©Operative Dentistry, 2012, **37-5**, 474-484

Laboratory Research

Adhesion of Indirect MOD Resin Composite Inlays Luted With Self-adhesive and Self-etching Resin Cements

T Inukai • T Abe • Y Ito
P Pilecki • RF Wilson • TF Watson
RM Foxton

Clinical Relevance

The dentin bond strengths of indirect composite inlay restorations cemented with self-adhesive and self-etching resin cements were reduced after loading, while microleakage increased. There were no significant differences in microtensile bond strengths and microleakage between the three resin cements.

Toshihiro Inukai, DDS, PhD, School of Dentistry, Aichi Gakuin University, Nagoya, Japan

Toshiyuki Abe, DDS, PhD, School of Dentistry, Aichi Gakuin University, Nagoya, Japan

Yutaka Ito, DDS, PhD, School of Dentistry, Aichi Gakuin University, Nagoya, Japan

Peter Pilecki, BSc, MSc, King's College London Dental Institute at Guy's, King's College and St. Thomas' Hospitals, King's College London, Department of Biomaterials, King's College London, London Bridge, London, United Kingdom

Ron F Wilson, PhD, MPhil, FIBMS, King's College London Dental Institute at Guy's, King's College and St. Thomas' Hospitals, King's College London, Department of Restorative Dentistry, King's College London, London Bridge, London, United Kingdom

Timothy F Watson, BDS, PhD, FDS RCS (Eng), King's College London Dental Institute at Guy's, King's College and St. Thomas' Hospitals, King's College London, Department of Biomaterials, King's College London, London Bridge, London, United Kingdom

*Richard Mark Foxton, BDS, PhD, MFDS RCS (Ed), FHEA, King's College London Dental Institute at Guy's, King's College and St. Thomas' Hospitals, King's College London, Department of Restorative Dentistry, London United Kingdom

*Corresponding author: Floor 25, Guy's Tower, Guy's Hospital, London Bridge, London SE1 9RT, United Kingdom; e-mail: foxton@kcl.ac.uk

DOI: 10.2341/11-081

SUMMARY

This study investigated the effect of loading on the bond strength to dentin and microleakage of MOD indirect composite restorations bonded with self-adhesive and self-etching resin cements with or without acid etching of the proximal enamel margins. Class II MOD cavities were prepared in 48 molar teeth into dentin and divided into three groups of 16 teeth. Impressions were taken and indirect composite inlays fabricated (Estenia C & B). The enamel margins of the proximal boxes of half the specimens were phosphoric acid etched, and the inlays were cemented with one of three cements (Panavia F 2.0, SA Cement, or Rely X Unicem). After luting, eight teeth in each cement group were mechanically loaded at 2.5 cycles/s for 250,000 cycles. Unloaded teeth acted as controls. Teeth were stored in Rhodamine B solution for 24 hours, sectioned buccolingually at the proximal boxes to examine microleakage using confocal microscopy, and further sectioned for μTBS testing of the resin-dentin interface. Analysis of variance was performed to assess the effect of

loading and acid etching on microleakage and bond strength. Acid etching had no effect on microleakage. No significant difference in the dentin bond strengths between the three cements existed after loading. Panavia F 2.0 exhibited a significant reduction in bond strength. With regard to microleakage at the proximal boxes, loading had no effect on dye penetration at the cavity floor. However, at the axial walls, loading had a significant deleterious effect on Panavia F 2.0. No difference in microleakage existed between the three cements at both sites before and after loading. In conclusion, the two tested self-adhesive cements exhibited similar bond strengths before and after loading to the self-etching resin cement. Loading reduced dentin bond strengths and increased microleakage at the resin-dentin interface. However, acid etching of the enamel margins had no significant effect on microleakage in the approximal regions of the bonded inlays.

INTRODUCTION

Clinicians are often faced with the challenge of restoring a tooth that has lost a substantial amount of tooth structure through caries or the combined effects of erosion, abrasion, and attrition. The patient often desires an esthetic, tooth-colored restoration, and therefore manufacturers offer a choice of resin composite or all-ceramic materials for construction of an inlay or onlay. In the case of resin composite made by the indirect technique, because fabrication and polymerization have taken place outside the mouth, this allows the composite to be placed in the cavity without any further shrinkage.[1] Moreover, inlays fabricated from hybrid resin composite are purported to exhibit similar physical properties to dentin, whereas those fabricated from ceramic cannot compensate for tooth deformation under occlusal loading.[1]

Several types of resin cement are available to cement an indirect restoration. These differ in their pretreatment of the tooth surface prior to application of the resin cement and have been classified as etch-and-rinse adhesives, self-etching adhesives, and self-adhesive cements.[2] Self-adhesive cements have attracted the interest of both manufacturers and clinicians alike because they do not require any prior treatment of the dentin surface and are straightforward to use. Self-adhesive cements are reported to be able to adhere to tooth structure because they contain acidic monomers that can simultaneously demineralize and infiltrate the tooth structure, enabling micromechanical retention of the resin.[2]

It is important that *in vitro* testing of adhesive restorations tries to simulate the oral environment, and tests that involve accelerated aging through water storage, thermocycling, and cyclic loading have been developed.[3-6] While there have been several studies on the mechanical loading of direct composite restorations,[4-7] to date there has been only one published study on the effect of loading on the bond strength of indirect composite restorations.[8] However, this research was carried out on Class II cavities in premolar teeth. To date, there has been no published research on the adhesion of indirect composite restorations in larger MOD cavities in molar teeth with respect to microtensile bond strength and microleakage measurement within the same tooth.

Several *in vitro* studies on indirect restorations bonded with resin cements have looked at microleakage.[9,10] However, the validity of microleakage evaluation as a predictor of the clinical performance of materials has been called into question, and it has been suggested that research instead focus on laboratory tests that are validated with regard to their ability to predict the clinical performance of restorative materials despite the fact that no laboratory test can simultaneously reproduce all the conditions encountered in the oral environment.[11] Since clinical trials often include marginal integrity among the evaluation criteria,[12] combining microleakage measurements with another *in vitro* test, such as bond strength testing within the same tooth, may provide useful information on the durability of the bonded interfaces of indirect restorations.[13]

Therefore, the aim of this experiment was to investigate the effect of mechanical loading on the microtensile bond strength and microleakage of MOD indirect composite restorations bonded with one self-etching resin cement and two self-adhesive resin cements. In addition, the effect of additional phosphoric acid etching of the proximal enamel margins on microleakage was investigated. The null hypothesis was that loading would have no effect on the bond strength and microleakage of the tested cements.

MATERIALS AND METHODS

Forty-eight noncarious human lower third molars, extracted in accordance with the rules of the local ethics committee (King's College London Dental

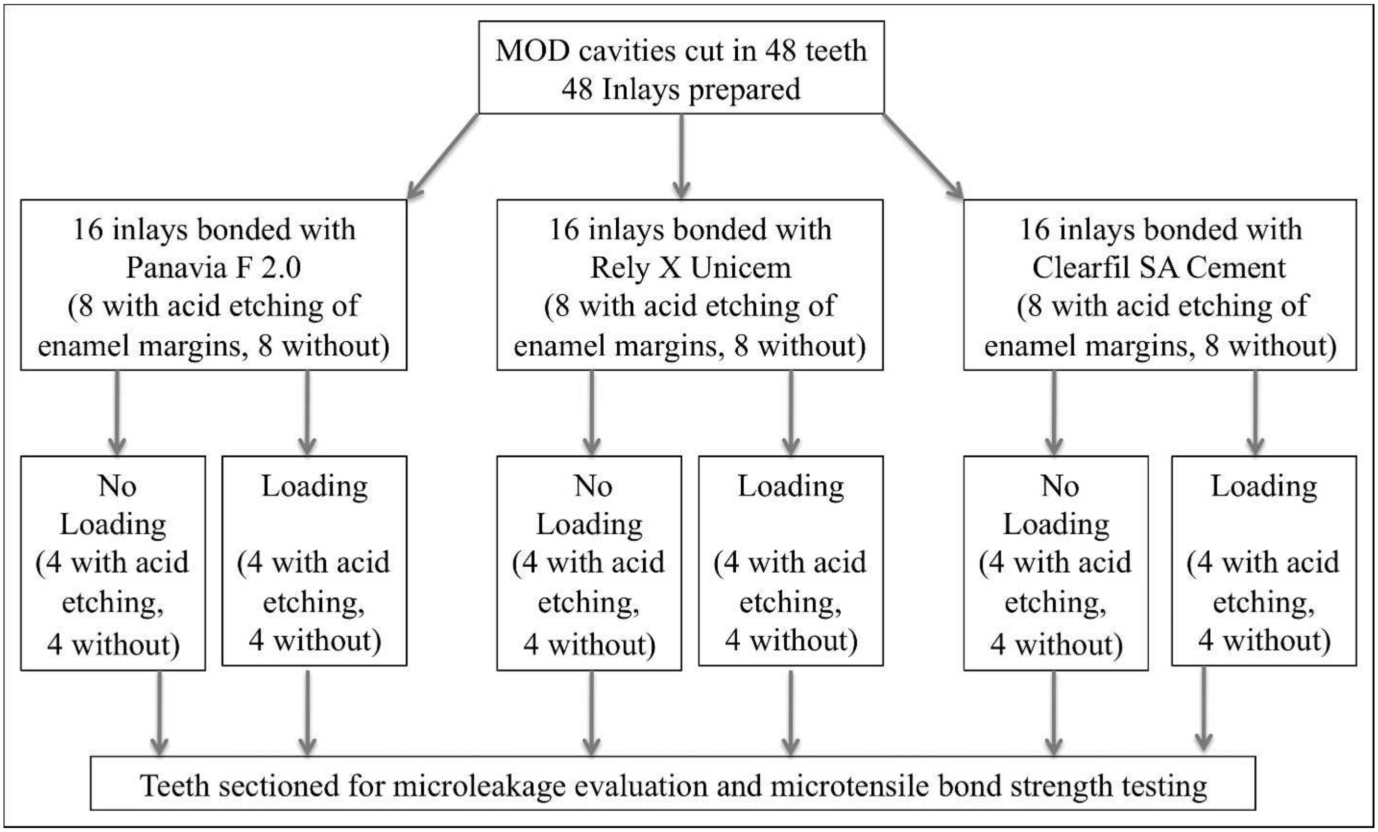

Figure 1. *Flowchart depicting the experimental design*

Institute Research Ethics Committee approval 04/Q0704/57) and after obtaining informed consent of the patients, were used in the study. Only caries-free lower third molars with no visible cracks and of similar dimensions were used. The teeth were stored in tap water at 4°C, undisinfected, in order to avoid chemical media–induced artifacts and were used within one month of extraction.

Each tooth was positioned in the center of the test chamber of the mechanical loading device to ensure that loading would be in the center of each restoration through the vertical axis of the tooth. To ensure that this position was maintained, an aligning method was developed and a dental milling machine used (Galloni, Milan, Italy). On a copolyester translucent disc (Erkodent, Pfalzgrafenweiler, Germany), a circular outline was scribed with the same diameter as the test chamber of the loading device. This disc was used to determine the center of the polysiloxane matrix. Then a rosehead bur (1 mm) was attached to the drill chuck of the milling machine and set in the center of the polysiloxane matrix. Each tooth was fixed with red beading wax (Kemdent, Dental Products Ltd, Purton, UK) to the rosehead bur. Autopolymerizing acrylic resin (cold cure modeling acrylic, Mr Dental, Old Woking, UK) was poured in the polysiloxane matrix from a height of 10 cm to ensure uniform filling of the matrix. Then the root base of each tooth was embedded in the acrylic resin to complete stabilization of the tooth.

Preparation Design

Figure 1 illustrates how the specimens were prepared. Each tooth was prepared with a diamond bur to receive an MOD inlay (FG 845C, Sybron Kerr, Orange, CA, USA) mounted on a high-speed hand piece under water coolant. The dimensions of the preparations were 4 mm buccolingually, 3 mm deep at the isthmus, and 4 mm deep at the mesial and distal boxes, and the boxes were also 1.5 mm at the base toward the pulp. The cavities were prepared 1-1.5 mm above the cemento-enamel junction, and the boxes were prepared with butt margins gingivally. All the internal line angles were smoothed to reduce the possibility of stress concentrations. The burs were replaced after every four preparations in order to ensure high cutting efficiency. All cavity dimensions were strictly standardized during preparation by securing specimens to a microscope stage converted into a specimen holder/cutting guide. Each

Table 1: *Resin Cements Used and Their Manufacturers and Composition*

Adhesive	Manufacturer	Composition
Panavia F 2.0 (batch no. 41247)	Kuraray Medical (Okayama, Japan)	ED Primer II: Primer A—HEMA, MDP, chemical initiator, water, 5-NMSA
		Primer B—5-NMSA, chemical initiator, water Panavia F 2.0
		A Paste—quartz, glass, MDP, methacrylate, photoinitiator
		B Paste—barium glass, NaF, methacrylates, chemical initiator
Rely X Unicem (batch no. 346518)	3M ESPE (St Paul, MN USA)	Powder—silica, glass fillers, calcium hydroxide, chemical-curing initiators, light-curing initiators
		Liquid—methacrylated phosphoric esters, dimethacrylates, chemical-curing initiators
Clearfil SA Cement (batch no. 06AAA)	Kuraray Medical (Okayama, Japan)	Paste A—Bis-GMA, TEGDMA, MDP, silanated filler, hydrophobic aromatic dimethacrylate, benzoyl peroxide, initiator
		Paste B—Bis-GMA, hydrophobic aromatic dimethacrylate, hydrophobic aliphatic dimethacrylate, silanated fillers, surface-treated NaF, accelerators, pigments

Abbreviations: HEMA, 2-hydroxyethyl methacrylate; MDP, 10-Methacryloyloxydecyl dihydrogen phosphate; 5-NMSA, N-methacryloyl 5-aminosalicylic acid; NaF, Sodium fluoride; Bis-GMA; Bis phenol-A diglycidylmethacrylate; TEGDMA; tri-ethylene glycol dimethacrylate.

cavity was cut by keeping the position of the hand piece constant and slowly moving the stage in the x, y, and z directions.

The prepared teeth were randomly divided into three groups of 16 teeth each, which were assigned to be bonded with one of three cements: Panavia F 2.0 (Kuraray Medical Inc, Okayama, Japan), Clearfil SA Cement (Kuraray Medical), and Rely X Unicem (3M ESPE, St Paul, MN, USA; Table 1).

Fabrication of Inlays

In order to make an impression of the prepared cavity, equal amounts of the base and catalyst of the low-viscosity poly vinyl siloxane (PVS) impression paste (Panasil initial contact light, Kettenbach GmbH & Co KG, Eschenburg, Germany) were syringed into the prepared cavity and on the surrounding tooth. At the same time, a glass specimen vial, 2 cm deep, was filled with high-viscosity PVS (Panasil putty fast set, Kettenbach) and seated onto the light-bodied material until the rim of the glass vial touched the dental stone embedding the tooth. This ensured that the impression of the cavity was embedded in a thickness of impression material of at least 10 mm. The cavity was temporarily restored using acrylic resin (Duraseal, Reliance, IL, USA). The impression was cast in a hard natural stone (Moonstone, Bracon Dental Laboratory Products, Etchingham, UK), which was mixed in the recommended water-to-powder ratio of 23 cc to 100 g.

The indirect composite resin inlay was fabricated using Estenia C & B (Kuraray Medical) in accordance with the manufacturer's instructions. In order to closely reproduce the clinical situation, cusps and fissures were created in accordance with the existing morphology of the tooth being restored. The base of the cusps was gently rounded to create a shallow central fissure that enabled accurate positioning and seating of the tip of the loading device at the center of the inlay both in a buccolingual and a mesiodistal direction.

Cementation of Inlays

Prior to cementing the inlays, half of the teeth in each group (eight) had the enamel margins of the prepared cavities etched with 37% phosphoric acid (K-etchant gel, Kuraray Medical) using a sponge microapplicator. After silanating the fitting surface of the inlay (Clearfil Ceramic Primer, Kuraray Medical), it was cemented in the prepared cavity using one of the three cements (Table 1). All the bonded specimens were stored in 37°C distilled water for 24 hours.

Mechanical Loading

Eight teeth in each group were fatigued in a water bath maintained at 37°C (JB1, Grant Instruments Ltd, Shepreth, UK). The fatiguing regime consisted of 250,000 cycles of 80-N loads at a rate of 2.5 loads per second. Static loading was applied vertically via a 2-mm-wide, round-ended, stainless-steel shaft attached to a LAL90 linear actuator (SMAC Europe Ltd, Horsham, UK), which generates force and motion using speaker coil technology to the midpoint of the composite restoration both mesiodistally and buccolingually. The actuator was operated via computer coding stored in an LAC1 controller (SMAC Europe) linked to a computer by an RS232 interface, allowing the input of loading parameters using the HyperTerminal program (Hilgraeve Inc, Monroe, MI, USA). The remaining eight teeth in each group were stored in water at 37°C for an equivalent time span.

Microleakage Evaluation

The method of specimen preparation for microleakage evaluation is illustrated in Figure 1.

There were four groups (nonetched enamel margins unloaded, nonetched enamel margins loaded, etched enamel margins unloaded, and etched enamel margins loaded) of four teeth for each of the three resin cements with respect to the evaluation of microleakage at the approximal boxes of the restored cavities.

The teeth were sealed with two layers of nail varnish up to 1.0 mm from the restoration margins after the root apices were sealed with wax. They were then immersed in a 0.25% solution of Rhodamine B in distilled water, for 24 hours. After storage, the teeth were thoroughly cleaned in an ultrasonic water bath (Biosonic, Coltène/Whaledent Inc, Cuyahoga Falls, OH, USA). Each tooth was sectioned twice buccolingually with a diamond wafering blade (Benetec Ltd, London, UK), yielding two end tooth sections close to the axial wall–gingival floor line angles of the proximal boxes. In preparation for examination using confocal microscopy, the sections were manually wet polished using 1,000-grit carborundum paper (Struers, Solihull, UK) for 20 seconds each. After polishing, the sections were ultrasonicated (Biosonic) in distilled water for three minutes each. Microscopy followed, in which each specimen was examined with a tandem scanning confocal microscope (TSM, Noran Instruments, Middleton, WI, USA) using a 20/0.80× NA oil immersion objective lens. Following calibration of an acetate measuring sheet to the objective lens' output to an iXon 885 EM-CCD camera (Andor Technology, Northern Ireland, UK), each margin could be scored for dye penetration. Detection of Rhodamine B infiltration was possible via suitable emission and excitation filters: 546 nm (green) and 600 nm (red), respectively. Using the CCD in fixed-gain mode in order to isolate the fluorescent signal, images were relayed to an LCD monitor via iQ capture software IQ (Andor Technology). Dye penetration was measured using the calibrated scale on the acetate sheet at each wall separately and expressed as a percentage. Dye penetration into enamel and dentin was not considered independently. For the axial walls, each tooth had four walls measured: buccal and lingual walls of both the mesial and the distal specimens. For the cavity floor, measurements for the mesial and distal slices were considered together.

Microtensile Bond Test

The method of specimen preparation for the microtensile bond strength test is illustrated in Figure 1. Sectioning of the two approximal slabs for microleakage evaluation left the central region of the bonded inlay to be used for microtensile bond strength measurement. This enabled evaluation of the bond between the inlay-resin cement and the cavity floor, which was dentin at a depth of 3 mm, measured from the enamel occlusal surface.

Since adhesion to the dentin of the cavity floor was to be evaluated and not the enamel cavity margins, the nonetched and etched enamel groups of bonded specimens were pooled together. This resulted in two groups of eight teeth (unloaded and loaded) for each of the three resin cements.

The remaining bonded specimens were sectioned buccolingually and then in a mesiodistal direction to obtain beams with an approximate surface area of 1 mm^2. The dimensions of each beam were checked using a digital caliper before the microtensile bond test was performed. A maximum of 32 beams per group of eight teeth could be harvested for testing. In order to prevent the beams from becoming dehydrated prior to testing, they were stored at 100% humidity on moistened gauze in 7-ml glass vials. Each specimen was attached to a customized microtensile jig with cyanoacrylate adhesive (Zapit, Dental Ventures of America, Corona, CA, USA), which was mounted on a linear actuator (LAL 300, SMAC Europe)and stressed until failure at a speed of 1 mm/min.

Statistical Analysis

Data were analysed using Stata 10 (Stata Corp, College Station, TX, USA) software. Mean values of proportional microleakage for the four axial walls and the two cavity floors in each tooth were calculated. These microleakage data were not normally distributed and were described using a median and interquartile range. Three-way analysis of variance (ANOVA) was used to test the effect of type of cement, loading status, and etching on microleakage. For this analysis, the microleakage data were transformed to the square root of the proportion. Two-way ANOVA was used to test the effect of type of cement and loading status on microtensile bond strength. Subsequent post-ANOVA tests were performed using a Bonferroni correction for multiple comparisons. A *p*-value less than 0.05 was regarded as indicating statistical significance ($p<0.05$).

RESULTS

The results of the microtensile bond strength test and microleakage evaluation are presented in Tables 2, 3, and 4. A maximum of 32 beams per group could be harvested for testing. There were no pretest failures.

With regard to the microtensile bond strength test, when the specimens were not loaded, the bond strength of SA Cement was significantly less than both Panavia F 2.0 and Rely X Unicem. All three cements showed a significant reduction in bond strength after loading. However, there was no significant difference in bond strength between the three cements after loading (Table 2).

With regard to dye penetration into the adhesive interfaces, three-way ANOVA indicated that etching had no statistically significant effect on dye penetration and was excluded as a factor in subsequent analysis.

Panavia F 2.0 showed a lower level of microleakage at the axial walls than the other cements prior to loading, the difference being statistically significant in comparison with SA Cement (p=0.036). All three

Table 2: *Mean (SD) Bond Strengths (MPa) by Treatment and Loading*

Cement	Loading		*p*-Value
	No	Yes	
Panavia F 2.0	20.0 (4.1)	15.8 (3.9)	<0.001
SA Cement	14.1 (3.6)*	12.1 (2.6)	0.011
Rely X Unicem	18.0 (4.2)	15.5 (4.3)	0.021

** Significantly different from Panavia F 2.0 and Rely X Unicem (p=0.001).*

Table 3: *Median (Interquartile Range) of Percentage Microleakage at Axial Walls by Cement and Loading*

Cement	Loading		*p*-Value
	No	Yes	
Panavia F 2.0	12.7 (11.2–23.7)	38.4 (31.5-45.1)	<0.001
SA Cement	29.2 (24.2–34.5)*	45.5 (36.4–52.5)	0.040
Rely X Unicem	21.8 (19.8-33.4)	36.3 (31.4–44.9)	0.114
p- value	0.028	0.596	

** Significantly different from Panavia F 2.0 (p=0.036).*

Table 4: *Median (Interquartile range) of Percentage Microleakage at Cavity Floor by Cement and Loading*

Cement	Loading		*p*-Value
	No	Yes	
Panavia F 2.0	13.5 (10.5-38.8)	56.2 (26.1–76.9)	0.059
SA Cement	52.0 (39.5–67.7)*	69.6 (52.2–78.5)	0.604
Rely X Unicem	35.8 (21.3–54.3)	47.8 (35.1–63.0)	0.477
p-value	0.050	0.612	

** Significantly different from Panavia F 2.0 (p=0.047).*

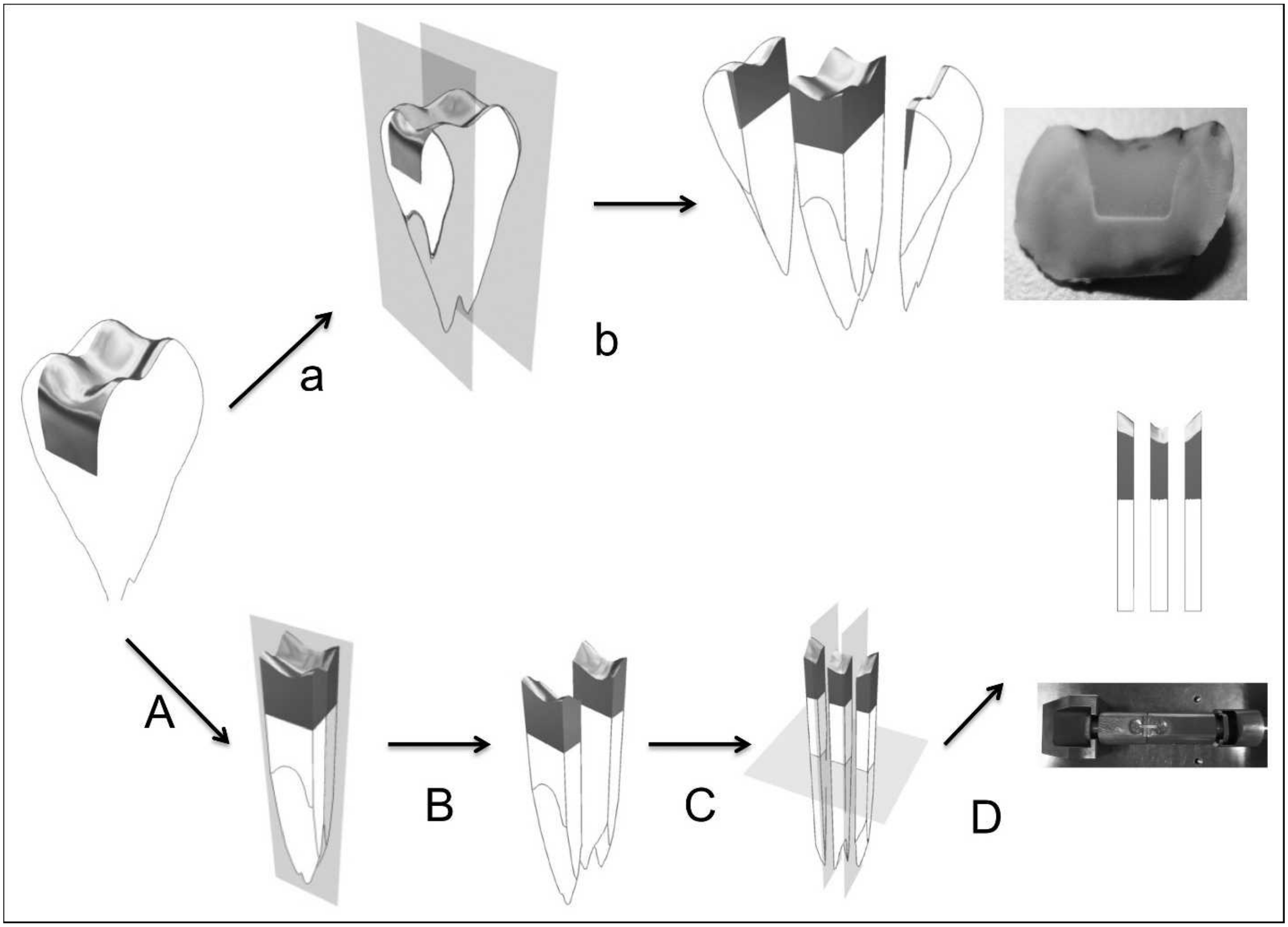

Figure 2. *Schematic representation of the method of specimen preparation for dye penetration and microtensile bond strength test of loaded specimens. (a and b): Two slices obtained for microleakage by cross-sectioning the tooth buccolingually close to the pulpal floor–axial wall line angle. (A): Occlusal portion of restoration selected for bond strength evaluation. (B): Buccolingual, then mesiodistal, slicing (C) to obtain beams for the microtensile bond strength test (D).*

cements exhibited an increase in dye penetration after loading, although the difference was statistically significant only in the case of Panavia F 2.0 and SA Cement (Table 3).

Panavia F 2.0 showed a lower level of microleakage at the cavity floor than the other cements prior to loading, the difference being statistically significant in comparison with SA Cement (p=0.047). All three cements exhibited an increase in dye penetration after loading, although none of the differences were statistically significant (Table 4). Representative observations of microleakage in the TSM images are shown in Figures 2 and 3.

The modes of failure of the beams are shown in Table 5. Almost all the beams of both the unloaded and the loaded groups of the three cements failed at the cement-dentin interface.

DISCUSSION

Large cavities in posterior teeth are challenging to restore from the point of view of creating a restoration with the correct anatomical form and proximal contacts. However, to date, there has been no information published on the *in vitro* durability of indirect composite inlays bonded in large MOD cavities of human molar teeth with either a self-etching or a self-adhesive cement. *In vitro* mechanical load cycling of restorations underwater is an important method for evaluating their clinical potential.[5,7] A force of 80 N was chosen as an average of the masticatory forces observed by Anderson,[14] and the loading condition of 250,000 cycles has been verified as one year of clinical wear.[15] The load was applied to the midpoint of the occlusal portion of the restoration. It has been

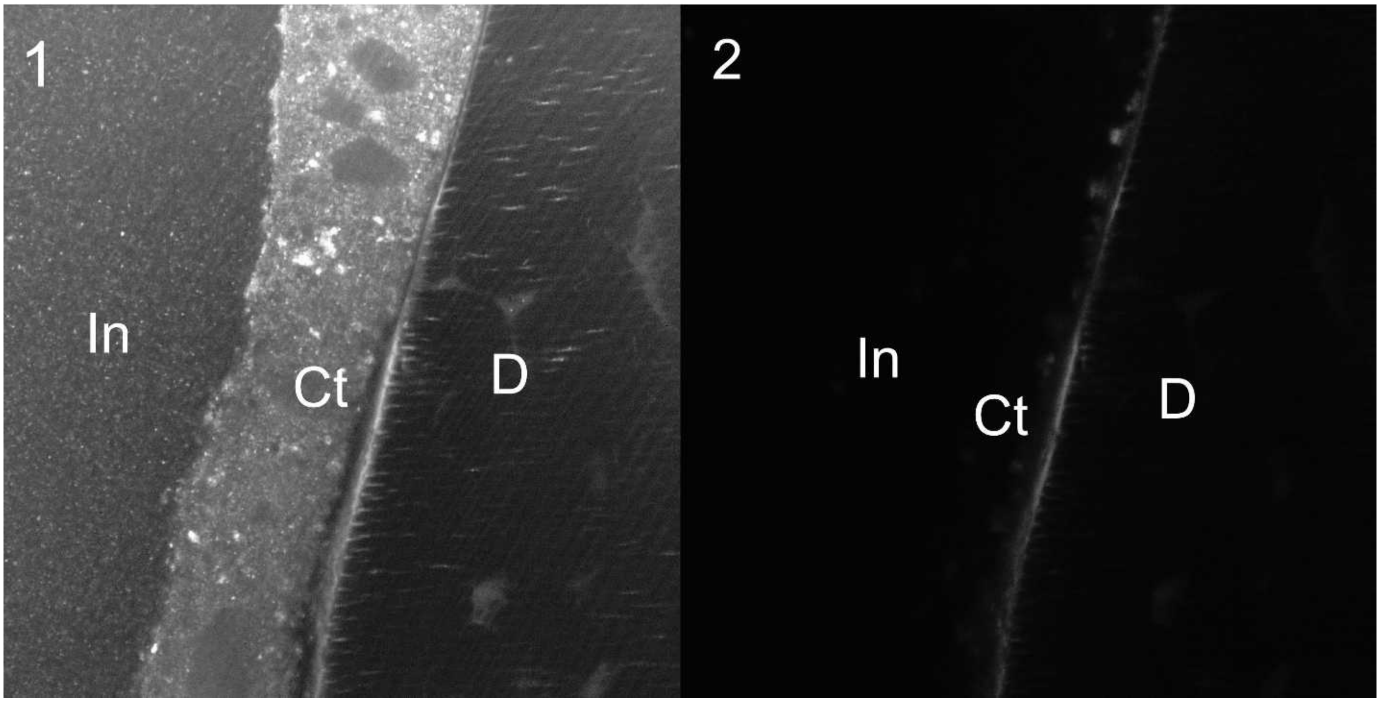

Figure 3. *Representative confocal scanning micrographs of fluorescence evaluation of an unloaded, etched Panavia F 2.0 axial wall specimen. (1): Reflection (546-nm illumination). (2): Fluorescence (546/600-nm excitation/emission) images of an area of axial wall. In, inlay; Ct, resin cement; D, dentin 20/0.80× oil immersion objective.*

reported that the application of a compressive load in the middle of the restoration would create tensile stresses along the bonded interface at the mesial and distal aspects of the restoration.[16] It was suggested that this would mimic the situation when occluso-proximal restorations are loaded directly by the opposing teeth during mastication.[16] The present study evaluated two self-adhesive cements and one

Table 5: *Failure Mode by Treatment and Loading*

	Cohesive in Inlay	Failure at Inlay-Cement Interface	Failure at Cement-Dentin Interface	Cohesive in Dentin
Panavia F 2.0				
No loading	0	0	31	1
Loaded	0	0	30	2
SA Cement				
No loading	0	0	31	1
Loaded	0	0	30	2
Rely X Unicem				
No loading	0	0	31	1
Loaded	0	0	31	1

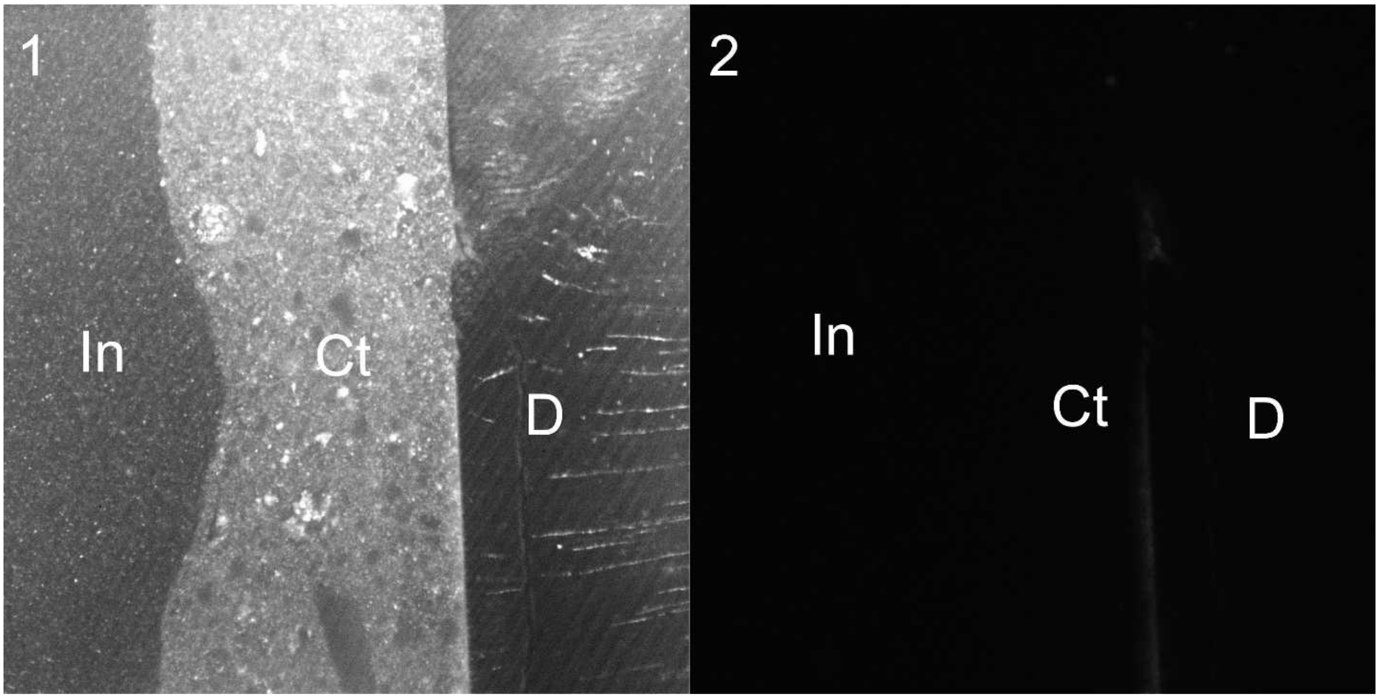

Figure 4. *Representative confocal scanning micrographs of fluorescence evaluation of a loaded, etched Panavia F 2.0 axial wall specimen. (1): Reflection (546-nm illumination). (2): Fluorescence (546/600-nm excitation/emission) images of an area of axial wall. In, inlay; Ct, resin cement; D, dentin 20/0.80× oil immersion objective.*

self-etching resin cement that acted as the control material. After mechanical loading of the restorations, both the self-etching and the self-adhesive resin cements exhibited a significant reduction in bond strength; however, the three tested cements had equivocal bond strengths and exhibited a similar mode of failure. This result indicates that using a self-adhesive cement to cement an indirect composite inlay would offer comparable bond strength and durability to a self-etching resin cement.

To ensure that the cavities were prepared into dentin of a standardized depth and therefore similar morphology, only caries-free upper third molars that were of a similar size were selected for the study. For the microleakage evaluation, dye penetration was measured at both axial walls of the proximal boxes of the cavities and on the gingival floor. Moreover, the enamel margins of the proximal boxes of half the prepared cavities in each group were etched with phosphoric acid prior to application of the cement. To date, there has been no previously published data on the microleakage of MOD indirect resin composite inlays cemented in molar teeth with self-etching or self-adhesive cements. In the present experiment, it was found that acid etching of the enamel margins of the proximal boxes had no statistical effect on dye penetration in the cements. All the resin cements exhibited an increase in dye penetration after loading, with Panavia F 2.0 and SA Cement exhibiting a significant increase at the axial walls. On the cavity floors, all the resin cements exhibited increased dye penetration after loading, but the increases were not significant. However, there was no difference in dye penetration between the three cements after loading both at the axial walls and on the cavity floors. Moreover, dye penetration, when present, was observed in all the specimens at the resin cement–dentin interface and not at the inlay–resin cement interface. Previous research has investigated the nanoleakage patterns of Panavia F 2.0 and Rely X Unicem in which indirect resin composite blocks of Estenia C & B were bonded to flat occlusal dentin surfaces.[2] It was found that Panavia F 2.0 exhibited a significantly greater silver particle penetration than Rely X Unicem.[2] The authors attributed this difference to the cements' different mechanisms of adhesion to dentin. They reported that in the case of Panavia F 2.0, incomplete penetration of resin monomers into the demineralized dentin surface may result in the formation of nanospaces. On the other hand, the adhesion of Rely X Unicem to dentin occurs through the interaction of ionised phosphoric acid-methacrylate with dentin.[2] An increased chemical action with the calcium from hydroxyapatite has been reported.[17] The other self-adhesive cement investigated in the present study, SA Cement, is a dual-cured resin cement that contains the adhesive phosphate monomer MDP but does not require the prior application of a self-etching primer. These findings indicate that in a bonded indirect composite restoration, the interface at which failure is most likely to occur is the resin cement–dentin interface and that strengthening of this interface is necessary to improve its resistance to mechanical loading. Observation of the failure modes in the present experiment support this supposition in that almost all the specimens failed at the resin-dentin interface.

The present experiment employed the microtensile bond strength test to evaluate the resin cement–dentin bond strengths. The advantages and disadvantages of the microtensile bond strength test have been comprehensively discussed in several recent review articles.[18-20] It has been reported that the microtensile bond strength test enables multiple specimens to be obtained from one tooth, reducing the number of teeth required to around five, and facilitates improved stress distribution at the resin-dentin interface as well as good control of potential regional differences in tooth structure.[18,19] On the other hand, it has been pointed out that it is difficult to measure low bond strengths, and this can result in pretest failures and specimens dehydrating rapidly.[18-20] In the present experiment, resin cement–dentin bond strengths were measured at the base of the cavities in the occlusal region following removal of approximal slices for evaluation of microleakage. The sectioned beams were kept moist prior to being bonded to a specially designed jig that ensured correct alignment of the beams and standardization within the test setup.

In our previous experiment, resin coating of the dentin surface with a dentin bonding agent and flowable composite improved the microleakage of CAD/CAM Cerec inlays cemented with resin cement.[11] It has also been reported that resin coating of the dentin improved the bond strength of MO inlays fabricated from indirect composite resin.[21] Therefore, further research is needed on whether resin coating the dentin substrate might improve the bond strength and reduce the microleakage of indirect resin composite restorations bonded with self-adhesive resin cements. Moreover, further *in vitro* research is needed on indirect resin restorations that are bonded and tested in cavities under conditions that more closely reproduce the clinical environment.

CONCLUSIONS

It can be concluded that the two tested self-adhesive cements exhibited similar bond strengths before and after loading to the self-etching resin cement. After loading, resin cement–dentin bond strengths were significantly reduced. Dye penetration was observed at the resin cement–dentin interfaces of the cemented inlays but not at the resin-cement-inlay interface. Increases in dye penetration were observed in all three cements after loading, and the increases were significant for Panavia F 2.0 and SA Cement at the axial walls. However, after loading, there were no significant differences between the three cements. Within the limitations of the present experiment, prior acid etching of enamel margins of the prepared cavities had no significant effect on microleakage in the approximal regions of the bonded inlays.

Acknowledgements

The authors acknowledge support from the Department of Health via the National Institute for Health Research (NIHR) comprehensive Biomedical Research Centre award to Guy's & St Thomas' NHS Foundation Trust in partnership with King's College London and King's College Hospital NHS Foundation Trust.

(Accepted 14 November 2011)

REFERENCES

1. Dukic W, Dukic OL, Milardovic S, & Delija B (2010) Clinical evaluation of indirect composite restorations at baseline and 36 months after placement *Operative Dentistry* **35(2)** 156-164.
2. Makishi P, Shimada Y, Sadr A, Wei S, Ichinose S, & Tagami J (2010) Nanoleakage expression and microshear bond strength in the resin cement/dentin interface *Journal of Adhesive Dentistry* **12(5)** 393-401.
3. Bedran-de-Castro AK, Pereira PNR, Pimenta LAF, & Thompson JY (2004) Effect of thermal and mechanical load cycling on nanoleakage of class II restorations *Journal of Adhesive Dentistry* **6(3)** 221-226.
4. Cavalcanti AN, Mitsui FHO, Silva F, Peris AR, Bedran-Russo A, & Marchi GM (2006) Effect of cyclic loading on the bond strength of class II restorations with different composite materials *Operative Dentistry* **33(2)** 163-168.
5. Mitsui FHO, Bedran-de-Castro AK, Ritter AV, Cardoso PE, & Pimenta LAF (2003) Influence of load cycling on marginal microleakage with two self-etching and two one-bottle dentin adhesive systems in dentin *Journal of Adhesive Dentistry* **5(3)** 209-216.
6. De Munck J, Van Landuyt K, Peumans M, Poitevin A, Lambrechts P, Braem M, & Van Meerbeek (2005) A critical review of the durability of adhesion to tooth tissue: Methods and Results *Journal of Dental Research* **84(2)** 118-132.
7. Nikaido T, Kunzelmann KH, Ogata M, Harada N, Yamaguchi S, Cox CF, Hickel R, & Tagami J (2002)

Evaluation of thermal cycling and mechanical loading on bond strength of a self-etching primer system to dentin *Dental Materials* **18(3)** 269-275.

8. Aggarwal V, Logani A, Jain V, & Shah N (2008) Effect of cyclic loading on marginal adaptation and bond strength in direct vs indirect class II MO composite restorations *Operative Dentistry* **33(5)** 587-592.

9. Behr M, Rosentritt M, Regnet T, Lang R, & Handel G (2004) Marginal adaptation in dentin of a self-adhesive universal resin cement compared with well-tried systems *Dental Materials* **20(2)** 191-197.

10. Kitayama S, Nasser NA, Pilecki P, Wilson RF, Nikaido T, Tagami J, Watson TF, & Foxton RM (2011) Effect of resin-coating and occlusal loading on microleakage of class II computer-aided design/computer-aided manufacturing fabricated ceramic restorations: A confocal microscopic study *Acta Odontologica Scandinavica* **69(3)** 182-192.

11. Heintze SD (2007) Systematic reviews: I. The correlation between laboratory tests on marginal quality and bond strength. II. The correlation between marginal quality and clinical outcome *Journal of Adhesive Dentistry* **9(Supplement 1)** 77-106.

12. Frankenberger R, Krämer N, Lohbauer U, Nkolaenko SA, & Reich SM (2007) Marginal integrity: Is the clinical performance of bonded restorations predictable in vitro? *Journal of Adhesive Dentistry* **9(Supplement 1)** 107-116.

13. Kitayama S, Pilecki P, Nasser AN, Bravis T, Wilson RF, Nikaido T, Tagami J, Watson TF, & Foxton RM (2009) Effect of resin coating on adhesion and microleakage of computer-aided design/computer aided manufacturing fabricated all-ceramic crowns after occlusal loading: A laboratory study *European Journal of Oral Sciences* **117(4)** 454-462.

14. Anderson D (1956) Measurement of stress in mastication. II *Journal of Dental Research* **35(5)** 671-673.

15. Sakaguchi RL, Douglas WH, Delong R, & Pintado MR (1986) The wear of a posterior composite in an artificial mouth: A clinical correlation *Dental Materials* **2(6)** 235-240.

16. Li H, Burrow MF, & Tyas MJ (2002) The effect of load cycling on the nanoleakage of dentin bonding systems *Dental Materials* **18(2)** 111-119.

17. Al-Assaf K, Chakamakchi M, Palaghias G, Karanika-Kouma A, & Eliades G (2007) Interfacial characteristics of adhesive luting resins and composites with dentine *Dental Materials* **23(7)** 829-839.

18. Van Meerbeek B, Peumans M, Poitevin A, Mine A, Van Ende A, Neves A, & De Munck (2009) Relationship between bond strength tests and clinical outcomes *Dental Materials* **26(2)** e100-e121.

19. Salz U, & Bock T (2010) Testing adhesion of direct restoratives to dental hard tissue—A review *Journal of Adhesive Dentistry* **12(5)** 343-371.

20. Armstrong S, Geraldeli S, Maia R, Raposo LHA, Soares CJ, & Yamagawa J (2010) Adhesion to tooth structure: A critical review of "micro" bond strength test methods *Dental Materials* **26(2)** e50-e62.

21. Sultana S, Nikaido T, Matin K, Ogata M, Foxton RM, & Tagami J (2007) Effect of resin coating on dentin bonding of resin cement in Class II cavities *Dental Materials Journal* **26(4)** 506-513.