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The Effect of Resin-modified Glass-ionomer Cement Base and Bulk-fill Resin Composite on Cuspal Deformation

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Clinical Relevance

Comparing resin composite restorations with flowable resin composite base, resin-modified glass-ionomer cement base, and no base indicates no difference in reducing cuspal movement. Reducing the stresses from polymerization shrinkage is multifactorial.

SUMMARY

Objectives: This study investigated cuspal deformation in teeth restored with different types of adhesive materials with and without a base.

Methods: Mesio-occluso-distal slot cavities of moderately large dimension were prepared on extracted maxillary premolars (n=24). Teeth were assigned to one of four groups and restored with either a sonic-activated bulk-fill resin composite (RC) (SonicFill), or a conventional nanohybrid RC (Herculite Ultra). The base materials used were a flowable nanofilled RC (Premise Flowable) and a high-viscosity resin-modified glass-ionomer cement (RMGIC) (Riva Light-Cure HV). Cuspal deflection was measured with two direct current differential transformers, each contacting a buccal and palatal cusp. Cuspal movements were recorded during and after restoration placement. Data for the buccal and palatal cusp deflections were combined to give the net cuspal deflection.

Results: Data varied widely. All teeth experienced net inward cuspal movement. No statistically significant differences in cuspal deflection were found among the four test groups.

Conclusions: The use of a flowable RC or an RMGIC in closed-laminate restorations produced the same degree of cuspal movement as restorations filled with only a conventional nanohybrid or bulk-fill RC.

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DOI: 10.2341/14-331-L

INTRODUCTION

Stresses from polymerization shrinkage are an inherent drawback of resin composite (RC).[1] These stresses, if sufficiently large, can negatively affect the bond integrity, forming gaps between the cavity surface and restoration[2] and leading to ingress of bacteria. Microleakage, tooth sensitivity, and recurrent caries are potential sequelae. Although the strength of the bonded interface may sustain the stresses from polymerization shrinkage, the bonded restoration can pull on the bonded tooth structure, causing tooth movement and therefore deformation.[3] Layering techniques and light-curing unit parameters have been variables used to investigate the factors that influence polymerization shrinkage stresses.[4,5] For instance, incremental layering of RC with a thickness <2 mm aims to minimize overall shrinkage stress on the bond, which is related to the configuration factor.[3] In addition, polymerization stress is not only affected by polymerization shrinkage and the rate of polymerization[6] but also by the elastic modulus of the material.[7] It has been widely discussed[3,8,9] that lining a cavity with a flexible, low elastic modulus layer of restorative material can absorb the stresses from the polymerization of the overlying conventional RC, thereby reducing the stresses on the interfacial bond.

Restorative materials that possess low elastic moduli, such as resin-modified glass-ionomer cement (RMGIC) or conventional glass-ionomer cement (GIC) have been indicated for use as a lining or base material. The elastic moduli of GIC-based materials have been found to be generally less than that of RC.[10] In RMGIC/GIC-RC laminate restorations, the presence of an intermediate layer of a GIC-based material could lead to less stress on the tooth-restoration interface from polymerization. In heavily restored teeth, this may potentially result in less tooth deformation. Limited literature exists regarding the degree of cuspal flexure from polymerization shrinkage in RMGIC/GIC-RC laminate restorations.[11-13] Restoring endodontically treated teeth with a GIC base has been shown to reduce cuspal strain.[13] Flowable RC (FRC) has also been suggested to act as a stress-absorbing layer and is recommended as a lining or base material.[8,14] Cara and others[15] reported a reduction in cuspal deflection with the use of a FRC liner. De Munck and others[16] found no benefit when an additional layer of elastic FRC was placed between the adhesive and RC. Varied study designs and lack of standardization makes it difficult to achieve a general consensus regarding the effects of FRC and RMGIC/GIC liners on the remaining tooth structure. In addition, no published studies to date have compared a GIC-based lining to FRC lining in RC restorations.

Bulk-fill RCs are materials designed to allow light-curing of RC in bulk, rather than in 2-mm increments. It has been demonstrated that restoring cavities with RC in increments rather than in bulk produces less overall volumetric shrinkage.[4,17,18] In moderately sized restorations, the shrinkage could lead to marked cuspal deformation with microfractures or loss of bond integrity between the adhesive and tooth or RC. There are also concerns that light-curing in bulk, up to 4-mm thick, will lead to insufficient light-curing due to light attenuation at the deepest part of the restoration. If the RC is not polymerized completely, it will potentially lead to resin adhesive degradation and hydrolysis and will affect the physical properties of the restoration.

Recently, a bulk-fill material was introduced (SonicFill, Kerr Corporation, Orange, CA, USA) specifically for the complete restoration of posterior teeth up to a 5-mm depth. This type of bulk-fill RC is extruded into the cavity while connected to a specific handpiece that is claimed to emit sonic energy. According to the manufacturer (Kerr Corporation), the sonic energy causes the viscosity of the composite to reduce and flow into the cavity. The material then returns to its viscous nature before light polymerization. No studies have examined the polymerization effects of this thixotropic bulk-filling material on cuspal movement.

This study aimed to investigate cuspal deformation in teeth restored with different types of adhesive materials with and without a base. Slot mesio-occluso-distal (MOD) cavities were prepared. A sonic-activated bulk-fill RC and conventional RC were used. The base materials used were an FRC or RMGIC.

The null hypotheses tested were that there would be no differences in cuspal deformation in the restoration of approximal cavities with, first, a conventional nanohybrid resin composite or a bulk-fill nanohybrid resin composite, and, second, the presence or absence of low elastic modulus base materials.

METHODS AND MATERIALS

Tooth Selection and Cavity Preparation

Twenty-four intact maxillary premolars extracted for orthodontic reasons were collected. The teeth

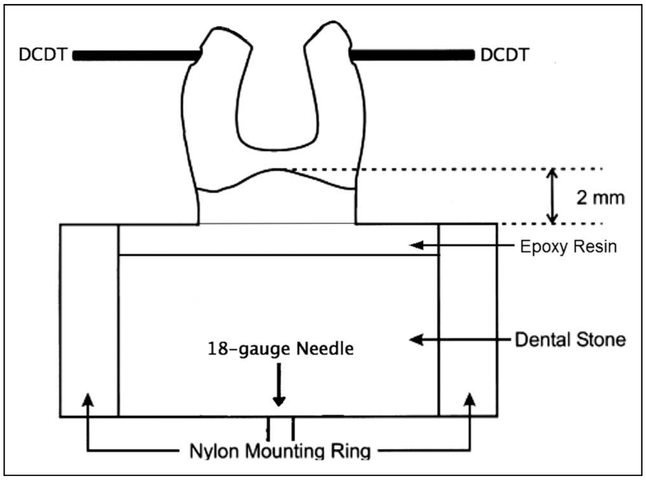

Figure 1. *Diagram of the experimental setup of the prepared tooth mounted in the testing apparatus, with a DCDT probe contacting each cusp to measure cuspal displacement.*

were initially stored in 1% chloramine T solution and then kept in distilled water at 4°C until use. All teeth were used within six months of extraction. Consent was obtained from patients to retain and use their teeth for research under a protocol approved by the appropriate ethics committee. Teeth were sectioned 3 mm below the cementoenamel junction (CEJ) with a diamond saw under water coolant (Struers, Ballerup, Denmark). Pulp tissue was removed with a barbed broach, taking care to avoid contacting the walls of the pulp chamber. The teeth crowns were then immersed in 1% sodium hypochlorite (Endosure Hypochlor 1%, Dentalife, Ringwood, Australia) for 10 minutes, then for an additional five minutes in an ultrasonic cleaner (L & R, Kearny, New Jersey, USA). This was followed by a five-minute period in the ultrasonic cleaner with distilled water, rinsing under running distilled water, and drying before mounting.

The sectioned teeth were mounted in nylon mounting rings and oriented so that the long axis of each tooth was vertical. Before mounting, each ring was filled with type III dental stone (Yellowstone, Ainsworth, Sydney, Australia), just 4 mm short of the top edge, to allow the remainder of the ring to be filled with epoxy resin (EpoFix, Struers, Ballerup, Denmark) flush with the top of the ring. Epoxy resin was left for 24 hours to completely set before a hole was drilled into the center of the set stone to allow placement of an 18-gauge needle. A second epoxy resin (Araldite Ultra Clear, Sellys, Padstow, Australia) was used to seal and cover the sectioned teeth from the set epoxy resin surface to within 2 mm of the CEJ (Figure 1). The maximum buccolingual width of each tooth was measured with a digital micrometer (Bocchi, Pontoglio, Italy) accurate to 0.001 mm. These measurements were used with digital images of each tooth to determine the intercuspal widths (ICWs) using image analysis software (Image J 1.46r, National Institutes of Health, Bethesda, MD, USA). The ICWs were used to equally distribute specimens into four groups of six teeth (Table 1). One-way analysis of variance (ANOVA) using Fisher's least significant difference (LSD) test for multiple comparisons (p=0.05) was used to determine if there were statistically significant differences in the mean ICW between the test groups. The mounted teeth were hydrated for 24 hours with distilled water before cavity preparation.

Table 1: *Intercuspal Width (mm) of Premolar Teeth for Each Group (n = 6 for H, HP, and SF; n = 5 for HRLC)*

Group	Mean (SD)
H	5.69 (0.36)
HP	5.56 (0.23)
HRLC	5.67 (0.59)
SF	5.5 (0.53)

Abbreviations: H, Herculite Ultra; HP, Herculite Ultra + Premise Flowable; HRLC, Herculite Ultra + Riva LC HV; SF, SonicFill.

Standardized slot MOD cavities were prepared in the mounted teeth with a high-speed cylindrical diamond bur (837010, 100-120 μm medium grit, Horico, Berlin, Germany) under water coolant (Figure 2). The occlusal isthmus was prepared to half the ICW with an occlusal depth of 3.5 mm from the central fissure and measured with a periodontal probe. All cavity margins were finished in enamel. The buccal and lingual walls of the cavity were prepared parallel with rounded internal angles. A new bur was used after five teeth were prepared.

Restorative Procedures

Details of the materials used are listed in Table 2. There were four groups, including one control, representing four different direct adhesive restorative procedures as follows:

H = Optibond XTR + Herculite Ultra (control)
HP = Optibond XTR + Premise Flowable base + Herculite Ultra
SF = Optibond XTR + SonicFill
HRLC = Riva LC HV base + Optibond XTR + Herculite Ultra

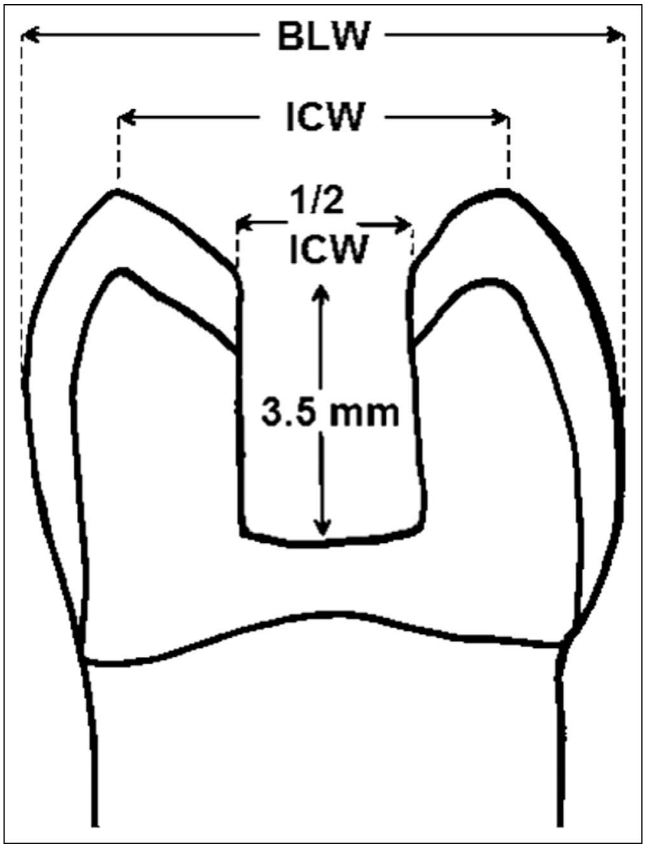

Figure 2. *Cross-sectional diagram of mesio-occluso-distal (MOD) slot cavity prepared in extracted maxillary premolars.*

For the specimens in group HRLC, the dentin was conditioned with 25-30% polyacrylic acid for 10 seconds, followed by rinsing with 5 mL of distilled water. The tooth was placed in the cuspal deflection measurement device while still connected to a distilled water reservoir under 0 kPa hydrostatic pressure. The surface was blot dried with a microbrush before placement of RMGIC (Riva LC HV). A two-step self-etch adhesive, Optibond XTR, was applied in accordance with manufacturer's instructions (Table 2). All groups except for group SF and H were restored with a base, which covered the dentin floor of the cavity. Subsequently, a nanohybrid RC restorative was placed in nine increments with an oblique layering technique. The two proximal walls were restored first (three increments each), followed by three incremental layers within the central occlusal portion. The thickness of each increment was no more than 2 mm to ensure effective light polymerization.[19] For group H, the first increment was also recorded as a pseudo-base for comparison of initial cuspal movement.

Teflon tape 5-mm wide was placed around the circumference of the tooth to act as a matrix band and avoid interfering with the cuspal deflection measuring device. Proximal walls were restored first, followed by the occlusal table. Each increment was cured for 20 seconds using a light-emitting diode (LED) light-curing unit (DemiPlus LED, Kerr Corporation) with an output of 1100 mW/cm^2. A radiometer (Demetron LED radiometer, Kerr Corporation) was used to validate the light intensity immediately before curing the bonding resin, base material, and RC. The light-curing tip was maintained 2 mm above the cusp tips. One operator performed all restorative procedures. Teeth in group SF were restored with SonicFill, a bulk-fill nanohybrid RC. For group SF, after placement and curing of the adhesive, one bulk increment was placed and light-cured for 20 seconds. This was repeated twice more with the light-curing tip placed occlusally toward the proximal region (according to manufacturer's instructions). The total curing time was 60 seconds. Following light-curing of the base and light-curing of the final increment of RC, measurement of cuspal deflection was recorded five minutes after light-curing was completed. This was to allow time for stress relaxation of the polymerized RC.[19] All procedures were performed under 0 kPa hydrostatic pressure. For the groups with an FRC or RMGIC base, the material was placed on the floor of the central part of the MOD slot cavity, approximately 2 mm short of the proximal margins and 1.0-1.2 mm thick. This was measured using a periodontal probe and verified with light-bodied polyvinylsiloxane (PVS) impressions (Elite HD, Zhermack SpA, Rovigo, Italy).

Cuspal Deflection Measurement

Direct current differential transformers (DCDTs, model 7DCDT-050, Hewlett Packard, Rockville, MD, USA) were used to detect linear cuspal displacement. The devices were calibrated to an accuracy of $\pm$1.0 μm. After the tooth was placed in the cuspal deflection measurement device, the DCDTs were checked for stability before and after recording. The ambient temperature during recordings was 24°C. Two DCDTs were mounted on adjustable arms such that the tip of each rod contacted the buccal or lingual enamel within a shallow depression created 1.0 mm below the cusp tip. The DCDTs were aligned perpendicular to the tooth axis in a buccolingual direction (Figure 1). The DCDTs were placed on either side of the tooth to detect horizontal displacement of the tooth away from the neutral position. Measurements of the two cusps were combined to provide a net inward or outward cuspal movement (in

Table 2: *Materials, Manufacturers, and Chemical Composition*

Type	Material (Manufacturer)	Composition	Batch No.
Resin-modified glass-ionomer cement	Riva Light-Cure HV A3.5 (SDI Limited, Bayswater, Australia)	Liquid: polyacrylic acid, tartaric acid, HEMA; powder: FAS glass	K1201185EG
Dentin conditioner	Riva conditioner (SDI Limited)	Polyacrylic acid	111140
Two-step self-etch adhesive	Optibond XTR (Kerr Corporation, Orange CA, USA)	Primer: pH = 2.4; GPDM, HEMA, MEHQ, CQ, water, ethanol, acetone. Adhesive: pH = 3.3; cross-linking monomers, CQ, inert fillers, barium glass and nano-silica, sodium hexafluorosilicate in ethanol	LD02290
		Instructions: 1) Apply primer to tooth using scrubbing motion for 20 seconds, 2) air thin with medium air pressure for 5 seconds, 3) apply adhesive using light brushing motion for 15 seconds, 4) air thin with medium air pressure and then strong air for at least 5 seconds, 5) light-cure for 10 seconds	LD02291
Flowable nanofilled resin composite	Premise Flowable A3 (Kerr Corporation)	Filler % (wt/vol): 72.5/54.6	4635057
		Filler composition: PPRFs, barium glass, silica; resin composition: bis-EMA, TEGDMA, light-cure initiators, and stabilizers	
Bulk-fill nanohybrid resin composite	SonicFill A3 (Kerr Corporation)	Filler % (wt/vol): 83.5/68	34923
		Filler composition: silica and barium aluminoborosilicate glass; resin composition: TMSPMA, bis-EMA, bisphenol-A-bis-(2-hydroxy-3-methacryloxypropyl) ether, TEGDMA	
Nanohybrid resin composite	Herculite Ultra XRV A3 enamel (Kerr Corporation)	Filler % (wt/vol): 78/57.5	34339
		Filler composition: silica and barium glass, PPRFs, TiO_2, MEHQ, BPO, trimethylolpropane triacrylate, and initiators; resin composition: uncured methacrylate ester monomers	

Abbreviations: bis-EMA, ethoxylated bis-phenol-A-dimethacrylate; BPO, benzoyl peroxide; CQ, camphorquinone; FAS, fluoroaluminosilicate; GPDM, glycerol phosphate dimethacrylate; HEMA, 2-hydroxyethyl methacrylate; HV, high viscosity; MDP, methacryloxydecyl dihydrogen phosphate; MEHQ, 4-methoxyphenol; PPRF, prepolymerized resin fillers; TEGDMA, triethylene glycol dimethacrylate; TiO2, titanium dioxide; TMSPMA, 3-trimethoxysilylpropyl methacrylate.

micrometers). Data from the DCDTs were recorded on a computer using Labview 7.0 software (National Instruments Corp, Austin, TX, USA) then analyzed on a spreadsheet (Microsoft Excel 14.3.6, Microsoft Corporation, Redmond, WA). Data from the two DCDTs were converted from voltages (x) to micrometers (y) via a previously calibrated equation:

$$y = 7.4958x + 10.648$$

Displacement was measured after placement of the base, immediately after final restoration, and then after increasing intrapulpal pressure from 0 kPa to 15 kPa.

Scanning Electron Microscopy (SEM) Examination

Additional specimens (one per group) were prepared, restored, and immersed in distilled water at 37°C for at least 24 hours. Each of the four teeth was sectioned vertically in the mesiodistal plane using a diamond saw (Struers) with water lubricant and then polished using wet 600-, 1200-, 1500-, 2400-, and 4000-grit SiC abrasive papers. All polished tooth sections were etched with 1% HCl for 10 seconds, rinsed with water, immersed in 1% sodium hypochlorite (Endosure Hypochlor 1%, Dentalife) for two minutes and rinsed with 5 mL distilled water. Except for sections with RMGIC, the prepared tooth sections were directly mounted on carbon tape–lined aluminum stubs, gold sputter-coated, and examined using scanning electron microscopy (SEM; Quanta, FEI, Hillsboro, OR, USA) at high vacuum and operating at 2kV. Replicas of the RMGIC tooth sections were produced by taking impressions of the polished sections in PVS; epoxy resin was then poured into the impressions. The epoxy resin replicas were mounted for SEM imaging. The bonding interfaces of the tooth sections were observed.

Table 3: *Mean Cuspal Deflection for Each Restorative Procedure, Mean ± SE*

Group	n	Cuspal deflection (μm)			
		After Base	After Restoration 0kPa	After Restoration 15kPa	Total Deflection
H[a]	6	6.9 (3.84)	12.1 (6.32)	0.93 (0.717)	19.9 (7.87)
HP	6	6.7 (2.41)	13.6 (4.86)	0.38 (0.811)	20.6 (6.86)
HRLC	5	11.7 (5.54)	17.3 (5.16)	0.046 (0.568)	29.0 (7.76)
SF	6	-	23.5 (3.32)	0.86 (0.836)	24.3 (2.76)

Abbreviations: H, Herculite Ultra; HP, Herculite Ultra + Premise Flowable; HRLC, Herculite Ultra + Riva LC HV; SF, SonicFill.
[a] For group H, the first increment was also recorded as a pseudo base for comparison of initial cuspal movement.

Statistical Analysis

Cuspal displacement was calculated by summing the readings of the DCDTs, taking into account the direction of movement of each cusp. The results were normally distributed and analyzed using one-way ANOVA (Minitab 16.2.3, State College, PA, USA), and multiple comparisons were carried out using Fisher's LSD test at a 0.05 level of significance.

RESULTS

Tooth Dimensions

As illustrated in Table 1, the dimensions of the teeth did not vary significantly among the four groups ($p>0.05$).

Base

There was wide variability in the net cuspal movement (Table 3; Figure 3). No statistically significant differences in inward cuspal movement were found between groups HP and HRLC (ie, after an FRC base and an RMGIC base was placed) ($p=0.63$). Additionally, there was no statistically significant difference ($p=0.39$) for specimens with an increment of conventional RC (group H) placed.

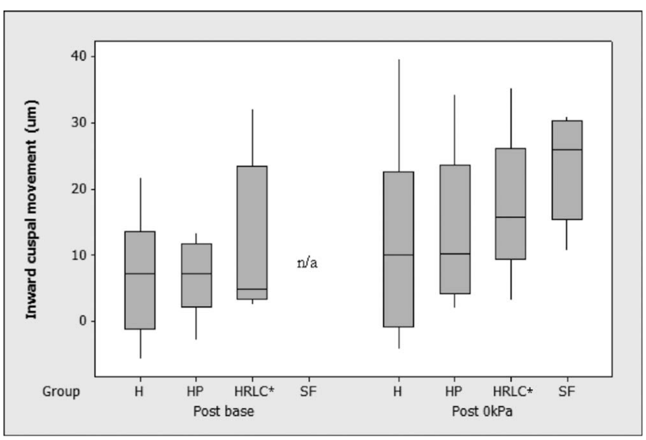

Figure 3. *Box plot displaying the net cuspal deflection for each of the four groups at two stages of the restorative procedure: after base placement (post base) and immediately after restoration with the simulated intrapulpal pressure of 0kPa (post 0kPa). (H = Herculite Ultra; HP = Herculite Ultra + Premise Flowable; HRLC = Herculite Ultra + Riva LC HV; SF = SonicFill) (n = 6 for H, HP, and SF; n = 5 for HRLC).*

Total Deflection

All teeth exhibited inward cuspal movement from baseline (Table 3). There were no statistically significant differences in cuspal deflection values among the four groups immediately after restoration ($p=0.392$). Inward cuspal movement occurred on completion of restoration, which was higher than the cuspal movement immediately after base placement for the HP and HRLC groups and after placement of the first RC increment in group H. Group SF produced the highest and lowest range of inward cuspal movement in contrast to group H (Figure 3). Once the hydrostatic pulpal pressure increased from 0 kPa to 15 kPa, there was minimum deflection and no statistically significant difference in cuspal deflection values among the four groups after restoration (p=0.83). There were no statistically significant differences found in the total deflection among the four groups, ($p=0.772$).

DISCUSSION

Polymerization shrinkage causes stress on the bonding surfaces. In three-surface approximal restorations, both marginal ridges of the tooth are removed, causing the strength of the tooth to be severely compromised.[20] Depending on the polymerization shrinkage and bond strength, placing adhesive restorations in severely compromised teeth will cause cuspal movement. Factors such as elastic modulus of the restorative material, volumetric shrinkage, and rate of polymerization affect the generation of contraction stresses, thereby affecting the durability of the bond.[3,4,21,22] A base or lining material with a low elastic modulus could reduce the degree of overall polymerization shrinkage stress[9] and thereby cause less cuspal movement from the internal compensation of polymerization shrinkage of the overlying RC.

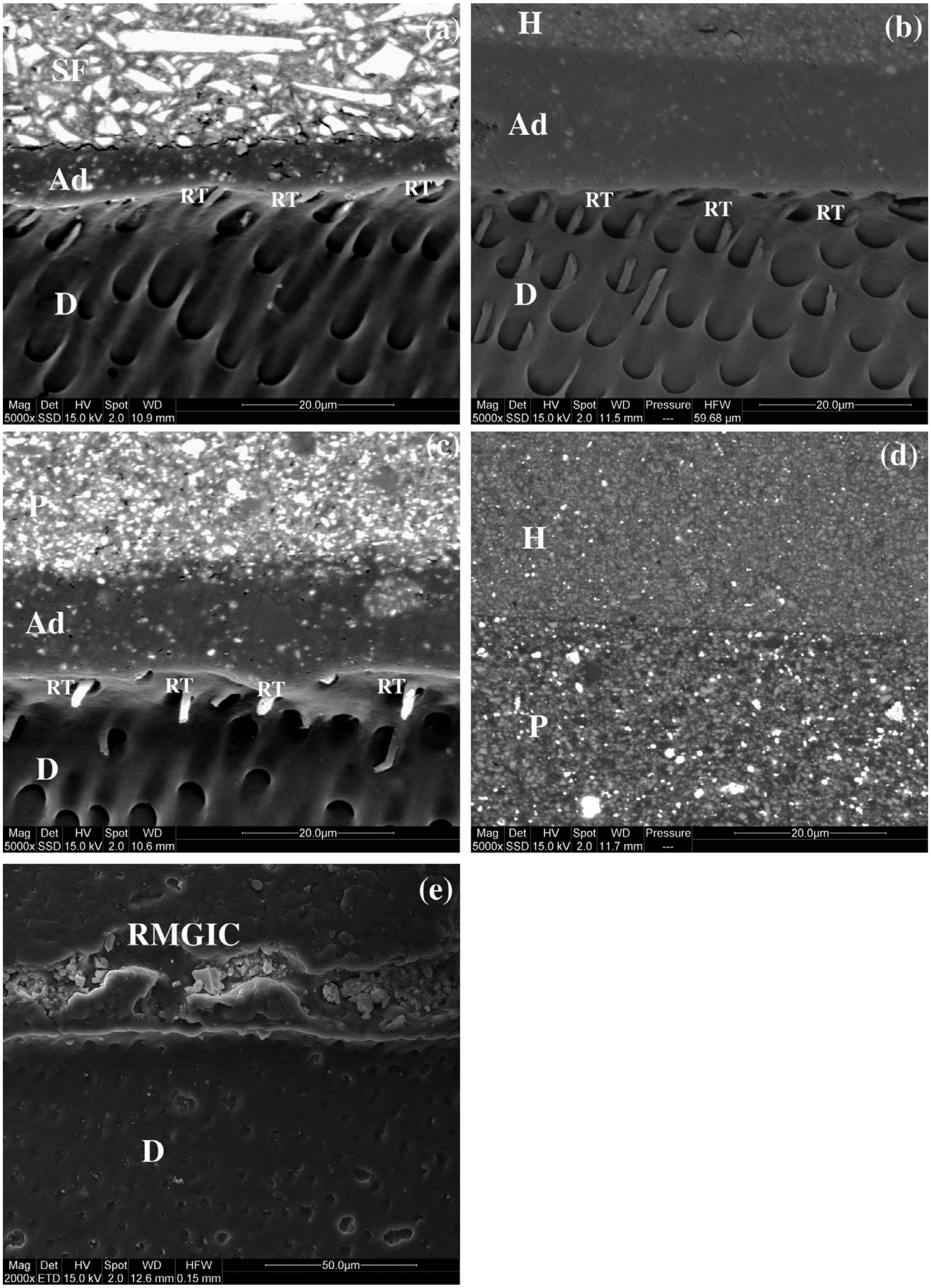

Figure 4. *Representative SEM image of sectioned teeth (a-e). In a-c, resin tags (RT) are evident from the two-step self-etching adhesive, Optibond XTR. Most of these areas showed good adaptation of the adhesive and restorative to the tooth. The filler particles in SonicFill (SF) are irregularly shaped compared with conventional nanohybrid resin composite (H). Selective SEM imaging of the samples from group H displayed adhesive bond layers of 20μm (Ad), as shown in (b). This thickness was more than three times that of the adhesive layers shown in (a) with 6μm thickness, and larger than that in (c). The 15-μm-thick layer may have helped relieve the contraction stresses.[9] In (d), Premise Flowable (P) almost possesses as much filler*

In the current study, an RMGIC base was used as it has a lower elastic modulus than conventional GIC.[23,24] The elastic modulus of RMGIC ranges from 9.0 GPa to 10.8 GPa, which is less than that of high-viscosity GICs and has reported values between 14.4 GPa and 19.3 GPa.[23] The lower elastic modulus is attributed to the resin component in the RMGIC, in particular, the hydrophilic (poly) 2-hydroxyethyl methacrylate.[25] Placing an elastic intermediate layer, such as RMGIC, could reduce stress on the bonded interfaces, thereby reducing cuspal strain and, thus, movement. However, the results failed to show any statistically significant differences in cuspal movement. This could be attributed largely to the wide variability of the data and limited sample size.

RMGICs have also been shown to undergo volumetric contraction after polymerization, which is compensated by a delayed expansion in the presence of water.[26] In a clinical situation, closed-laminate restorations limit absorption of external moisture into the RMGIC base. With the laboratory conditions, the dentin was an internal source of moisture. However, the level of moisture was insufficient to offset the setting contraction of the RMGIC, which explains the comparable degree of inward cuspal movement with teeth restored with FRC base (group HP). However, moisture absorption is gradual as observed from the changes in cuspal movement during the period after restoration. In contrast to the results of this study, a reduction in cuspal deformation with teeth restored with a GIC-based material has been reported.[11] However, these teeth were endodontically treated and subsequently restored with open laminate restorations with a thicker base of 1.5-2 mm. Restoring a portion of the marginal ridge with a thick layer of GIC likely contributed to the reduced cuspal flexure. Alternatively, using FRC could allow relief of developing shrinkage stresses, thereby reducing cuspal strain. However, this was not observed in the current study.

Although FRCs generally have larger shrinkage values than conventional RCs, they have been shown to induce less stress on the interfacial bond.[22] There are limited studies that support this argument[15,22] and studies disputing such claims.[4,9,12] Oliveira and others[12] concluded that the use of liners with low elastic moduli does not compensate for the polymerization shrinkage stress of the overlying RC. They used the FRC Filtek Flow (3M ESPE, St Paul, MN, USA) and the RMGIC Vitrebond (3M ESPE) with a 2.0-mm thickness. However, a three-dimensional photoelastic model was used. Although Filtek Flow possesses an elastic modulus of 13.54 GPa, this was insufficient in relieving the polymerization shrinkage stresses. Braga and others[9] concluded that placing FRCs with elastic moduli of more than 5 GPa is unlikely to produce significant stress relief, even with a thickness of 1.4 mm. This supports the findings of the current study. The results suggest that not all FRCs, such as Premise Flowable, would be indicated for use as an intermediate layer to reduce stress buildup. Premise Flowable has a relatively high flexural modulus of 7.1 GPa (technical information, Kerr Corporation). This likely explains the comparable cuspal deflection values between groups H and HP. It seems that the main clinical benefit of FRC is its handling properties. In addition, representative SEM images (Figure 4) indicated variability in the adhesive thickness between different samples, which may have influenced the results. The thickness of the adhesive ranged from 6 to 20 μm, and this thick resin layer possesses a much lower elastic modulus than the lining materials tested (RMGIC and FRC) in this study.[9] Stresses were likely to have been relieved within this thick adhesive layer.

The higher cuspal deflection values observed in the current study, compared with values reported by other studies,[4,11,19] could be attributed to the high curing light intensity, difficulties in cutting standardized cavity preparations on natural teeth, and possible undetected microfractures in some of the specimens. Moorthy and others[27] reported net cuspal deflection values of approximately 11 μm with the measuring gauge placed 2.5 mm below the cusp tip. As the cuspal wall tapers toward the tip, data recorded with the DVDT probes fixed closer to the tip would detect higher cuspal movement values than if the probes were located more gingivally. It was the authors' intention to create moderate to large cavity preparations, thereby producing noticeable cuspal movements from light polymerization of the restorative materials. In a pilot study, the recording device using DCDTs was shown to be very sensitive (between 5 to 25 μm).

The lowest standard deviation in the SF group would suggest a low technique-sensitive procedure with the bulk-fill system compared with manually placing oblique increments of the conventional RC.

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volume as Herculite Ultra (H), thus appearing very similar to Herculite Ultra with good adaptation to dentin (D) and Herculite Ultra. In (e), although the irregular surface topography has resulted from the acid preparation, RMGIC appears to have an intimate adaptation to dentin (D).

Although an increase in filler loading in an RC leads to a reduction in shrinkage, this has been shown to result in higher contraction stresses.[14] SonicFill, an RC designed for bulk-filling, has a filler volume of 68% compared with conventional RC, Herculite Ultra, which has a filler volume of 57.5%. The high filler volume of SonicFill may have offset the volumetric shrinkage from polymerization, as high shrinkage stress was expected from bulk placement of the RC.[17] High shrinkage stress was expected to result in greater cuspal deformation.[4]

According to the manufacturer, the SonicFill material contains modifiers that cause the viscosity to reduce by 87% when a special handpiece is used to dispense the flowable RC into the cavity (technical information, Kerr Corporation). Once in the cavity, the material returns to a viscous material and can then be contoured and light polymerized. It is speculated that reducing the viscosity of SonicFill to allow for efficient restoring procedures is analogous to preheating of RC before incremental placement. Both methods are aimed to improve and simplify adaptation of the restorative material to the cavity by increasing the flowability of the material.[28] Preheating RC before placement in incremental layers does not affect the mechanical properties.[28,29]

There is concern about the efficacy of light polymerization of bulk-fill RCs. Positive correlations between the degree of conversion and microhardness measurements of RC have been observed in previous studies.[30,31] Vickers hardness testing of Sonicfill was done in a pilot study as an indirect method[32] to assess the extent of polymerization in the resin material inside the cavity. If the polymerization is not optimized, this variable would affect the study outcomes. The results from the pilot indicated that there was no difference in the level of polymerization at a curing depth of 4 mm for SonicFill placed in bulk and Herculite Ultra placed in two 2-mm increments. Additionally, another pilot study observed changes in dentin permeability and found that SonicFill provides a comparable seal to an incrementally placed RC, Herculite Ultra. Although these findings suggest that SonicFill can be effectively light polymerized in bulk, the degree of conversion of SonicFill needs further assessment.

The filler and resin composition in restorative materials specifically designed for bulk-filling must account for light attenuation. One approach has been to increase the translucency of bulk-fill restorative materials to enhance the depth of cure. Campodonico and others[33] found no difference in cuspal flexure between the bulk-filling material, X-tra fil (VOCO GmbH, Cuxhaven, Germany), and Filtek Supreme Plus (3M ESPE) a conventional RC. Hardness testing found significantly lower values when Filtek Supreme Plus was light-cured in a 3.5-mm bulk layer, as opposed to X-tra fil.[33] This indicates that X-tra fil can be light polymerized in bulk and did not produce large contraction stresses. However, it has been shown to have a relatively high elastic modulus,[34] which is likely attributed to the high filler volume (70.1% volume). This filler volume is similar to that of SonicFill (68% volume). Moreover, with the findings suggesting adequate light polymerization of the SonicFill restorative material, high contraction would be expected, leading to potentially high levels of stress on the interfacial bond. This could therefore result in high cuspal strain, which contradicts the results of the current study.

Polymerization shrinkage is associated with the polymerization rate and degree of conversion of the restorative material.[21] As the distance of the light-curing tip to the bulk-fill restorative material decreases, the intensity of the polymerizing light is gradually decreased. Hence, in teeth restored with SonicFill, less contraction stress was generated in the deepest portions of the cavity, as the low light intensity in these areas would have allowed some relaxation of the polymer chains. The low intensity allowed a delay in reaching the gel point, thereby encouraging stress relief from the effects of polymerization.[35] There was sufficient light irradiance due to the long duration of light-curing performed (60 seconds for each bulk increment), as recommended by the manufacturer (Kerr Corporation). This would have ensured adequate exposure of the energy density for polymerization.[36] The hypothesis supports the comparable cuspal flexure values between bulk-fill and incrementally placed RC restorations obtained.

CONCLUSION

Within the limitations of this study, the null hypothesis cannot be rejected. The use of flowable RC as a base in adhesive restorations led to cuspal strain, which was not significantly less than that of closed-laminate restorations with an RMGIC base and nonlaminate RC restorations. None of the restorative methods appeared to be more beneficial than the other for reducing cuspal deformation. Reducing the contraction stresses between the adhesive restorative material and tooth substrate is complex and involves the interaction of different factors, such as the elasticity of the material, polymerization rate, degree of conversion, and hydration conditions. Moreover, the bulk-fill RC appears to induce similar degrees of cuspal movement compared with teeth restored with conventional restorative materials.

Acknowledgements

This investigation was supported by NHMRC grant No. 1039604 and the Australian Dental Research Foundation Inc. The authors would like to thank Kerr Corporation and SDI Limited for the donation of materials, Ms Emily Szycman for SEM imaging, Mr Ilya Zalizniak for technical assistance, and Associate Professor Graham Hepworth for statistical advice. This study was undertaken as part of Dr Khanh Nguyen's thesis, in partial fulfillment of the requirements for the MPhil degree.

Regulatory Statement

This study was conducted in accordance with all the provisions of the local human subjects oversight committee guidelines and policies of Ethics in Human Research Committee of the University of Melbourne, Australia. The approval code for this study is 23 1136562.

Conflict of Interest

The authors have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in this article.

(Accepted 16 June 2015)

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