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Debonding of adhesively restored deep Class II MOD restorations after functional loading

Introduction

Deep cavity preparation, as in endodontically treated teeth, significantly weakens the tooth structure. Various techniques have been suggested to strengthen the tooth with retentive and adhesive restorative methods (Trope et al., 1986). Resin-based composites (RBC) in combination with resin bonding systems or glass ionomer cements perform well in strengthening the weakened tooth after endodontic therapy (Wendt et al., 1987; Hernandez et al., 1994). In particular, the latest dentine bonding agents used in combination with RBC are effective in restoring the cusp fracture resistance of endodontically treated maxillary premolars (Hernandez et al., 1994; Ausiello et al., 1997). Some of these adhesive systems restored the strength to a level, which did not differ significantly from a sound tooth’s one. Usually, when studying cusp fracture resistance, the restored sample teeth are statically loaded until fracture (Salis et al., 1987). However repeated loading, with a force below the level of fracture prior to the fracture test, may yield different results. In practice, adhesive or cohesive failure is considered as the ultimate consequence of a preceding phenomenon of local debonding of the restoration as a result of chewing effects or para-functions. Under clinical circumstances, a restoration is repeatedly stressed and that is due to the dimensional

changes caused by temperature fluctuations and non-uniform deformation of the components during mechanical loading. These stresses will concentrate in correspondence of mechanical discontinuities such as those at the interface between the cavity walls and the restoration. Adhesive restorations have to adapt these stresses along the margins by having stress-absorbing capabilities (Quist, 1983), but these stresses may occasionally exceed the adhesive or cohesive strength of the materials involved. As a result, the restorations may lose part of their original strength by micro-fracturing and partial separation. In addition, separation will affect leakage which, in non-vital conditions too, has to be considered as an important cause of clinical failure in endodontic therapy (Bishop and Briggs, 1995). Therefore, the effects of functional loading on the marginal integrity deserve interest, when studying restorative methods to reinforce weakened teeth.

This study investigated the effect of functional loading on the marginal integrity of deep Class II MOD restorations, adhesively restored with RBC or amalgam in endodontically treated teeth and correlated the data with the cusp fracture strength of similar restorations from a previous study (Ausiello et al. 1997).

**Materials and Methods**

Eighty-four extracted sound maxillary premolars were used. Special attention was given to selecting teeth with comparable buccolingual and mesio-distal dimensions. All teeth were endodontically treated. Access was created with a tungsten carbide bur (#245, Intensive, Zurich, Switzerland) using high-speed and water coolant. The root canals were cleaned and prepared with the step down technique until size 25, in the third apical section of the root, was reached. The root canals were filled with gutta-percha and Pulp Canal Sealer (Kerr, Romulus, MI, USA).
In each tooth sample a non-retentive MOD Class II cavity was prepared using a diamond bur (#330, Intensiv, Zurich, Switzerland) in a high-speed hand piece. The axial depth of the preparation was approximately 1.0 mm below the enamel-cementum junction. Special care was taken on the buccal-palatal width of the preparation. The thickness of the buccal and palatal cusps was approximately 3 mm when measured at the bottom of the box (Fig. 1). The enamel margins of the restorations intended to be restored with RBC, were bevelled (0.5 mm wide at 45°). Throughout the entire procedure care was taken to avoid dehydration of the teeth.

Fig. 1 - Schematically representation of the MOD cavity preparation.

The 84 teeth were divided into seven groups of 12 samples; each group was restored with a different material combination (Table 1). The materials were handled according to the manufacturers' instructions (unless otherwise stated) using one of the restorative procedures
as described below. When light curing was required Visilux unit (3M Dental Products Division, St. Paul, MN, USA) was used.

### Group 1. Scotchbond Multi-Purpose/Z100 (SBMP/Z100) - The whole cavity was treated with 10% maleic acid solution for 15 seconds (SBMP conditioner, 3M Dental Products Division, St. Paul, MN, USA), then washed and gently air-dried. SBMP primer (3M Dental Products Division, St. Paul, MN, USA) was applied and after a gentle air blow, SBMP adhesive (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 steel matrix band was placed and the cavities were restored using Z100 (3M Dental Products Division, St. Paul, MN, USA) in three increments.
each light-cured for 40 seconds. The restorations were finished with Composhape (Intensive, Zurich, Switzerland) diamond burs at low speed with water coolant and polished with Soflex discs (3M Dental Products, St. Paul, MN, USA). The teeth were stored in NaCl 0.9% solution for 1 week before testing.

Group 2. Clearfil Liner Bond 2/Clearfil Ray Posterior (CLB2/CRP) - After positioning a clear matrix band, the entire cavity was treated with CLB2 Primer A and B (Kuraray, Co, Osaka, Japan) for 20 seconds, air-dried and light-cured for 20 seconds. CLB2 adhesive (Kuraray, Co, Osaka, Japan) was applied and light-cured for 20 seconds. In addition a thick layer of Protect Liner (Kuraray, Co, Osaka, Japan) was applied to the cervical wall of the cavities and light-cured for 20 seconds. The cavities were restored, using CRP (Kuraray, Co, Osaka, Japan) in three increments, each light-cured for 40 seconds. The restored teeth were finished and polished in the same way as in Group 1 and stored in 0.9% NaCl-solution for a week before testing.

Group 3. 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, then washed and gently dried. OB primer (Kerr, Romulus, MI, USA) was applied with a sponge, spread with air and light-cured for 20 seconds. OB dual cure adhesive 3A + 3B (Kerr, Romulus, MI, USA) was mixed and applied in a thin layer on the entire cavity and light-cured for 30 seconds. The cavities were restored using HXRV (Kerr, Romulus, MI, USA) RBC in three increments, each light-cured for 40 seconds. The restored teeth were finished and polished in the same way as in Group 1 and stored in 0.9% NaCl-solution for 1 week before testing.

Group 4. Panavia 21/Valiant (P21/VLT) - The enamel and the dentine surfaces of the cavity were treated with Panavia 21 ED Primer (Kuraray, Co, Osaka, Japan) for 60 seconds while a gentle airflow was
used to promote evaporation of the solvent, turning the surfaces into a glossy appearance. After placing a Tofflemire steel matrix band, a mixture of P21 paste (Kuraray Co. Osaka, Japan) was applied in a thin layer to the primed cavity in less than 1 minute. The VLT (Caulk/Dentsply, Milford, DE, USA) amalgam was condensed into the cavity while the P21 paste was still wet. After carving, Oxyguard II (Kuraray Co. 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. Finishing and polishing were carried out with a set of diamond fine burs (amalgam shape, Intensive, Zurich, Switzerland) at low speed under water coolant. Samples were stored in 0.9% NaCl solution for 1 week before testing.

Group 5. Superbond D-liner/Valiant (SBDL/VLT) - The cavities were conditioned with 10% citric acid and ferric chloride solution for 30 seconds on enamel and for 15 seconds on the dentine. After washing and drying, a thin layer of the SB priming solution was applied and gently blown with air. Then the adhesive agent SB D-Liner (Sun Medical, Tokyo, Japan) was applied and a steel matrix band placed. The VLT amalgam was condensed, 60 seconds after application of the adhesive agent. Finishing and polishing were carried out with a set of diamond fine burs (amalgam shape) at low speed under water coolant. Samples were stored in NaCl 0.9% solution for 1 week before testing.

Group 6. Compoglass/Tetric (CPG/TC) - After positioning a clear matrix band, the dentine surface was treated with Compoglass SCA bonding agent. After waiting for 20 seconds, the material was spread by softly blowing air and light-cured for 20 seconds. Compoglass (Vivadent, Schaan, Liechtenstein) was applied in layers of 3 mm thickness, each light-cured for 40 seconds. The bevelled enamel margins were acid-etched with 37% phosphoric acid solution. After washing
and drying, Tetric (Vivadent, Schaan, Liechtenstein) resin-based bonding system was applied and Tetric RBC inserted in three increments, each light-cured for 40 seconds. The restored teeth were finished and polished in the same way as in Group 1 and stored in 0.9 % NaCl-solution for 1 week before testing.

Group 7. Fuji II LC / Z100 (FIILC/Z100) - After positioning a clear matrix band, the entire cavity was treated with GC Conditioning solution for 10 seconds, washed and air-dried. Fuji II LC (GC Corporation, Tokyo, Japan) glass ionomer cement was placed in three increments, each light-cured for 20 seconds. After bevelling, the enamel of the lateral and the occlusal walls were etched with a 37% phosphoric acid gel. After washing and drying, a thin layer of SBMP adhesive was applied on the glass ionomer and on the bevelled enamel margins and light-cured for 20 seconds. The cavities were restored using Z100 RBC in three increments, each light-cured for 40 seconds. The restored teeth were finished and polished in the same way as in Group 1 and stored in 0.9% NaCl-solution for a week before testing.

Six teeth in each group were used in a load cycling test following Procedure A and the remaining six teeth served as controls, following Procedure B.

Procedure A (load cycling test): Plastic rings, 10 mm in diameter and 20 mm in length, were filled with stone (Velmix, Kerr, Romulus, MI, USA) and the teeth (six of each group) were placed into the stone exactly in the middle of the rings up to 2/3 of the root. After complete setting of the stone the teeth were loaded in a device, which delivered an intermittent force between 2.0 - 125 N at 1 cycle/minute (1 Hz) lasting 4000 cycles. The intermittent force was applied on a steel rod, 6.0 mm in diameter, resting with its lateral surface on the buccal and lingual cusps without touching the restoration (Ausiello et al., 1997). The magnitude of the force was chosen in accordance with literature values (Davidson and Abdalla, 1994). During and after the loading
procedure, the teeth were immersed in a 2% methylene blue solution for a total exposure time of 48 hours.

Procedure B (control): The six teeth left in each group were coated with nail polish 1 mm shorter than the margin of the restorations and used as controls. They were kept in the methylene blue solution for an equivalent period of time (48 hours) as the loaded teeth.

After immersion for 48 hours in the dye, all 84 samples were cleaned with water and axially sectioned in mesio-distal direction through the restorations by means of a diamond saw (Buehler Ltd., Lake Bluff, IL, USA). The sections were evaluated for dye penetration at the gingival level with an optical microscope. The penetration depth was expressed as a percentage of the mesio-distal length of the cross-sectional adhesive interface. The leakage scores of the six teeth in each group were then averaged.

The data were analysed using the SPSS package (release 8.0 for Windows 95). With the aid of the GLM subprogram a MANOVA was performed with the amount of leakage as the dependent variable. Restorative procedure (groups 1-7) and loading condition (control versus functional loading) were entered as between subject factors. Whenever an effect was significant it was further analysed by means of appropriately chosen contrasts and tests for simple effects using the GLM and ANOVA subprograms.

Pearson correlation was calculated between the averages for leakage after functional loading determined in this study and the averages of cusp fracture strengths of similarly prepared restorations in a previous study (Ausiello et al., 1997).

Results

The results of dye penetration scores are shown in Table 2. All control and loaded groups showed some dye penetration. The leakage in the control samples is an indication of imperfect bonding.
Both main effects (restorative procedure and loading condition) as well as the restorative procedure by loading interaction effect were significant ($P = 0.000$) at the 0.05 level. On the average, the amount of leakage turned out to be greater for the loading condition compared to the control condition. This difference however varied between the restorative procedures used; the interaction effect was significant (Fig. 2). It was apparent that the restorative procedures P21/VLT and SDL/VLT were the most sensitive to loading where leakage is concerned. Computation of “simple condition within restorative
procedure" effects showed these restorative procedures to be the only ones for which the loading condition was significant (P = 0.000).

The "simple material within control condition" effect was not significant (P = 0.149), meaning that the restorative procedures did not differ in amount of leakage in the control condition.

The "simple restorative procedure within loaded condition" effect however was significant at the 0.05 level (P = 0.000). Differences between restorative procedures existed in the loaded condition only. Therefore subsequent contrasts were calculated for the loaded condition exclusively. Weights for the contrasts were chosen to enable a distinction among the three categories: (1) bonded RBC restorations, (2) bonded amalgam restorations and (3) sandwich restorations. All three categories differed significantly from one another, whereas restorative procedures within the same category were not significantly different.

Pearson correlation between leakage after functional loading and cusp fracture strength was 0.857 (P = 0.014), showing that leakage gets worse as the strength decreases.
Discussion

Adhesive restoration of deep MOD cavities fulfills two goals: strengthening of the weakened structure and sealing the exposed dentine. For both purposes, it is of paramount importance that the adhesion between restoration and cavity walls remains flawless. Wendt et al. (1987) showed the possibility of restoring the strength of a maxillary premolar with Class II MOD preparations with adhesive filling materials. In another study by Wendt (1991) on large MOD Class II preparations, restored with resin inlays or direct RBC in combination with past generation dentine bonding agents, all the adhesive restorations started to leak after thermal-cycling. Leakage is an indication of a defective interface and thus an indication of weakening of the restored tooth. The adhesion at the composite-enamel interface is usually able to resist both shrinkage and loading stresses, while it is difficult to obtain and maintain a good seal at dentine (Prati, 1989). Eakle and Nakamoto (1989) showed that not only after thermal cycling the sealing at the dentine cavity wall was significantly inferior to the enamel margins, but that imperfections of dentine sealing were already present in the controls, apparently caused by insufficient bonding and by the polymerization shrinkage of the restorative materials.

In the present investigation, the cervical margins in the MOD Class II preparations were positioned 1 mm below the enamel-cementum junction, which is a most critical situation in adhesive dentistry to obtain a strong and durable bond (Lundin and Noren, 1991; Cagidiaco et al., 1997). Marginal defects at the RBC-dentine interface were scored from dye penetration depths after immersing the restored teeth in a dye solution for a period of 48 hours. For the teeth, which were load-cycled, the immersion period included the load cycling procedure to allow dye penetration in gaps that are transiently opened by force. When the immersion is done only after loading, these
gaps may have closed so tight that dye penetration is prevented and separation cannot be revealed. Similar to Eakle and Nakamoto's study (1989), leakage was already found in the control samples, even with the variety of different and new adhesive procedures. However, functional loading of the restorations in groups 1-3 did not increase leakage, which may show that the RBC in combination with hybridizing bonding systems do not undergo marginal deterioration from cyclic loads, a finding which was reported earlier (Darbyshire et al., 1988).

In deep MOD preparations of maxillary premolars, the configuration is most unfavourable for RBC with respect to shrinkage stress. If damage occurs by the polymerization shrinkage stress then it will be seen cervically, since the adhesion to enamel is usually stronger than to dentine. It was very interesting to observe that the use of the self-etching Liner Bond 2 primer or the weak 10% maleic acid solution of the Scotchbond Multi-Purpose system showed cervical defects of similar magnitude as the use of the strong 37% phosphoric acid solution of the OptiBond system. However, this does not necessarily mean that the situation is the same at the enamel interface, since enamel requires stronger acids or a longer etching time (Ferrari et al., 1996).

Groups 1-3 performed significantly better than the RBC sandwich restorations in group 6 and 7. This is in contrast with the literature (Wendt, 1991; Abdalla and Davidson, 1993; Nakabayashi et al., 1982) since it was shown that the use of the glass ionomer sandwich technique, in Class II restorations offered a superior seal at the external margins, when compared with resin bonding systems. However, comparisons with other studies are often difficult or useless, because the conditions, the size of preparations, the techniques and materials are seldom alike. e.g. Abdalla and Davidson (1993) positioned the cervical margins completely within the enamel, and both the glass ionomers and resin bonding agents were substantially different at the time the study was conducted. In the present investiga-
tion, some new generation dentine bonding agents were tested, which infiltrate the dentine tubuli as well as the inter-tubular dentine to form a hybrid layer, well documented as the resin-dentine inter-diffusion zone (Nakabayashi et al., 1982). Furthermore, the high viscosity of these bonding agents guarantees the presence of a continuous elastic layer between the dentine walls and the restoration, which can act as a stress absorber during curing and load stressing (Davidson, 1994). In this respect, it is remarkable that the use of the compomer and resin-modified glass ionomer (group 6 and 7) materials, both with a relatively low elastic module, did not work effectively as stress absorbers. Loading worsened the cervical seal in both groups significantly. An explanation might be sought in less effective bonding with the latter systems. For the conventional and resin-modified glass ionomers in a sandwich technique, problems related to adhesion with the RBC were reported (Hotta and Aono, 1994; Subrata and Davidson, 1984), but their bonding capacity to dentine proved to be effective. This could not be observed for the compomers (Ferrari et al., 1996), which require additional conditioning and bonding. As the compomers were initially marketed without instructions for conditioning the dentine, a conditioning procedure was followed in this investigation. However, for optimal bonding, these materials apparently also require substrate pre-treating, as in the case of RBC systems (Ferrari et al., 1996; Garcia-Godoy and Hosoya, 1998).

The bonded amalgam restorations (groups 4 and 5) performed significantly worse when compared to the other adhesive restorative procedures. Especially after loading, the amalgam restorations showed leakage along the whole cavity wall. The most probable explanation for the failure is that the bonding to amalgam might still be limited while the amalgam is too stiff to comply with the deformation stresses during loading.

When a Pearson correlation was calculated between the averages of leakage after functional loading and the averages of cusp fracture
strengths of similarly prepared restorations from a previous study (Ausiello et al., 1997). A significant correlation (P < 0.05) could be demonstrated. This observation might be an indication that debonding due to repeated loading, originates from an initial poor bond strength.

From this study, it can be concluded that it is still difficult to restore endodontically treated teeth free of any leakage with adhesive techniques and plastic materials. The marginal integrity of the restorations in hybrid RBC combined with hybridizing resin-bonding systems was resistant to functional loading. Imperfections of the bond, due to polymerization shrinkage stress or mechanical functional loading, will not only negatively affect the sealing of the restoration, but might also affect the resistance to fracture.