Cervical microleakage in Class II open-sandwich restorations: an *in vitro* study

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SUMMARY

Introduction: The open-sandwich technique was proposed to solve the problem of cervical micro-leakage of deep Class II composite restorations by making use of the self-adhesive nature of the glass-ionomers. Recent advances in the properties of this family of materials may continue to make the technique relevant today.

Aims and objectives: The aim of this *in vitro* study was to determine the effect of thermocycling, cervical position and the use of different materials on the cervical microleakage of Class II open-sandwich restorations.

Methods: Two hundred standardised Class II cavities with the cervical margins placed in either enamel (100) or dentine (100) were prepared in 100 extracted human molars. Ketac Molar, set with ultrasound (US), Ketac Molar, Ketac Nano and Vitremer were used in equal groups to restore the cervical boxes, while Filtek Z250 was used to complete the restorations and also provided a control group in which the sandwich technique was not used. One half of each group was subjected to thermocycling. Microleakage was assessed by measuring the distance of penetration of basic fuchsin dye along the cervical step.

Results: The open-sandwich technique significantly ($p<0.001$) reduced the microleakage otherwise seen in Filtek Z250 when margins were placed in dentine and thermocycled.

Conclusions: The use of an ultrasonically cured glass-ionomer in the open-sandwich resulted in the least microleakage (after thermocycling) when the cervical margins of Class II restorations were placed in dentine.

INTRODUCTION

McLean and Wilson[1] first described the open-sandwich technique in 1977, proposing it as a method to improve adhesion of resin composite restorations. The technique was developed to limit the shortcomings of posterior composite restorations, particularly their lack of permanent adhesion to dentine, which could result in microleakage and postoperative sensitivity. Mount[2] advocated that the glass-ionomer (GI) at the cervical margin be left exposed to allow released fluoride to protect the surrounding tooth structure. This became known as the open-sandwich technique.

Given the advances in dentine-bonding agents and resin composites, one would think that the technique would by now have become obsolete. However, the clinical success of posterior composite restorations is still limited with respect to leakage[3,4,5] and longevity[6,7], and this has meant that the sandwich technique is still in use today. The restoration of deep approximal cavities also requires that several problems must be overcome, the difficulty of placement of a rubberdam, the time-consuming incremental packing technique, and the intricate handling required by some dentine bonding systems.[8]

It is therefore relevant to look at these relatively old materials with the aim of solving current problems in adhesive bonding because the GI family is naturally self-adhesive to tooth structure.[9]

The open-sandwich technique failed clinically when conventional GI's were used to restore the cervical margins of Class II restorations, mainly because of a continuous loss of material.[10,11,12,13] Consequently, the then newly developed resin-modified glass-ionomers (RMGI) were used in place of conventional GI. The inclusion of resin in the GI formulation allowed these newer materials to polymerise upon light activation. The resin also supplemented the chemical bond that GI achieves with tooth structure by bonding micromechanically.[14] This double adhesion mechanism is the main determinant of the retention and marginal sealing capacity of the material.[15] It has been reported that higher bond strengths were achieved with RMGI than with conventional GI.[16,17,18]

Recently, Kleverlaan, van Duinen and Feilzer[19] investigated the mechanical properties and compressive strength of GI's that were either chemically cured, ultrasonically activated or heat cured, and concluded that the mechanical properties of GI's significantly improved after ultrasound or heat curing. An ultrasonically cured GI demonstrated increased hardness, a decrease in the soft surface layer and negligible creep at a significantly shorter time after placement, suggesting that the curing process may be accelerated immediately after ultrasonic activation.[20]

However, comparative microleakage studies have not yet been performed.

While most current restoratives might obtain high initial bond strengths, it is uncertain how their adhesion to tooth structure will stand up to the test of time. Intra-oral thermal changes may compromise the bond between restorative material and tooth structure and create the potential for microleakage.[21] Thermocycling may be used *in vitro* to stress the adhesive bond by alternating immersion of test restorations in baths of warm and cold water.

The aim of this *in vitro* study was to determine, in a controlled laboratory environment, the effect of thermocycling, cervical position and the use of different materials on the cervical microleakage of Class II open-sandwich restorations. The hypothesis was that the use of an intermediate layer at the cervical margin would improve the marginal seal of resin composite restorations, irrespective of thermocycling or cervical position.

METHOD AND MATERIALS

One hundred intact extracted human molars were selected after each had been cleaned with pumice and water and after examination under a light microscope had found them to be caries-free and undamaged by extraction. The teeth were stored in 0.2% thymol solution (Merck, Darmstadt, Germany) at 4°C until commencement of the study. The apices of the teeth were then embedded in self-curing acrylic (Excel Rapid Repair, Wright Health Group, Dundee, Scotland) to seal the canals and to simplify handling of the specimens.

A Class II cavity preparation was made on the mesial and distal surface of each tooth with the cervical margins placed, respectively, 1mm coronal and 1mm apical of the cemento-enamel junction (CEJ). The cavities measured 5mm bucco-lingually, and were 2mm deep, with rounded internal line angles and a cavo-surface margin at 90° to the tooth surface.

Cavity preparations were performed with a diamond dome shaped fissure bur (ISO 314 141), in a high-speed handpiece and under copious water spray. The bur was replaced after every tenth cavity preparation.

The 100 teeth were randomly divided into five groups of 20 teeth. In each group, the cervical margin was restored with a specific material, namely Filtek Z250 (control), Vitremer, Ketac Nano, Ketac Molar (conventional) or Ketac Molar set with ultrasonic activation (US) (all materials from 3M ESPE St Paul, MN, USA).

The prepared cavities were rinsed with water and slightly air dried with a three-in one syringe. Etchant was first applied to all enamel cavity surfaces for 15 seconds and to the dentine of the pulpal floor for 10 seconds. Cavities were then rinsed for five seconds with water and blotted dry. A Tofflemire matrix band (Hawe Neos Dental, Bioggio, Switzerland) was placed to confine the restorative materials. The prescribed material and technique were then used to prepare the interproximal box surface of the cavity for the relevant sandwich (see Table 1 for a summary of the preparation of specimens and the routine of curing the restorations).

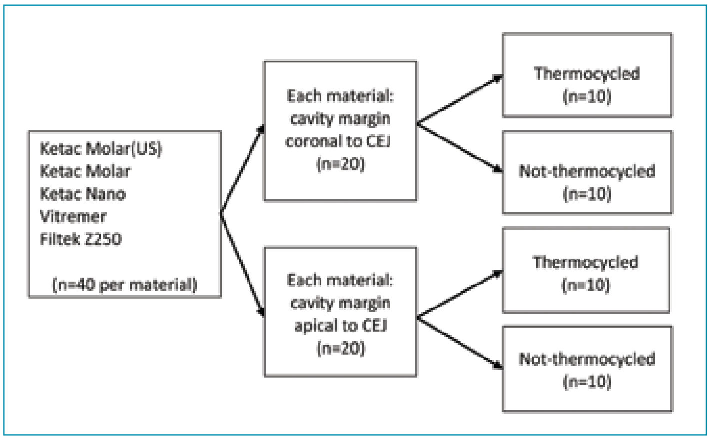

Figure 1: Flow diagram indicating the distribution of materials, position of cervical cavity preparation and thermocycling condition.

Sandwich materials were placed in bulk, except for the Filtek Z250 control group, to fill the interproximal box level with the pulpal floor. Where necessary, a ball burnisher moistened in SBMP adhesive was used to adapt the materials. In all specimens the material was light-cured according to the manufacturer's instructions with an Optolux 501 light curing unit (Kerr, California, USA). Restorations were completed with a final two increments of Filtek Z250, placed obliquely, and individually light cured for 20 seconds. The light intensity was maintained between 400 and 500Mw/cm^2 and was regularly checked with the light meter of the curing unit.

The restored teeth were stored for seven days at 37°C in tap water, before the cervical margins were finished with a fine diamond bur under water cooling and polished with a medium grit Sof-Lex disc (3M ESPE). Half of the restored specimens for each material and cervical position (n = 10) were then thermocycled in tap water for 500 cycles, between baths at 5°C and at 55°C with a dwell time in each of 30 seconds. The other half of each group (n = 10) were not thermocycled.

Figure 1 demonstrates the group allocation of materials, position of cervical cavity preparation and thermocycling condition to arrive at the final group size of ten for statistical testing.

The teeth were prepared for microleakage testing by sealing their remaining external surfaces with nail varnish up to one millimetre from the restoration margins. Samples were then immersed in a 0.5% solution of basic fuchsin (Merck, Darmstadt, Germany) for 24 hours at 37°C. Care was taken to keep teeth wet, where at all possible, throughout the procedures.

After immersion the teeth were scrubbed to remove the nail varnish and embedded in a clear self-curing acrylic. Three

Table 1: Summary of the preparation and cure of specimens

Material	Material for Surface preparation	Technique for preparation of interproximal box	Cure of sandwich material
Filtek Z250	Scotchbond Multipurpose Plus (SBMP)	Etchant: Etch enamel 15 seconds, dentine 10 seconds. Rinse, blot dry. Primer: Air dry 5 seconds. Adhesive: Apply, light cure 10 seconds.	Increments of 2mm, light cured for 20 seconds.
Vitremer	Vitremer Primer	Apply, leave 30 seconds, air dry, light cure 20 seconds.	Light cure 40 seconds.
Ketac Nano	Ketac Nano Primer	Apply, leave 15 seconds, air dry 10 seconds, light cure 10 seconds.	Light cure 30 seconds.
Ketac Molar	Ketac Conditioner	Apply for 10 seconds, rinse, blot dry.	Leave 5 minutes.
Ketac Molar (US)	Ketac Conditioner	Apply for 10 seconds, rinse, blot dry.	Apply scaler tip for 30 seconds, 30 KHz.

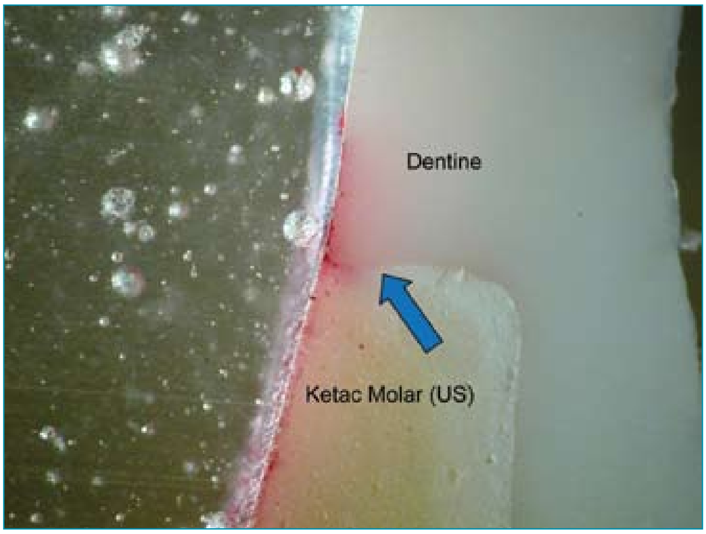

Illustration 1: Photomicrograph of a cross section of a tooth restored with Ketac Molar (US) displaying a value of 1 for micro-leakage of the cervical margin in dentine.

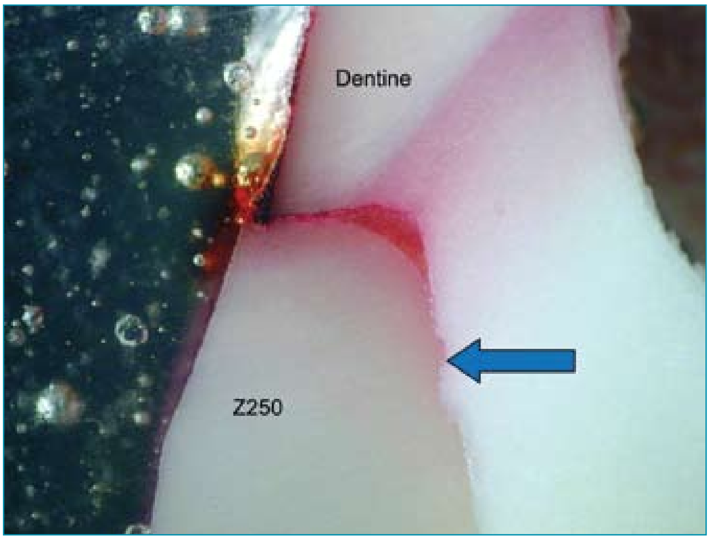

Illustration 2: Photomicrograph of a cross section of a tooth restored with Filtek Z250 (control) displaying a value of 3 for micro-leakage of the cervical margin in dentine.

longitudinal cuts of the embedded teeth were made 2mm apart with an Accutom-2 precision saw (Struers, Ballerup, Denmark) to yield on each restoration two sections and four surfaces for evaluation.

A single operator evaluated each section through an Olympus BH2 light microscope at four times magnification.

Microleakage was scored from 0 to 3, as listed below:
0 = no microleakage
1 = leakage less than half the distance to the axial wall (Illustration 1)
2 = leakage more than half the distance to the axial wall
3 = leakage up to the axial wall (Illustration 2).

For each specimen, microleakage scoring was repeated several times and then averaged to yield a mean score for a specific material, cervical position and thermocycling condition. Therefore, although microleakage was scored on a discrete scale between 0 and 3, taking the average of several repetitions rendered it possible to regard the data on a continuous scale. All the data was pooled and captured in a Microsoft Excel 2003 spreadsheet and exported to the SAS© statistical package. A multivariate statistical model was built with the three independent variables (material, thermocycling and cervical position) and with microleakage as the dependent variable. An analysis of variance (ANOVA) was applied to test for differences of the dependent variable. From the average microleakage data the least square means (LS means) were calculated for comparisons of materials and experimental conditions. Comparisons were made of the LS means and differences were deemed statistically significant when the associated p value was less than 0.05.

Table 2: p-values for microleakage comparisons of thermocycling vs no-thermocycling when restoration margins were placed respectively in dentine and enamel (n = 10 per group for combination of experimental conditions) (Significant values in bold)

Material	Enamel	Dentine
Ketac Molar (US)	0.4433	0.0821
Ketac Molar	**0.0040**	0.2907
Ketac Nano	0.3283	0.8739
Vitremer	**0.0075**	**<.0001**
Filtek Z250	0.4278	0.5787

Table 3: p-values for microleakage comparisons of dentine vs enamel cervical margins when samples were respectively not-thermocycled or thermocycled (n = 10 per group for combination of experimental conditions) (Significant values in bold)

Material	Not-thermocycled	Thermocycled
Ketac Molar (US)	**0.0037**	0.6721
Ketac Molar	0.8739	**<.0001**
Ketac Nano	0.1022	**0.006**
Vitremer	**<.0001**	**0.0022**
Filtek Z250	**<.0001**	**<.0001**

Table 4: p-values for microleakage comparisons between the different materials placed in enamel and not-thermocycled, where: 1 = Ketac Molar (US), 2 = Ketac Molar, 3 = Ketac Nano, 4 = Vitremer, 5 = Filtek Z250 (n = 10 per group for combination of experimental conditions) (Significant values in bold)

Not-thermocycled, Enamel	1	2	3	4	5
1. Ketac Molar (US)		**0.004**	0.1328	**0.0037**	0.8118
2. Ketac Molar	**0.004**		0.162	0.9789	**0.0081**
3. Ketac Nano	0.1328	0.162		0.1543	0.2051
4. Vitremer	**0.0037**	0.9789	0.1543		**0.0075**
5. Filtek Z250	0.8118	**0.0081**	0.2051	**0.0075**	

RESULTS

The results of the cervical microleakage tests of the different materials are illustrated in Tables 2 to 6.

With respect to the effect of thermocycling on the microleakage of different materials, the p-values are depicted in Table 2. The process of thermocycling significantly reduced microleakage when Ketac Molar was placed in enamel.

When the cervical margin was placed in dentine, microleakage increased significantly for most of the materials, irrespective of whether the samples were thermocycled or not (Table 3).

When cervical margins were placed in enamel and not thermocycled, significantly less microleakage was observed with Ketac Molar (US) and Filtek Z250 than with Ketac Molar and Vitremer (Table 4, Figure 2). Thermocycling reduced the differences between materials, so that there were no statistically

Table 5: p-values for microleakage comparisons between the different materials placed in dentine and not-thermocycled, where: 1 = Ketac Molar (US), 2 = Ketac Molar, 3 = Ketac Nano, 4 = Vitremer, 5 = Filtek Z250 (n = 10 per group for combination of experimental conditions) (significant values in bold).

Not-thermocycled, Dentine	1	2	3	4	5
1. Ketac Molar (US)		0.8948	0.8324	**<0.0001**	**0.0001**
2. Ketac Molar	0.8948		0.9367	**<0.0001**	**0.0002**
3. Ketac Nano	0.8324	0.9367		**<0.0001**	**0.0002**
4. Vitremer	**<0.0001**	**<0.0011**	**<0.0001**		0.3415
5. Filtek Z250	**0.0001**	**0.0002**	**0.0002**	0.3415	

Table 6: p-values for microleakage comparisons between different materials placed in dentine and thermocycled, where: 1 = Ketac Molar (US), 2 = Ketac Molar, 3 = Ketac Nano, 4 = Vitremer, 5 = Filtek Z250 (n = 10 per group for combination of experimental conditions) (significant values in bold).

Thermocycled, Dentine	1	2	3	4	5
1. Ketac Molar (US)		**0.0037**	**0.0354**	**0.0332**	**<.0001**
2. Ketac Molar	**0.0037**		0.4126	0.4278	**0.0010**
3. Ketac Nano	**0.0354**	0.4126		0.9789	**<.0001**
4. Vitremer	**0.0332**	0.4278	0.9789		**<.0001**
5. Filtek Z250	**<.0001**	**0.0010**	**<.0001**	**<.0001**	

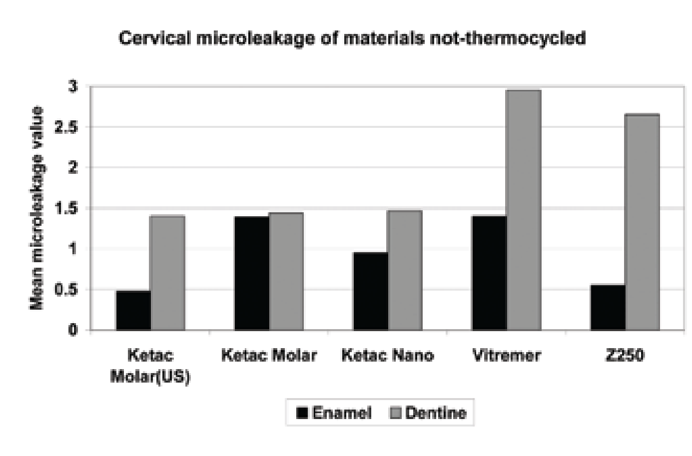

Figure 2: Cervical micro-leakage of materials not-thermocycled.

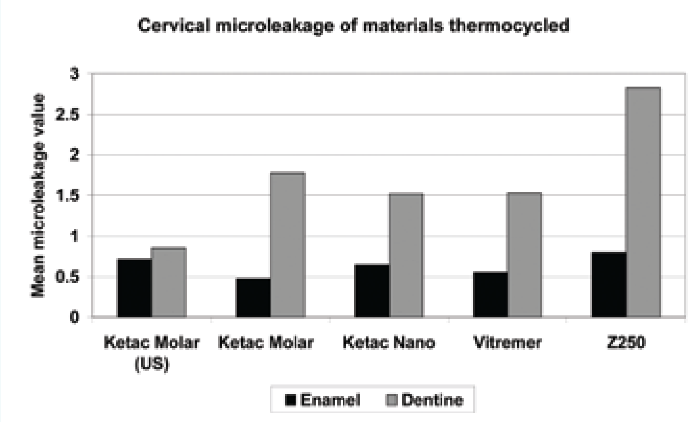

Figure 3: Cervical microleakage of materials thermocycled.

significant differences between materials placed in enamel and thermocycled (Figure 3).

When cervical margins were placed in dentine and not thermocycled, Ketac Molar (US), Ketac Molar and Ketac Nano prevented microleakage significantly better than did Filtek Z250 and Vitremer (Table 5, Figure 2). When specimens were subjected to thermocycling, microleakage in dentine was significantly the least for Ketac Molar (US) and significantly the most for Filtek Z250 compared with the other materials (Table 6, Figure 3). From Figure 3 it can be seen that when the cervical margin was placed in dentine and thermocycled, microleakage with Filtek Z250 nearly always extended up to the axial wall.

Summary of key results:

- The placement of restorative margins in dentine lead to greater cervical microleakage than when the margin was in enamel (Figure 2), especially when samples were thermocycled (Figure 3).
- When restorative margins were placed in dentine, the use of the sandwich technique significantly reduced cervical microleakage. This was especially true for thermocycled samples (Figure 3).

DISCUSSION

The decrease in microleakage seen after thermocycling of Vitremer in dentine and enamel is explained in the literature by the effect of water sorption by the material as a result of the use of unfilled resins.[22,23,24,25] The water sorption allows for compensation for the difference between the coefficient of thermal expansion (COTE) of the RMGI and the tooth structure.[26] Hand mixed materials such as Vitremer allow the inclusion of air bubbles that expand in volume during thermocycling, influencing the snugness of fit of the restoration.[27]

In this study, thermocycling of the resin composite resulted in a non-significant, but consistent, increase in microleakage, a feature also observed in other studies.[28,29] Bullard[22] and Doerr[27] attribute this observation to the difference in COTE between tooth and restorative material that will manifest as increasing microleakage with repeated thermocycling and temperature variations.

The use of a resin composite (Filtek Z250) consistently resulted in high microleakage values when the cervical margins of the Class II restorations were placed in dentine. This finding is consistent with the current literature.[4,30,31,32] Poorer bond strengths may also be expected as the restoration margin in enamel approaches the CEJ. An explanation given is that as the enamel approaches the CEJ, it becomes increasingly aprismatic, which allows only a poor bond structure. From as much as 1.5mm coronal to the CEJ, both the quality and strength of the resin composite bond to tooth structure are equivalent to the bond achieved to dentine rather than to enamel.[33] Another explanation for the poor performance of Class II composite restorations with margins in dentine is ascribed to the dimensional changes of the composite.[34] The shrinkable bulk of composite is reduced by using a sandwich material such as a RMGI.[35]

The use of RMGI in the open-sandwich technique has been shown to improve the marginal seal and adaptation of direct Class II restorations as compared with base or total bond restorations[8,36,37,38] and is in agreement with the results obtained with Ketac Nano, used as a nano-ionomer in this study.

The benefit of using Vitremer only became significant when it was placed in dentine and thermocycled. The otherwise poor performance of Vitremer is in contrast with the results described by another author[39] who showed promising results with a combination of Vitremer and Z100.

The fact that the conventional GI performed so well is in contrast with the finding of Garcia-Godoy[40] that the initial bond between GI and tooth structure may be insufficient to withstand the polymerisation contraction stress of the resin composite. However, should the shrinkage stress of the material in fact be sufficient to disrupt the bond between the material and the tooth structure, it is very probable that the tissue will remain protected from the oral environment by a thin film of cement.[41]

The finding that the ultrasonically cured GI performed even better than the conventional GI in dentine when thermocycled, may be ascribed to the fact that the material reaches its final characteristics in a far shorter time than does the conventionally cured GI's.[20]

This study demonstrates that, apart from the results obtained with Vitremer when placed in dentine and not thermocycled, the use of the sandwich technique significantly reduces the cervical microleakage of Class II restorations.

CONCLUSIONS

The study hypothesis was therefore partially proven: the use of an intermediate layer at the cervical margin of Class II restorations improved the marginal seal of composite restorations especially when placed in dentine and thermocycled. The GI family of materials should be recommended for use in the open-sandwich technique when cervical margins are placed in dentine, but the choice between conventional and RMGI remains controversial. Though the results of this study favour the use of an ultrasonically cured GI, the question remains whether this improved material will withstand the test of time and will not succumb to material loss, as reported by Wellbury and Murray.[10]

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