Polymerization and loading stress distribution in adhesive resin-based composite class II restorations
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Fracture resistance of endodontically treated premolars adhesively restored

Introduction

Endodontically treated teeth can be reinforced considerably with bonding techniques (Sorensen and Martinoff, 1984; Helfer et al., 1972; Lu, 1987). The use of adhesive restorative materials is so effective that retention with only a post was shown to be inferior to an adhesive resin composite build-up without a post (Hoag and Dwyer, 1982). Moreover, Trope et al. (1986) demonstrated that preparation for a post weakens the tooth significantly. Apparently, adhesive restorative materials not only offer sufficient retention but can also form an adherent bridge between the facial and lingual cusps of a significantly weakened tooth. Trope et al. (1986) showed that the resistance against fracture of endodontically treated premolars increased considerably when the teeth were restored intra-coronally with resin composites in combination with the acid-etch technique.

Trope and Tronstad (1991) investigated the contribution of glass ionomer cement to the fracture resistance. Deep MOD cavities were completely restored with glass-ionomer cement or a resin composite and also resin composites and amalgam restorations were placed on a floor of glass ionomer cement. Static loading revealed that the all-resin composite restoration was the strongest. In recent years, both resin composites and glass ionomers as well as the dentine bonding systems have been improved significantly (Prati et al., 1994).

This in vitro study evaluated the resistance to cusp fracture of maxillary premolars, which were weakened by endodontic treatment and subsequently restored with representative examples of contemporary adhesive systems.

Materials and Methods

Selection of teeth: After visual and radiographic examination, 72 carefully extracted sound maxillary premolars were selected on comparable bucco-lingual and mesio-distal measurements to form a group of samples as uniform as possible. They were stored in an aqueous thymol solution until use. During preparation, care was taken to avoid dehydration.

Twelve groups of six teeth each were used in this investigation. Group 1 was left untouched to serve as a control. For the samples of the remaining groups, access cavity was prepared and endodontic treatment was performed by traditional instruments to size 45 and the root canals were filled with gutta-percha and Pulp Canal Sealer (Kerr, Romulus, MI, USA) cement. MOD cavities were prepared with a diamond bur (#330, Intensive, Zurich, Switzerland) at high speed under water coolant. The cavity was cut so that the gingival walls were positioned 1 mm below the enamel-cementum junction. The occlusal part of the facial wall was 2 mm wide and the gingival part 3 mm. Axial and gingival walls were cut non-retentive, approximately at a 90° angle. In the sample teeth to be used for groups 5-12, 0.5 mm wide, 45° bevels were prepared at the cavo-surface enamel margins. In groups 3 and 4, all enamel margins in the occlusal portion were cut as butt joints. Each gingival margin of the cavities was trimmed with a gingival margin trimmer. One group of six teeth with only a MOD cavity was left unrestored (group 2). The materials combinations used in each group are shown in Table 1.
The following restorative procedures were carried out. The manufacturers' instructions were followed, unless otherwise stated. The light-curing unit used in this study was Visilux (3M. Dental Products, Division St Paul. MN. USA).

Group 3. Superbond D-liner/Valiant (SND/VLT) - The cavity walls were conditioned with a 10% citric acid and ferric chloride.
solution for 30 seconds on enamel and for 15 seconds on the dentine. After 15 seconds washing and gently drying, a thin layer of the Superbond priming solution was applied and gently blown. The adhesive agent, Superbond D Liner (Sun Medical, Shiga, Japan) was applied to the dental tissues and a Toffelmire matrix band was positioned. The amalgam Valiant (Caulk/Dentsply, Milford, DE, USA) was condensed, 60 seconds after application of the adhesive agent. After 24-hour storage in a 0.9% NaCl solution, finishing and polishing was carried out with a set of fine diamond burs (amalgam shape, Intensiv, Zurich, Switzerland) at low speed with water coolant.

Group 4. Panavia 21/Valiant (P21/VLT) - The enamel and the dentine surfaces of the whole cavity were treated with Panavia 21 ED Primer (Kuraray Co, Tokyo and Osaka, Japan) for 60 seconds and a gentle air flow was used to promote evaporation until the surfaces appeared glossy. A Tofflemire matrix band was placed. After mixing, the Panavia 21 paste was applied in a thin layer to the entire primed cavity in less than 1 minute. The amalgam Valiant was placed into the cavity while the Panavia 21 paste was still wet. After carving, Oxyguard II (Kuraray Co, Tokyo and Osaka, Japan) was applied to all the margins with a small brush and left in place until the amalgam had set. Then the Oxyguard II was removed with a water spray. After 24-hour storage in a 0.9% NaCl solution, finishing and polishing were done as in Group 3.

Group 5. Scotchbond MP/Z100 (SB/Z100) - The whole cavity was treated with a 10% maleic acid solution for 15 seconds (Scotchbond MP conditioner, 3M Dental Products Division, St. Paul, MN, USA). After 15 seconds washing, the cavities were air-dried gently for 2-3 seconds and Scotchbond MP Primer (3M Dental Products Division, St. Paul, MN, USA) was applied. After a gentle blow of air.
Scotch-bond MP resin (3M Dental Products Division, St. Paul, MN, USA) was applied in a thin layer on the enamel and dentine surfaces and light-cured for 10 seconds. A Tofflemire matrix band was applied and Z100 (3M Dental Products Division, St. Paul, MN, USA) was incrementally inserted and light-cured for 40 seconds per increment. After 24-hour storage in a 0.9% NaCl solution, samples were finished with diamond burs (Composhape, Intensive, Zurich, Switzerland) at low speed with a water coolant. Polishing was performed with Sof-lex discs (3M Dental Products Division, St. Paul, MN, USA).

Group 6. Optibond/Herculite XRV (OB/HXRV) - After positioning a clear matrix band, the whole cavity was treated with 37% phosphoric acid gel on enamel for 30 seconds and on dentine for 15 seconds. The substrate was washed for 15 seconds and gently air-dried. Optibond Primer (Kerr, Romulus, MI, USA) was applied with a sponge, spread with an air stream and light-cured for 20 seconds. Optibond Dual Cure adhesive 3A + 3B was mixed, the solution was applied in a thin layer on the whole cavity, and was light-cured for 30 seconds. Herculite XRV (Kerr, Romulus, MI, USA) was placed incrementally and light-cured for 40 seconds per increment. Samples were finished and polished as described for Group 5.

Group 7. Clearfil Liner Bond System/Clearfil Ray Posterior (LB1/CRP) - After positioning a clear matrix band, the enamel and the dentine of the whole cavity were treated with a 10% citric acid solution and calcium chloride (Ca Agent) for 40 seconds. They were then rinsed for 20 seconds and carefully air-dried. SA Primer was applied with a brush to the entire cavity in a thin layer and then blown with air. Photobond catalyst and universal were mixed in a 1:1 ratio, applied to the surfaces and light-cured for 40 seconds. Protect Liner was applied with a small brush and polymerized for 20 seconds in all dentine areas. The cavities were restored with Clearfil Ray Posterior
and incrementally light-cured for 40 seconds per increment. Finishing and polishing were done as in Group 5.

Group 8. Clearfil Liner Bond 2/Clearfil Ray Posterior (LB2/CRP) - After positioning a clear matrix band, the whole cavity was treated with Clearfil Liner Bond 2 Primer A and B for 20 seconds, dried and light-cured for 20 seconds. Clearfil Liner Bond 2 resin was applied and cured for 20 seconds. In addition, a thick layer of Protect Liner was applied to the cervical wall of the cavities as a liner and light-cured. The cavities were incrementally restored with Clearfil Ray Posterior, each increment cured for 40 seconds. Finishing and polishing were performed as in Group 5.

Group 9. Ketac-Fil Aplicap/Z100 (KF/Z100) - After positioning a clear matrix band the whole cavity was treated with a 10% polyacrylic acid solution (ESPE, Seefeld, Germany) for 10 seconds, washed thoroughly and air-dried. The glass ionomer cement (ESPE, Seefeld, Germany) was mixed (VariMix II, Caulk/Dentsply, Milford, DE, USA) according to the manufacturer’s instructions and forcefully condensed into the cavity to a layer of approximately 2 mm thickness. After bevelling, the glass ionomer base and the enamel margins were etched for 20 seconds with a 37% phosphoric solution gel, then washed and dried. A thin layer of Scotchbond MP unfilled resin was applied on the conditioned surfaces and light-cured for 30 seconds. The cavities were filled incrementally with Z100 resin composite and each increment light-cured for 40 seconds. Finishing and polishing were carried out with diamond fine and superfine diamond burs (Intensive, Zurich, Switzerland) at low speed.

Group 10. Fuji II / Z100 (FII/Z100) - After positioning a clear matrix band, the whole cavity was treated with Fuji II conditioning solution (GC Corporation, Tokyo, Japan) for 10 seconds, washed for
15 seconds and gently air-dried. Fuji II LCI light curing glass ionomer cement (GC Corporation, Tokyo, Japan) was placed incrementally and cured for 20 seconds per increment. After bevelling, the enamel of the lateral and the occlusal walls were etched with a 37% phosphoric acid gel. After 15 seconds washing and gently drying, a thin layer of Scotchbond MP adhesive was applied onto the glass ionomer and on the bevelled enamel margins and cured for 20 seconds. The cavity was finally filled with Z100 resin composite and incrementally light-cured for 40 seconds. Finishing and polishing were done as in Group 5.

Group 11. Vitremer/Z100 (VMR/Z100) - After positioning a clear matrix band, the dentine surface was treated with Vitremer Primer (3M. Dental Products Division, St. Paul, MI, USA) for 30 seconds. After gently air blowing the primed surfaces, light curing was performed for 20 seconds. Two layers of Vitremer (3M. Dental Products Division, St. Paul, MI, USA) were incrementally placed as a base. Each layer was light-cured for 40 seconds. After bevelling, the enamel margins were etched with a 37% phosphoric acid solution. After 15 seconds washing and gently drying, Scotch-bond MP unfilled resin was placed in a thin layer on the glass ionomer and on the etched margins. Z100 resin composite was applied incrementally and light-cured for 40 seconds per increment. Finishing and polishing were done as in Group 5.

Group 12. Compoglass/Tetric (CPGITC) - After positioning a clear matrix band, the dentine surface was treated with Compoglass SCA bonding agent (Vivadent, Schaan, Liechtenstein). After waiting for 20 seconds, the material was spread by gentle air and light-cured for 20 seconds. Compoglass (Vivadent, Schaan, Liechtenstein) was applied in layers of maximal 3 mm thickness. Each increment was light-cured for 40 seconds. The bevelled enamel margins were acid-etched with 37% phosphoric acid solution. After 15 seconds washing and gently
drying Tetric resin bonding system was applied and Tetric resin composite was placed incrementally and each layer light-cured for 40 seconds. Finishing and polishing were done as in Group 5.

After restoration, all the samples were stored in distilled water at 37 ± 1°C for 1 week prior to testing. Then they were mounted in a ring with gypsum (Vel Mix stone, Intensive, Zurich, Switzerland) in order to fix them in an Instron loading machine for axial loading (Instron, High Wycombe, UK). A stainless steel cylinder was positioned on the facial and lingual cusps without touching the restorations (Fig. 1). A loading speed of 0.5 mm/second was used. For statistical analysis, ANOVA, Kruskal-Wallis and Mann-Whitney tests were employed.

Results

Mean fracture resistance and standard deviations for the experimental groups are shown in Table 2. The highest fracture resistance
<table>
<thead>
<tr>
<th>Groups</th>
<th>Materials</th>
<th>Min</th>
<th>Max</th>
<th>Mean</th>
<th>s.d.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Snd</td>
<td>Sound teeth</td>
<td>631</td>
<td>1662</td>
<td>1061</td>
<td>504</td>
</tr>
<tr>
<td>2 MOD</td>
<td>Prepared Teeth</td>
<td>116</td>
<td>501</td>
<td>294</td>
<td>131</td>
</tr>
<tr>
<td>3 SDL/VLT</td>
<td>Superbond D Liner/Valiant</td>
<td>305</td>
<td>441</td>
<td>393</td>
<td>61</td>
</tr>
<tr>
<td>4 P21/VLT</td>
<td>Panavia 21/Valiant</td>
<td>246</td>
<td>833</td>
<td>465</td>
<td>213</td>
</tr>
<tr>
<td>5 SB/Z100</td>
<td>Scotchbond MP/Z100</td>
<td>289</td>
<td>977</td>
<td>705</td>
<td>240</td>
</tr>
<tr>
<td>6 OB/HXRV</td>
<td>Optibond/Herculite XRV</td>
<td>468</td>
<td>1187</td>
<td>804</td>
<td>264</td>
</tr>
<tr>
<td>7 LB1/CRP</td>
<td>Liner Bond 1/C. Ray Posterior</td>
<td>557</td>
<td>1217</td>
<td>790</td>
<td>222</td>
</tr>
<tr>
<td>8 LB2/CRP</td>
<td>Liner Bond 2/C. Ray Posterior</td>
<td>553</td>
<td>913</td>
<td>866</td>
<td>255</td>
</tr>
<tr>
<td>9 KF/Z100</td>
<td>Ketac Fil A./Z100</td>
<td>301</td>
<td>625</td>
<td>483</td>
<td>106</td>
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<td>Fuji II LC/Z100</td>
<td>314</td>
<td>518</td>
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<td>305</td>
<td>601</td>
<td>497</td>
<td>115</td>
</tr>
<tr>
<td>12 CPG/TC</td>
<td>Compoglass/Tetric</td>
<td>383</td>
<td>957</td>
<td>610</td>
<td>232</td>
</tr>
</tbody>
</table>

Table 2 - Fracture force values (N) and standard deviation of mean in each group (n = 6)

Values were recorded for sound teeth (Group 1, control), while the lowest were registered for the unrestored MOD samples (Group 2). From this table you can see that resin dentine bonding systems in combination with resin composites (Groups 5-8) showed the best fracture resistance results. On the other hand, adhesive amalgam samples (Groups 3, 4) fractured at a low force of about 400 N. In all cases, fracture of the restored tooth was at the tooth-restoration interface, illustrating an adhesive failure pattern.

A one-way ANOVA, showed a strong variability between the SD of the groups. So, instead of a parametric analysis, a non-parametric
Kruskal-Wallis test was performed. This test showed significant differences between the groups at \( P < 0.001 \). Mann-Whitney analysis of all the experimental groups versus the control group is displayed in Fig. 2. As it can be seen, the resin dentine bonding systems in combination with resin composites (groups 5-8) did not differ significantly from the sound group (control) with regard to the fracture resistance.

**Discussion**

Due to loss of bridging between the cusps in a deep MOD preparation, the fracture resistance of the tooth under occlusal forces is reduced (Helfer et al., 1972; Wendt et al., 1987). This was clearly demonstrated in this study. As it can be expected, adhesive restorations might contribute positively to the strength of the tooth (Reeh et al., 1989). Wendt et al. (1987) while studying restorations in endodontically treated maxillary premolars with various material combinations, showed
that a resin composite acid-etch combination had the highest fracture resistance, although there was no statistically significant difference with a glass ionomer cement/resin composite combination. Moreover, these authors did not find a statistically significant difference with the fracture resistance of the sound teeth. In contrast to this, the results of the present study showed significant differences in fracture resistance of the teeth, restored with various adhesive systems. Resin composite, placed on resin dentine bonding systems (groups 5-8) showed significantly higher values, than when placed on glass ionomer cements (groups 9-12). A possible explanation for this discrepancy between the two studies could be that Wendt et al. (1987) used a traditional glass ionomer cement as a liner and a past generation resin dentine bonding system, with only the enamel etch technique. Both systems offer only limited bond strength to dentine. In particular, the hydrophilic resin dentine bonding systems used in groups 5-8 have a significantly improved bond strength to dentine due to the hybridization of conditioned dentine (Nakabayashi et al., 1982). Possibly, the testing method of Wendt et al. (1987) was also not sufficiently discriminating, which is illustrated by the fact that they could not find a statistical difference between sound and restored teeth.

Although Trope et al. (1991) showed a more detailed discrimination, they still could not demonstrate a significant difference between those teeth restored with a glass ionomer cement as a base under resin composite or under amalgam. The present study, instead, was more discriminating, since the glass ionomer cement/composite combinations (groups 9-12) showed, significantly ($P < 0.01$), a lower fracture resistance in comparison with resin bonding systems/resin composite combinations. Among the latter groups, statistical differences were found only for Vitremer/Z100 and F11/Z100. The reasons for this different performance, compared with the resin bonding systems/resin composites groups is probably due to the strategy of adhesion, which is significantly modified with the total etch technique (Fusayama.
Nakabayashi et al. (1982) showed the importance of mechanical interlocking with peritubular and intertubular resin dentine penetration after acid conditioning, smear layer removal and hydrophilic priming of tissues. For the group of resin bonding systems, the bond strength proved to be superior to all the previous resin bonding systems, which partially or totally preserved the smear layer (Van Meerbeek et al., 1992). On the other hand, the present generation of resin modified glass ionomer cements in combination with various dentine pre-treatments, showed an improvement of bond strength values in comparison with traditional glass ionomer cements bonded directly to dental hard tissues. This is because of the dentine resin adhesion in combination with HEMA solution. It is well known they have not still reached a bond as strong as in resin dentine bonding systems (Garcia-Godoy et al., 1996). More recently, Hernández et al. (1994) also confirmed in their study the improved performance in cusp fracture resistance of endodontically treated premolars, restored with glass ionomer cement/resin composites combinations. Once again statistical differences were not found when compared with resin bonding systems/resin composite combinations. In that investigation, however, the cavities were firstly etched, washed and dried, and a layer of resin bonding was placed and light-cured before positioning the resin-modified glass ionomer cement VariGlass (Sun Medical, Shiga, Japan). Such a procedure does not differ greatly from an all resin procedure, because VariGlass has to be regarded as a resin composite rather than a glass ionomer. In groups 3 and 4 of the present study, bonded amalgam restorations did not add significantly to the fracture resistance of endodontically treated maxillary premolars. In fact, we did not find significant differences (P < 0.01) in comparing the amalgam restorations with the MOD unrestored preparations (group 2). The bonding systems for amalgam we used, certainly etched and primed the dentine to enhance bonding by resin inter-diffusion, but adhesion to the amalgam might be less strong and durable than to resin composites. In contrast to the
study of Hernández et al. (1994), where no statistical difference in fracture resistance could be demonstrated among bonded amalgam, bonded resin composite and glass ionomer cement/resin composite samples, the present investigation, where the very dentine bonding system (Super Bond D Liner/Amalgambond) was used in combination with the amalgam (Valiant), showed that the cusp fracture resistance of the dentine bonding systems/resin composite restorations (groups 5-8) was significantly higher than the bonded amalgam restorations' one (groups 3, 4).

In this study much care was given to the selection of sound teeth on shape and size. Yet a standard deviation of 50% in strength within the control could not be avoided. The wide variation in fracture strength of sound teeth, 631-1662 N with a mean of 1061, illustrates an intrinsic problem in studying the efficacy of restoration procedures in strengthening injured teeth. The wide spread can partially be explained by the unpredictable fracture pattern of sound teeth and thus failure can happen at a variety of force values. This is in contrast to prepared teeth, where the fracture pattern is more uniform (Salis et al., 1987) and therefore the comparison of the restored groups is more realistic. Besides this, it will be hard, as if not impossible, to replace the sound teeth in such studies by uniform artificial teeth because the strengthening comes from the efficacy of the bond to the dentine based on hybridization.

From this study, it may be concluded that hybrid resin composites in combination with hybridizing bonding systems are the materials of first choice to restore endodontically treated teeth if full coverage by cast metals is not indicated.