect and the techniques for using them. Resin composites and the acid etch technique represent two such major advances. Resin composites harden through a process of free radical polymerization of the methacrylate groups, which leads to a decrease in volume, causing polymerization shrinkage that may vary from 1% to 5% volume. The adverse effects of polymerization shrinkage have been reviewed by Soderholm and others in 2003. They stated that shrinkage stresses may produce defects in the composite-tooth bond, leading to marginal gap formation, marginal leakage, post-operative sensitivity, recurrent caries and eventually bond failure. In 1997, Causton and others reported that placement of bonded composite restorations in extracted teeth resulted in a decrease in the distance between cusps (cuspal flexure), which may have resulted in post-operative sensitivity and opened up pre-existing enamel micro-cracks. In the past, various techniques have been recommended to minimize the effects of polymerization shrinkage. They include incremental placement, the “guided shrinkage” technique, soft-start polymerization and pulse delay techniques, use of low modulus lining materials, such as glass ionomers, resinous liners, new-generation dentin bonding agents and megafillers. To date, no technique or material has been completely successful in counteracting the ill effects of polymerization shrinkage. The clinical consequences of polymerization shrinkage constitute the main reasons for replacement of direct resin composite restorations.

Considering these limitations, the concept of the heat-treated composite inlay/onlay was developed by Wendt in 1987. Wendt demonstrated in his *in vitro* studies that heat treating at 250°C for seven to eight minutes substantially improved hardness and wear resistance of the resins. Since then, post-cure units have evolved. Recent post-cure units use an additional light source, along with heat and pressure for post-curing the resin composites. The resin inlays can be fabricated by two methods: a combined direct-indirect/semi-direct technique and an indirect technique. In the direct-indirect technique, the resin composite inlay is fabricated directly onto the tooth preparation in the mouth, then the inlay is removed and cured in a curing oven. The alternative method of resin composite inlay fabrication is to make an impression of
the prepared tooth and fabrication of the inlay on a die. The advantage of the former technique is that it can be done in a single sitting, and the errors incorporated during the impression making and die fabrication are eliminated.

In the current study, it was found that cyclic loading affected the $\mu$TBS of both the direct and indirect composite restorations. The effect of cyclic loading was more pronounced in the direct composite restorations than in the indirect restorations. The values obtained in this study were lower when compared to those obtained using flat dentinal surfaces. One possible explanation may be the effect of the cavity configuration factor. In 2001, Bouillaguet and others reported a 20% reduction in the bond strength of Class II cavity walls compared with flat dentinal surfaces. Also, it has been reported that the tensile bond strengths were lower at the apical wall compared with the occlusal walls, because of the direction of the tubules.

In the current study, the resin-dentin margin was directly visualized under a low vacuum scanning electron microscope. The margin was evaluated for marginal gap formation. The maximum amount of marginal opening was measured and the scores were given as described in the Methods and Materials section. Categorical evaluation showed that indirect composites have a better marginal adaptation than direct composites. This is because of reduced polymerization shrinkage in indirect restorations. In direct composites, the resin-dentin interface is under stress due to polymerization shrinkage leading to marginal gap formation. In indirect restorations, the only shrinkage that occurs is in the thin layer of luting cement.

The SR Adoro system used in the current study is a microfilled composite system that consists of a low viscosity aliphatic dimethacrylate and a new aromatic aliphatic UDMA which are employed to replace Bis-GMA. In contrast to Bis-GMA and TEGDMA, these monomers do not comprise a hydroxyl group, therefore allowing for the development of composites that are less susceptible to water absorption and solubility. SR Adoro has a modulus of elasticity of 7-10 GPa, which is close to dentin (14.7 GPa). In the current study, during the fabrication of inlays, the first layer used was a flowable liner with a low modulus of elasticity (6 GPa). The other increments of resin composite were further added and adapted over it. Also, dual cure cement has a low filler loading and low modulus of elasticity. Both of these combine to form a stress-dissipating layer with the dentin and help to effectively transfer the mechanical stresses from the inlay to the underlying dentin. Direct resin composite does not provide a stress-dissipating layer, which probably explains the reason for the deterioration of resin-dentin bond strength after mechanical loading.

This study has shown that indirect composite restorations perform better under cyclic loading. The conditions in the oral cavity were different from laboratory conditions, though the same methods were used to simulate the oral environment. Therefore, the results of this study have to be verified by a long-term clinical study.

CONCLUSIONS

The following conclusions were drawn from the current study:

- The $\mu$TBS of both direct and indirect composite restorations are comparable before cyclic loading.
- The marginal adaptation of indirect composite restorations is better than direct composite restorations.
- Cyclic loading affected the $\mu$TBS and marginal adaptation of both direct and indirect composite restorations.
- The effect of cyclic loading was more pronounced in direct composite restorations than in indirect restorations, that is, indirect composite restorations resisted the stresses of cyclic loading better than direct composite restorations.

(Received 28 October 2007)

References


