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Marginal sealing of relocated cervical margins of mesio-occluso-distal overlays

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Abstract: We investigated the effect of cervical marginal relocation (CMR) on marginal sealing with two different viscosity resin composites, before adhesive cementation of composite computer-aided design/computer-assisted manufacture mesio-occluso-distal (MOD) overlays. Standardized MOD cavities prepared in 39 human molars were randomly assigned to three groups. The proximal margins on the mesial side were located 1 mm below the cementoenamel junction. On the distal side of the tooth, the margins were located 1 mm above the cementoenamel junction. In Groups 1 and 2, mesial proximal boxes were elevated with a hybrid composite (GC Essentia MD) and a flowable composite (GC G-ænial Universal Flo), respectively. CMR was not performed in Group 3. The overlays were adhesively cemented, and interfacial leakage was quantified by scoring the depth of silver nitrate penetration along the adhesive interfaces. Leakage score at the dentin-CMR composite interface did not significantly differ between the two tested composites but was significantly lower for Group 3. In all groups, scores were significantly higher at the dentin interface than at the enamel interface. These results indicate that the performance of flowable and microhybrid resin composites, as indicated by marginal sealing ability, is comparable for CMR.

Keywords: cervical margin relocation; proximal box elevation; indirect restorations; marginal seal.

Introduction

The use of adhesive resin restorative materials has improved the aesthetics of dental treatment in the posterior region (1-6). Conventional amalgam restorations have been replaced by minimally invasive adhesive restorations, which protect the intact tooth structure without sacrificing sound tooth structures for mechanical retention (7).

Direct composites are indicated and effective for small and medium-sized Class I and Class II cavities (8,9). However, in larger cavities, the risk of polymerization shrinkage may cause problems in marginal adaptation, such as fracture and microleakage (10,11), which can lead to postoperative sensitivity, marginal staining, and secondary caries (12,13). Because of the lower amount

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of resin to be cured, semidirect (14,15) and indirect (16) restorations may improve marginal adaptation by reducing polymerization shrinkage stress. In patients requiring an indirect restoration, the proximal box is often below the surrounding gingival margin and close to or below the cementoenamel junction (CEJ). Subgingivally positioned margins may complicate impression-making and adhesive luting.

Optimal isolation throughout adhesive luting is usually very difficult or impossible to achieve in deep subgingival margins. Surgical margin relocation can address this (17) but is associated with attachment loss and anatomic complications because of the proximity to root concavities and the furcation area (18). As an alternative to periodontal surgical procedures, the cervical margin can be elevated coronally by applying bonding and resin composite materials (19), in accordance with proximal box elevation technique (20-25), also referred to as cervical margin relocation (CMR) (26-28), deep margin elevation (18), or open-sandwich technique (29-32). CMR can be performed with hybrid or flowable composites, after placing the metal matrix and interproximal wedge. Subsequent impression-making is more predictable, and luting under rubber dam isolation is more likely to be successful because of the better control during removal of excess cement from the margins.

The absence of enamel at the cervical margin results in areas of weak bonding. Bonding to dentin is not as stable as bonding to enamel (33) and is associated with higher risks of microleakage, bacterial penetration, hypersensitivity, and secondary caries. In addition, resin composite material and its adhesive interfaces in CMR degrade under occlusal loading (34), thus allowing bacterial biofilm penetration at the dentin-restoration margin and, possibly, faster secondary caries development *in vivo* (35).

This *in vitro* study evaluated the effect of CMR on marginal sealing with two different viscosity resin composites, before adhesive cementation of composite computer-aided design/computer-assisted manufacture mesio-occluso-distal (MOD) overlays. The null hypotheses tested were that the marginal seal would not differ between flowable and hybrid resin composites used for CMR, and that the marginal seal of an MOD overlay would not differ between the enamel and dentin margins.

Materials and Methods

Teeth preparation

Thirty-nine intact, healthy, similarly sized human extracted molars without visible cracks, cavities, or restorations were selected for the study after informed consent was obtained from all patients. This study was approved by the Ethical Committee of the University of Siena.

The teeth were mechanically cleaned with hand scalers, brushed with a pumice, and stored in a 0.1% thymol solution for no longer than 3 months. Standardized MOD cavity preparations were created by using water-cooled diamond burs (Komet Burs Expert Set 4562/4562ST, Komet, Lemgo, Germany) in a high-speed handpiece. The remaining axial walls had a thickness of 2 mm and were reduced for a cuspal coverage. Proximal box-shaped preparations were made (1.5 mm in the mesiodistal and 4 mm in the buccolingual direction). The inner angles of the cavities were rounded, and the margins were not beveled. Proximal margins on the mesial side were located 1 mm below the CEJ; on the distal side, tooth margins were located 1 mm above the CEJ.

Teeth were randomly assigned to one of three groups (n = 13 specimens each), as follows (Tables 1, 2; Fig. 1). Group 1: mesial proximal margins below the CEJ were elevated in two increments of 1 mm with a viscous composite (Essentia; GC Corp., Tokyo, Japan). Group 2: mesial proximal margins below the CEJ were elevated in two increments of 1 mm with a flowable composite (G-ænial Universal Flo; GC Corp.). Group 3 (control): mesial proximal margins were not elevated.

Steel Kerr 2181 Adapt SuperCap matrices (0.038; height, 5.0 mm; Kerr, Orange, CA, USA) were used to create marginal elevation. The circumferential matrix was carefully adjusted to eliminate the risk of overhang of the composite material on the margins, and a 2-mm space was marked on the inner side of the matrix, to avoid overfilling the box. Distal proximal margins were not elevated in any sample. To perform CMR and immediate dentin sealing (IDS), a universal adhesive (GC G-Premio Bond; GC Corp.) was used in selective enamel etch mode. Enamel was etched for 15 s and rinsed for 15 s under laminar water flow. The cavity was gently air-dried, and the bonding agent was applied with a microbrush for 20 s, air blown at maximum pressure for 10 s, and light-cured for 20 s with a BA Optima 10 curing light (B.A. International Ltd, Northampton, UK). In Groups 1 and 2, the cervical margins on the mesial sides were filled with two 1-mm increments of the composite GC Essentia (Group 1) or G-ænial Universal Flo (Group 2). Adaptation of composites was performed with ball-ended hand instruments and a microbrush. Care was taken not to layer the composite at a thickness greater than 2 mm. Water-cooled diamond burs (Komet Burs Expert Set 4562/4562ST, Komet) on a high-speed handpiece were used to create the final shape of each cavity after CMR.

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Table 1 Description of the experimental groups

Groups	Restorative material for CMR	Restorative material for overlay	Adhesive system	Resin cement
1. Essentia	GC Essentia MD	GC Cerasmart	GC G-Premiobond	GC LinkForce
2. G-ænial Universal Flo	GC G-ænial Universal Flo A2	GC Cerasmart	GC G-Premiobond	GC LinkForce
3. Control (no CMR)	—	GC Cerasmart	GC G-Premiobond	GC LinkForce

Table 2 Chemical composition and application procedures for the tested materials

MDP

Material (manufacturer)/ Batch number	Type	Application procedure	Composition
G-Premio BOND (GC Corporation, Tokyo, Japan) lot: 1606272	Universal adhesive	Selective etching of enamel 15 s Rinsing 15 s Air blowing (max pressure) 10 s Light curing 20 s	1MDP, 4-MET, MDTP, dimethacrylate monomers, acetone, water, silicon dioxide, photoinitiators
Essentia MD (GC Corporation) lot: 1607271	Microhybrid resin composite	Each layer light cured for 20 s	UDMA, dimethacrylate monomers, silicon dioxide, fillers, pigments, photoinitiators
G-ænial Universal Flo (GC Corporation) lot: 1506131	High filled flowable resin composite	Each layer light cured for 20 s	UDMA, bis-EMA, dimethacrylate monomers, silicon dioxide, fillers, pigments, photoinitiators
G-CEM LinkForce (GC Corporation) lot: 1608231	Dual-cure adhesive luting cement	Mixture applied on restoration inner surface and preparation surface Overlays firmly pressed Each axial wall light cured 60 s	Paste A: UDMA, bis-GMA, dimethacrylate monomers, fillers, pigments, photoinitiators Paste B: UDMA, bis-EMA, dimethacrylate monomers, fillers, photoinitiators
G-Multi Primer (GC Corporation) lot: 1601141	Primer for glass ceramics, hybrid ceramics, zirconia, alumina, composites, metal bonding.	Applied with microbrush on restoration inner surface	Ethanol, phosphoric ester monomer, γ-methacryloxypropyl trimethoxysilane, methacrylate monomer
GC Etchant (GC Corporation) lot: 1610271	Etching gel 37% phosphoric acid	Selective etching of enamel 15 s	Phosphoric acid (37%), silicon dioxide, colorant
GC Cerasmart (GC Corporation) lot: 1609082	Force-absorbing hybrid ceramic CAD/CAM block	Sandblasting and silanization of inner surface	Raw materials of pre-cured composite block: UDMA, dimethacrylate monomers, bis-EMA, silicone dioxide, barium glass powder, pigments, initiator

Impression-making

An extraoral scanner (Aadva Lab Scan, GC Corp.) was used to make digital impressions of the prepared teeth. Scanned files were sent to a milling center (GC Corp., Leuven, Belgium) that created the resin composite overlays (Cerasmart, GC Corp.). The teeth were kept in fresh water for 2 weeks at room temperature until the overlays were luted. The fit of the overlays was examined under a digital microscope (Nikon Shuttle Pix, Tokyo, Japan), and digital photographs were obtained at 10× magnification.

Luting procedure

Before luting, the teeth were cleaned with ethanol, and the enamel was selectively etched for 15 s and rinsed with laminar water flow for another 15 s. Preparation surfaces were gently dried, and G-Premio Bond (GC Corp.) was applied with a microbrush for 20 s, air blown at maximum pressure for 10 s, and light-cured for 20 s (BA Optima 10, B.A. International Ltd.). Cerasmart overlays were sandblasted at approximately 3 bar pressure with 50-µm aluminum oxide particles. Later, G-Multi primer (GC Corp.) was applied to silanize the inner sandblasted surface of the overlays. An adhesive resin cement (G-Cem LinkForce; GC Corp.) was used to lute the over-

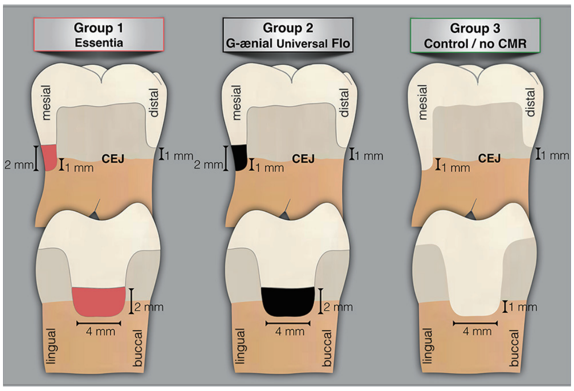

Fig. 1 Illustrations of the techniques used for all experimental groups.

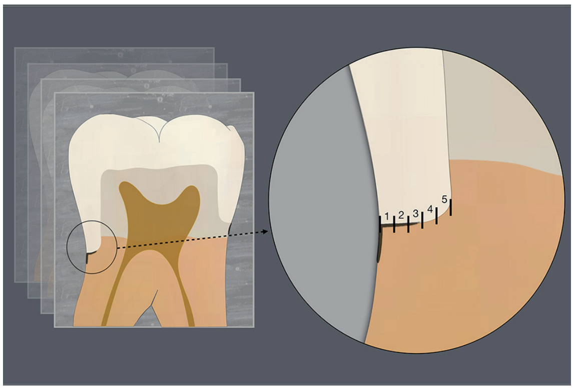

Fig. 2 Illustration of the scoring system.

lays in both groups. G-Cem LinkForce (GC Corp.) was mixed with its special mixing tip, and the initial mixture was discarded on clean paper. The subsequent mixture was applied to the inner surface of the restoration and the preparation surface. The overlays were pressed firmly on teeth, and excess luting materials were cleaned with a microbrush and cotton pellets. The restoration margins were covered with a water-based glycerine gel (Airblock, DeTrey-Dentsply, Konstanz, Germany). Each axial wall was light-cured for 60 s, and the occlusal surface was cured for 60 s. Margins were gently finished with flexible disks (SofLex Pop-on, 3M ESPE, St. Paul, MN, USA).

Evaluation of marginal seal

All tooth surfaces were covered with nail varnish. We left exposed the 1 mm around the area of the adhesive interfaces between the overlay and tooth and the CMR on the mesial aspect of the tooth. A diluted ammoniacal silver nitrate solution (1:4 ratio of ammoniacal silver nitrate to distilled water) was prepared, and the diluted solution was filtered with a Millipore filter (0.22-nm filter, Carrigtwohill, County Cork, Ireland) mounted on a syringe. Under laboratory light, each tooth was placed in a test tube with diluted ammoniacal silver nitrate solution. After 24 h, specimens were thrice rinsed in water for 10 min. Nail varnish around the tooth was removed with acetone, and each tooth was placed in a test tube with the diluted photo-developer solution (Kodak, Rochester, NY, USA; 1:10 ratio of photo-developer solution to distilled water). After 8 h, teeth were thrice rinsed in water for 10 min.

Each tooth was embedded in transparent self-curing acrylic resin. The teeth were then sliced with a low-speed diamond saw under water cooling (Isomet; Buehler, Lake Bluff, NY, U.S.A) into three or four 1-mm-thick slices along their long axis and perpendicularly to the proximal margins. Samples were examined with a digital microscope at 1×, 3×, and 6× magnification. Two observers independently scored the amount of tracer along the interface, by using the scheme follows (36) (Fig. 2). 0: no nanoleakage; 1: 0% to 20% of gingival floor interface showing nanoleakage; 2: 20% to 40% of gingival floor interface showing nanoleakage; 3: 40% to 60% of gingival floor interface showing nanoleakage; 4: 60% to 80% of gingival floor interface showing nanoleakage; 5: 80% to 100% of gingival floor interface showing nanoleakage.

Statistical analysis

The Kruskal-Wallis test was used to assess differences between the composite materials in leakage scores recorded at the dentin-composite interface in groups with CMR and to compare those score with scores at the dentin-overlay interface of the control group without CMR. The Wilcoxon signed-rank test was used to determine separately whether leakage significantly differed between the two substrates (i.e, dentin and enamel interface) for the tested CMR composite materials and in the control group.

The significance level was set at $P < 0.05$, and the analyses were performed with the software package SPSS IBM Statistics version 21 for Mac (SPSS Inc., Chicago, IL, USA).

Results

Nanoleakage along the dentin-bonding interfaces significantly differed among the three groups (Kruskal-Wallis, $P = 0.000$; Figs. 3-5). The Mann-Whitney U test showed no significant difference in leakage scores at the dentin-CMR composite interface between the two composites ($P = 0.279$); however, the control group showed significantly less nanoleakage. The median leakage score was 2 for both composites and 1 for the control group, with no CMR. Descriptive statistics for the leakage scores are

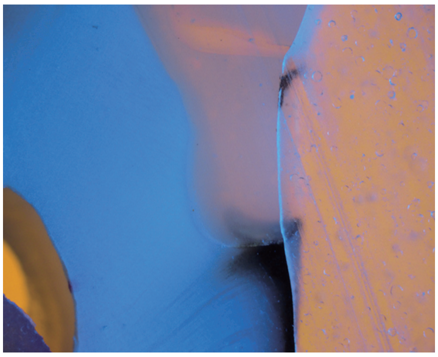

Fig. 3 Representative sample from Group 1 (Essentia group) with a nanoleakage score of 4 (×6).

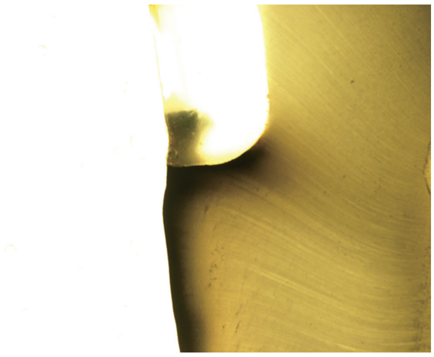

Fig. 4 Representative sample from Group 2 (Universal Flo group) with a nanoleakage score of 5 (×6).

Fig. 5 Representative sample from Group 3 (Control group) with a nanoleakage score of 3 (×6).

Table 3 Descriptive statistics for leakage scores recorded along dentin-composite interface (Groups 1 and 2) and dentin-overlay interface (Group 3)

Microleakage score	n	Mean	SD	Median	Interquartile range	
					25th percentile	75th percentile
1. Essentia^{B}	42	2.40	1.449	2.00	1.00	3.00
2. G-ænial Universal Flo^{B}	46	2.04	1.095	2.00	1.00	2.25
3. Control (no CMR)^{A}	45	1.18	0.777	1.00	1.00	2.00

n: number of slices; SD: standard deviation. Different superscript letters indicate statistically significant differences among groups. Kruskal-Wallis test, $P = 0.000$

Table 4 Descriptive statistics for leakage scores recorded at dentin-composite (Groups 1 and 2) and dentin-overlay (Group 3) interface and enamel-overlay interface (all three groups)

Microleakage score	n	Mean	SD	Median	Interquartile range	
					25th percentile	75th percentile
1. Essentia						
Dentin^{B}	42	2.40	1.449	2.00	1.00	3.00
Enamel^{A}	42	0.07	0.261	0.00	0.00	0.00
2. G-ænial Universal Flo						
Dentin^{B}	46	2.04	1.095	2.00	1.00	3.00
Enamel^{A}	46	0.24	0.480	0.00	0.00	0.00
3. Control (no CMR)						
Dentin^{B}	45	1.18	0.777	1.00	1.00	2.00
Enamel^{A}	45	0.16	0.367	0.00	0.00	0.00

n: number of slices; SD: standard deviation. Different superscript letters indicate statistically significant differences among groups. Wilcoxon signed-rank test, $P = 0.000$; three groups tested separately.

shown in Table 3.

Leakage significantly differed between the two bonding interfaces (enamel and dentin), when analyzed in aggregate, and in the Essentia ($P = 0.000$, Wilcoxon signed-rank test), G-ænial Universal Flo ($P = 0.000$, Wilcoxon signed-rank test), and control groups (no CMR) ($P = 0.000$, Wilcoxon signed-rank test), when analyzed separately. In all three analyses, leakage scores were significantly higher at the dentin interface (median 2, interquartile range 0-3) than at the enamel interface (median 0, interquartile range 0-0). The descriptive statistics are shown in Table 4.

Discussion

We evaluated the effects of cervical marginal relocation on marginal sealing when two resin composites with different viscosities were used before adhesive cementation of CAD/CAM MOD overlays. Since the first description of CMR, some researchers have suggested that flowables are the material of choice for elevating the deepest parts of the cavity (17,37). Others, however, support the use of flowable or restorative composite (18,26,27) or a combination of both if more material is needed (26,27). In addition, microhybrid or nanohybrid resin composite should be preheated, to facilitate placement and minimize the risk of interlayer gaps (18). There remains a lack of consensus regarding the preferred material and application technique for this clinical procedure.

The viscosity of flowables makes them favorable for use in CMR because they are easy to apply to deep proximal areas, result in fewer voids, and thoroughly wet the bonded surface (38); however, because of the low viscosity of flowables, excess and overhang are concerns (39).

We studied two resin composites that were used in combination with a proprietary adhesive material. The marginal seal did not differ between the two materials, and the first null hypothesis was therefore accepted. Thus, both flowables and microhybrid resin composites are suitable for CMR. Furthermore, we observed almost no leakage at the enamel-bonding interface, most likely because the cut and etched enamel prisms provide reliable micromechanical interlocking (40), thus preventing adhesive and cohesive fracture at the luting-enamel interface (41). In contrast, leakage was always observed at the dentin-bonding interface, and the second null hypothesis was therefore rejected.

Treatment of posterior proximal cavities with deep cervical margins below the CEJ is usually highly complex when an adhesive indirect restoration is selected. All prosthodontic steps, such as preparation of the cavity and both traditional and digital impression and luting, are difficult to perform properly (24). Therefore, placement of a few composite resin layers (CMR) was proposed as a method to facilitate clinical handling of indirect restorations (19). This procedure should be carried out under rubber dam isolation, followed by matrix placement (18). However, control of interproximal margins is a concern, as it requires both careful consideration of the arrangement of the emergence profile and a perfect subgingival fit for the CMR. Previous studies proposed specific matrix types for CMR, including circumferential and sectional matrices, and stainless steel and clear matrices (17,18,24,26,27), as well as matrices with curvature that provides an adequate emergence profile and tight subgingival fit (18,27). In the present study, the circumferential matrix was carefully adjusted to eliminate the risk of composite material overhang on the margins. In addition, a 2-mm space was marked on the inner side of the matrix, to avoid overfilling the box. Thus, polymerization shrinkage was reduced by the controlled thickness of the CMR composite.

In this study, two 1-mm increments of flowable or microhybrid composite were placed, to allow for an overall 2-mm elevation of the cervical margins. Application of CMR with meticulous layering of the two 1-mm increments of flowable or restorative composite had no effect on the quality of cervical margins (28).

Moreover, one-bottle universal self-etch adhesive was used in selective etch mode in combination with proprietary luting material. Universal adhesives are the latest-generation bonding system and reduce sensitivity to the clinical procedure (42). In addition, application of a universal adhesive on dentin decreases the risk of over-etching and ensures that the dentin substrate will not be too dry or too wet (42,43). To date, universal adhesive systems have yielded promising results (44-46).

This *in vitro* study evaluated all bonding interfaces involved in the CMR procedure, and leakage was always detected at the interface between the root cementum-dentin margin and composites. Analysis of the dentin margin showed that the marginal seal for the two tested materials did not significantly differ when they were used for CMR. However, the performance of the flowable composite was slightly better than that of the hybrid composite. The favorable performance of flowables may be explained by their easier application and adaptation to the cavity bottom (47). The present findings are consistent with those of previous studies (28,37,48), which showed that flowable and restorative composites did no differ in marginal quality when applied for a CMR approach on dentin.

This study also showed that direct placement of composite CAD/CAM overlays on dentin (without CMR), with the same luting procedure, resulted in a significantly better marginal sealing than that obtained with a CMR approach and either flowable or hybrid resin composite. In contrast, most previous studies reported no significant difference in marginal quality between restorations placed directly on dentin and those with CMR composite (20,25,28,48-50). However, two studies showed that, after being subjected to thermal and mechanical stress, luting directly to dentin (conventional technique) resulted in superior marginal adaptation as compared with CMR composite on dentin (21,23). The present findings might have been affected by polymerization shrinkage of the resin composite materials used for making the CMR and luting the overlay (51-54).

The present study used a leakage test to evaluate the marginal seal of restorations; however, previous studies evaluated margin quality by using low-magnification scanning electron microscopy (20,21,23,25,37,48-50-

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55). It is possible that previous studies under-evaluated the actual seal of restorations after CMR. Nevertheless, no previous study reported an experimental group with a perfect seal, which indicates that microscope type, technique, and magnification affect evaluation of margin quality. In other words, high-magnification examination of marginal seals, with silver nitrate perfusion testing along the hybrid layer, is likely a more rigorous test.

To date, only a few *in vitro* studies have examined CMR applied in indirect restorations. The investigated variables were marginal (20,21,23,25,27,28,49,50,55) and internal adaptation (37,48,50), bond strength to the proximal box floor (56), and fracture behavior of restored teeth (23). Marginal adaptation was usually evaluated by SEM examination of impression replicas, to determine the percentage of continuous gap-free margins before and after thermal and mechanical stress. Many studies (20,21,23,25,28,48-50,55) reported a consistent decrease of margin quality after exposure to stress. In the present study, teeth were not subjected to mechanical or thermal stress. Such exposure might increase leakage.

From a clinical perspective, CMR does not properly seal the cervical margin in the root cementum-dentin, regardless of the type of resin composite material used, perhaps because of difficulties in isolating the field (57), the presence of cementum-dentin substrate (58,59), the difficulty in achieving a proper seal on cementum-dentin substrate (60), the effectiveness of bonding procedure and material (43,61), shrinkage of resin composites (54), **(51)** operator skill and knowledge and the sensitivity of this technique (62), and occlusal stress transmitted to the margin through the indirect resin restoration (63)

CMR is a relatively new restorative procedure and information on its performance is limited. Future *in vitro* and *in vivo* studies should evaluate the effectiveness of CMR technique and the marginal seal of different bonding systems and luting cements in combination with CMR. In addition, randomized clinical trials should investigate the durability of CMR and the response of periodontal tissues.

In conclusion, the present results indicate that the performance (marginal sealing ability) of flowable and microhybrid resin composites is comparable for CMR. Furthermore, luting overlays directly to dentin, without CMR, appears to be a better method for limiting marginal leakage underneath CAD/CAM overlays.

Acknowledgments

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Conflict of interest

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

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