THE EFFECT OF GINGIVAL WALL LOCATION ON THE MARGINAL SEAL OF CLASS II RESTORATIONS PREPARED WITH A FLOWABLE BULK-FILL RESIN-BASED COMPOSITE

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SureFil SDR is a flowable resin-based composite that allows a single incremental bulk placement. The marginal seal of SureFil SDR at the gingival margins of class II restorations located apical to the cemento-enamel-junction (CEJ) has not been adequately evaluated compared to those located occlusal to the CEJ. Forty class II cavities were prepared in human molars. The gingival margins of 20 preparations were located 0.5 mm occlusal to the CEJ, and the other 20 preparations were located 0.5 mm apical to the CEJ. The cavities surfaces were bonded with XenoV dental adhesive and filled with SDR in one bulk increment up to 4 mm, after which they were covered with CeramX. The teeth were subjected to thermo- and load-cycling, and their gingival margins were exposed to 0.5% basic-fuchsin solution. The specimens were sectioned mesio-distally and scored for microleakage. A Wilcoxon test for pairwise comparison was performed to determine significance. Dye penetration was observed in 30% of the 20 restorations with cavo-surface margins located occlusal to the CEJ and in 55% of the 20 restorations with cavo-surface margins located apical to the CEJ. The bulk-fill flowable resin base SureFil SDR with XenoV dental adhesive provided a better marginal seal in class II restorations with gingival margins above the CEJ compared to restorations with gingival margins below the CEJ. SDR should not be recommended for class II cavity preparations with gingival margins located below the CEJ.

Tooth-colored restorative materials are increasingly requested by patients and clinicians. Resin composite materials and techniques are constantly being improved with the aim of producing ideal restorative material. Efforts have been undertaken to develop new products with simplified application techniques, reduced polymerization shrinkage, and increased wear resistance (1, 2). The physical properties of esthetic restorative materials, such as polymerization shrinkage, water sorption, solubility, elastic modulus and shear bond strength, all affect marginal behavior and influence the integrity of the restoration (3-5). Poor adaptation of the restoration to the prepared cavity walls may lead to the formation of gaps (6) and consequently to microleakage, postoperative sensitivity, recurrent caries and, finally, failure of the adhesive resin composite restoration (3).

One of the most crucial physical features of resin

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composite materials is the fact that they undergo different degrees of volumetric shrinkage during polymerization .The amount of volumetric change depends, among other aspects, on the elastic moduli that influences the accumulation of stress build-up in the material during polymerization (4). In order to decrease volumetric shrinkage and to reduce the amount of stress buildup, a meticulous incremental layering technique is mandatory during the application of resin composite restorative materials (5). The need for several applications, however, jeopardizes restoration integrity, and individual light-curing of each layering increases treatment duration, a characteristic that is considered inconvenient for the clinician and patient alike.Another important characteristic of resin composite materials that requires multiple application steps is their resistance to flow, i.e., the Bingham body behavior that displays a time-dependent response known as "viscoelastic and viscoplastic strain" (6, 7). During condensation, the material undergoes viscoelastic recovery, at the end of which some deformations are reversed. Therefore, multiple packing/pushing steps are required to achieve final adaptation of the filling material to the cavity walls (7).

The continuing search for improved restorative materials that would overcome the above features led to the development of flowable resin composites in the 1990s (8). The "flowables", as they are called, are low viscosity resin composites with 20%-25% less filler loading than the conventional resin composites (9). They possess good wetting ability, which favors their adaptation to the cavity walls with decreased risk for air entrapment and void inclusion (10, 11) and makes it possible to place them by injection with syringes. The first-generation of flowable resin composites was used only as liners and fissure sealant due to their inferior mechanical properties`, low elastic modulus and increased volumetric shrinkage (9, 11, 12). The latest generations of flowable resin composites, however, have higher filler content and are claimed to have increased mechanical properties (13), and so they have been proposed for use in one increment bulk up to a 4-mm thickness (14-17). One of these new flowable resin composites is SureFil SDR® (Smart Dentin Replacement) (DENTSPLY, Konstanz, Germany). SureFil SDR was introduced into the market as a flowable resin composite with the claim that it would allow a 4-mm bulk placement in one layer. This new product is a one-component, fluoride-containing, visible blue light–cured, radiopaque resin composite restorative material. It was designed to be used as a base in class I and class II restorations, and it must be overlaid with a methacrylate-based universal/posterior composite. The information on the chemical composition of flowable resin, provided by the manufacturer, indicates that the polymerization kinetics are better controlled than they are with other resins due to an organic matrix that consists of a patented urethane dimethacrylate with incorporated photoactive groups and to an enhanced translucency that allows light passage to the inner layers of the applied material.

Studies that analyzed the micromechanical properties and the shrinkage behavior of this new material described a high modulus of elasticity and a low shrinkage stress buildup after polymerization. It has minimal internal polymerization stresses due to a longer pre-gel phase, which is accomplished by the use of a "polymerization modulator" that interacts with camphoroquinone to reduce the contraction modulus and increase the number of linear bonds (14-18). These attractive properties are expected to provide good marginal adaptation, with reduced gap formation at the cavo-surface margin, thereby leading to an excellent marginal seal when using SDR restorative material.

The objective of the present study was to assess the marginal sealing of class II restorations done with SureFil SDR and covered with high filler-containing resin composite, and to compare the marginal seal at the gingival wall located above the cemento-enamel-junction (CEJ) to that located below the CEJ.

The tested null hypotheses were: (1) there will be penetration of the dye in class II restorations prepared with SDR flowable material, and (2) penetration of the dye would be greater in class II restorations with gingival walls below the CEJ.

MATERIALS AND METHODS

This study was carried out at the laboratory of Dental

Materials, Faculty of Dentistry, Tel-Aviv University, Israel and with the approval of the Tel Aviv Sourasky Medical Center Institutional Review Board (Helsinki Committee).

Twenty caries-free human molars freshly extracted for periodontal reasons were randomly assigned to the study groups (Fig. 1). They were cleaned with an ultrasonic device and stored in tap water at 4ºC prior to use. Forty class II cavities were prepared using a no. 330 tungsten-carbide burr (S.S.W. London, UK), with a high-speed hand piece (8000B GENTLEsilence LUX, KaVo Dental GmbH, Biberach, Germany) and an air-water spray. Two class II independent cavities, i.e., occluso-mesial and occluso-distal, were prepared for each tooth. The gingival margin of the preparation on one side was located 0.5 mm above the CEJ (enamel margins), and the gingival margin of the other preparation on the other side of the same tooth was located 0.5 mm below the CEJ (dentin/cement margins).

The study was designed so that one side of the tooth served as the control of the other side. There was a total of 20 preparations with gingival margins located above the CEJ and 20 preparations with gingival margins located below the CEJ. The preparations measured 3 mm buccolingually at the occlusal surface and 3.5 mm at the gingival surface. All the preparations and restorations were made by the same operator. The prepared teeth were surrounded with Toffelmire steel matrix bands to prevent cavity overfill. They were cleaned with a cavity cleanser, chlorhexidinedigluconate 2% (BISCO Corp. Schaumburg IL, USA), prior to restoration. Excess water was removed with a triple-action syringe. A one-component, self-etching dental adhesive, XenoV (Dentsplay De Tray, Konstanz, Germany), was applied uniformly with a small applicator and agitated for 20 sec to ensure sufficient wetting of all cavity surfaces. The solvent was evaporated by gentle blowing of air by means of an air-water syringe, until no movement of the adhesive was observed, and then light-cured for 20 sec.

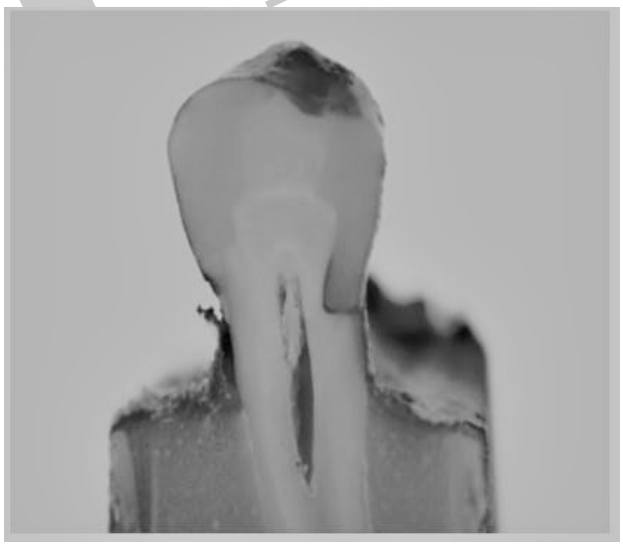

Fig. 1. *Section of tooth preparation.*

The gingival box of the cavity was filled with the SDR flowable composite in one bulk increment up to 4 mm, using slow and steady pressure. Dispensation began at the deepest portion of the cavity, while the tip was maintained close to the cavity floor and then gradually withdrawn as the cavity became filled. Curing followed after a few sec to allow the material to level itself. The material was then cured for 20 sec using a conventional one-level output method. The residual height of the cavity was filled with 2-mm oblique incremental layers of shade-D3, the Ceram X nano ceramic. Each layer was cured for 40 sec, according to the manufacturer's instructions. The dentin-bonding adhesive and the resin composite materials were polymerized using an ESPE Elipar TriLight unit (ESPE, Seefeld, Germany). To ensure a consistent light output of 650 mW/cm^2, the light was checked periodically during the experiment using a Demetron light-emitting diode and a halogen radiometer (Kerr Corporation, CA, USA).

Following removal of the matrix band, curing continued for an additional 20 secfor both sides of the restoration, i.e., bucco-proximal and linguo-proximal. Visible overhangs were removed using a no. 15 scalpel blade (Swann-Morton, UK). The proximal margins were immediately finished with flexible disks (SofLex Pop-on, 3M-ESPE, St. Paul, MN, USA), starting with the roughest flexible disk and finishing with the gentlest flexible disk, using a low-speed handpiece with air-water spray. No pressure was applied to the restorations. All the restored teeth were stored in distilled water at 37°C for 7 days and then subjected to thermo-cycling, i.e., thermal stress in water baths of 4°C and 55°C with 1,000 cycles of 10 sec in each bath and a dwelling time of 10 sec between baths using a TC-2000 automatic device (Y. Manes, Tel-Aviv, Israel).

The root apices were sealed with Duralay (Reliance Dental Mfg. Co., IL, USA). All of the other surfaces, except for the restoration and 1-2 mm of the cavo-surface margins, were covered with two layers of nail varnish to prevent dye penetration. The teeth were embedded in

auto-polymerizing acrylic material within a metal cylinder up to 2 mm apical to the restoration's margins and subjected to an occlusal load of 100 N for 1,000 cycles using an Ami lll Stress Cycling Machine (Y. Manes, Tel-Aviv, Israel). The load was pressed against the occlusal surface of the restoration during 1000 cycles, 0.5 seconds each. The teeth were submerged in 0.5% basic fuchsin solution at 37°C for 7 days and then rinsed under running tap water, carefully dried, and sectioned mesio-distally on their longitudinal axes into three sections using an ISOMET Plus low-speed saw (Buehler Ltd., IL, USA) (19). The sections were examined under a light-reflecting stereomicroscope at x18 magnification and by 2 independent examiners to assess dye penetration at the restoration margins (19). The depth of dye penetration at the gingival margins, if any, was assessed on the monitor attached to the microscope. All of the measurements were categorized according to the following scale:

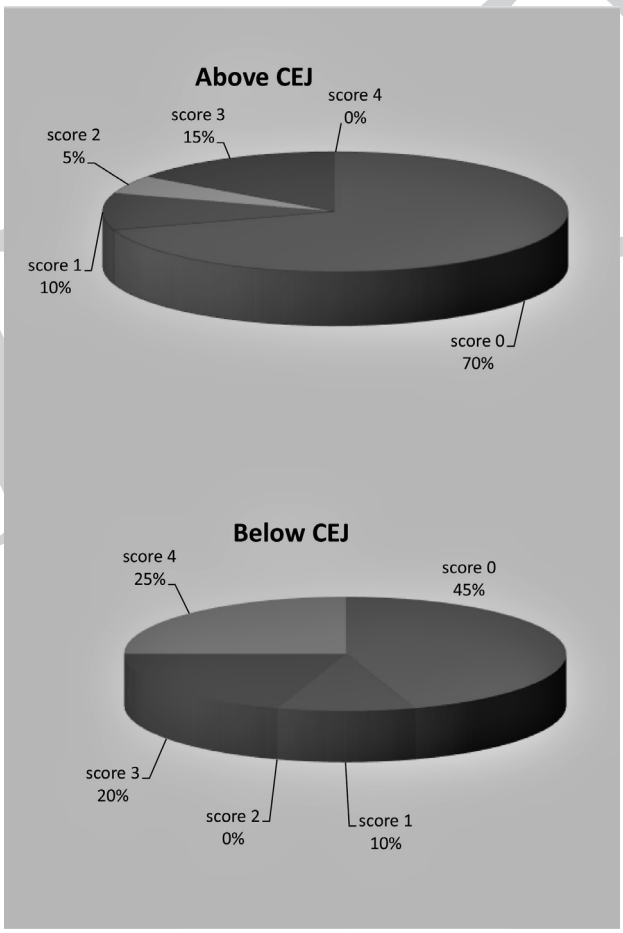

Fig. 2. *Dye penetration. Below the cemento-enamel-junction (CEJ): score = 4 (right); Above the CEJ: score = 1 (left).*

0 = No dye penetration (no leakage);
1 = Dye penetration up to 1/3 of the gingival wall from the cavity margins
2 = Dye penetration up to 2/3 of the gingival wall from the cavity margins
3 = Dye penetration up to the axial wall of the cavity margins
4 = Dye penetration along the axial wall into the tubules

The section with the highest dye penetration score was chosen for statistical analysis (Fig. 2). Two independent examiners evaluated all of the samples. Discrepancies between the two examiners were rare. In the event of a discrepancy, the section was reexamined by both examiners, and the higher score was always chosen. A non-parametric test (Wilcoxon's matched-pair signed-ranks test) for pairwise comparisons was performed to demonstrate significant differences (P=0.005) since the two study groups (enamel or dentin margins) did not exhibit a normal data distribution (Kolmogorov-Smirnov test).

RESULTS

Over one-half (56.5%) of all 40 restorations had no dye penetration (score 0). Of them, 65.5% were above the CEJ, and 25% were below the CEJ. Out of all of the restorations, 12.5% were scored 4, and they were all below the CEJ (Table I). Seventy percent of all the restorations above the CEJ had no dye penetration whatsoever and 30% had a dye penetration score between 1 and 3. No restorations had a dye penetration score of 4 (Fig. 2). Out of all the restorations below the CEJ, 45% had no dye penetration, 25% had a dye penetration score of 4 and 30% had a dye penetration score between 1 and 3 (Fig. 2).

There was a significant difference in the dye penetration for the two restorations with gingival margins located above and below the CEJ for the same tooth (P=0.005). All the teeth but one showed the same or more dye penetration in the restorations below the CEJ compared to the restorations above CEJ for the same tooth (Tables II).

DISCUSSION

The present study evaluated the marginal seal of

Table I. *Distribution of dye penetration.*

Dye penetration scale along the gingival wall	0	1	2	3	4
Restorations with gingival wall above the CEJ (No.)	14	2	1	3	0
Restorations with gingival wall below the CEJ (No.)	9	2	0	4	5

CEJ: *cemento-enamel-junction.* ***0:*** *No dye penetration (no leakage);* ***1:*** *Dye penetration up to 1/3 of the gingival wall from the cavity margins;* ***2:*** *Dye penetration up to 2/3 of the gingival wall from the cavity margins;* ***3:*** *Dye penetration up to the axial wall of the cavity margins;* ***4:*** *Dye penetration along the axial wall into the tubules.*

Table II. *Comparison of dye penetration for both sides of the same tooth.*

Tooth No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Above CEJ	2	0	0	3	0	1	0	0	0	0	0	0	3	0	0	1	0	0	3	0
Below CEJ*	4	0	3	4	0	0	0	0	0	3	0	1	4	0	1	3	3	0	4	4

CEJ: *cemento-enamel-junction. *: The same or more dye penetration was found in the restorations below the CEJ in all but one tooth.*

SureFil SDR by dye penetration in class II restorations with a gingival wall placement above or below the CEJ. The cavities were restored with a bulk-fill flowable composite, SureFil SDR and covered with a more wear-resistant resin composite, Ceram X. The restored teeth were subjected to thermo-cycling and occlusal loading cycling, which simulate months of daily use.

Marginal seal is one of the key factors for long-lasting restorations. Previous studies had evaluated the marginal integrity of standardized class II cavities, which were incrementally filled with resin-bonded composites with or without bulk-fill flowable resin base and after thermo-mechanical loading. Those investigations found no difference in the cervical microleakage scores between the groups when the gingival walls were located above the CEJ (14-17). Roggendorf et al. (17) also found that SDR had no advantages over conventional posterior resin composites in reducing marginal microleakage in class II restorations with gingival walls below the CEJ. The degradation of the marginal seal quality was further exacerbated after thermo-mechanical loading (17).

Another study (20) that examined the microleakage of Class-V restorations, carried out with three restorative materials on both dentin and enamel substrates, also reported that all groups showed dye penetration but, in opposition to the finding of Roggendorf et al. (17) study, those authors found that the SDR group were advantaged as they had obtained a better seal, especially in the dentin margins. They also reported that there was less dye penetration on the enamel for all the restorative material (20).

In the present study, overall poor margin sealing performance was documented in 30% and 55% of the enamel and dentin margins, respectively, which were leaking to some degree at the gingival floor interface. A comparison of the performance of SDR below the CEJ and above the CEJ of the same tooth revealed dye penetration of different depths, regardless of gingival wall placement, in 17 of 40 cases (representing 42.5% of the studied restorations). There had been no dye penetration in 70% of the restorations above the CEJ, and in only 45% of the restorations below the CEJ.

With regard to the marginal seal on both sides of each tooth, all of the restorations above the CEJ consistently showed less or the same extent of dye penetration relative to those below the CEJ, with only one exception. The marginal seal quality of the enamel/SDR interface was much better than that of the dentin/cement/SDR interface (P=0.005), but still not good enough.

The finding that inadequate marginal seals were obtained with SDR restorations even when the cavo-surface had been located on the enamel may be explained by the Roggendorf et al. (17) report of para-marginal enamel fractures occurring slightly more frequently with SDR restorations. Other studies that analyzed the shrinkage behavior of SDR concluded that the experimental flowable material showed the lowest shrinkage-stress-rate but was also more rigid (higher modulus of elasticity) and more plastic than the regular flowable materials, thus making its effect on interfacial stress build-up difficult to predict (14, 16).

On the other hand, Ilie and Hickel's study on the bulk-fill SDR flowable material showed different behavior when compared to other flowable composites and to nano- and micro-hybrid composites. Those authors demonstrated a low shrinkage-stress rate after polymerization, a high modulus of elasticity and high creep values (16). Van Ende et al. (15) evaluated SDR's bond strength to dentin in different C-factor cavities. They found that bulk-fill flowable base SDR can be cured in bulk without harming the bond to cavity-bottom dentin, in addition to having good adaptation to cavity walls (15). Those features are regarded as being optimal for cavity adaptation and sealing. However, the marginal seal was less than optimal in both of the present study groups and there was greater dye penetration in the group with marginal walls below the CEJ. The difference between the two groups can be explained by the importance of the remaining enamel in class II preparations above the CEJ in providing improved and more reliable micromechanical adhesion between the tooth and the flowable composite SDR (21).

The bonding of resin to enamel is largely micromechanical and relies on the preparation of a high-energy etched surface that can be wetted easily by low-viscosity bonding resins to produce micromechanical resin tags (21). The bonding of resin to dentin involves a similar procedure, although dentine substrate parameters vary greatly from the enamel in the organic composition and water content. Dentin surface preparation is critical for creating a "hybrid zone" of demineralized dentin into which a hydrophilic monomer can penetrate and interlock with exposed collagen to provide another form of micromechanical retention (22). The hybrid layer is the resulting resin-infiltrated surface layer in dentin.

A good adhesive should prevent leakage along the restoration margins and provide a long-lasting marginal seal. Inadequate surface preparation and inadequate surface wetting are major factors associated with bonding failure. In the present study, the self-etching dental adhesive material, XenoV, was used according to the manufacturer's recommendations. An earlier study that compared the adhesive performance of several adhesive materials used with SDR did not observe any incompatibility between other adhesives and the SDR flowable resin composite (18). It was also confirmed that the use of a total etch technique provided a better marginal seal (23-25). On the other hand, Roggendorf et al. (17) reported that para-marginal fractures occurred slightly more frequently in SDR restorations when an etch-and-rinse bonding technique was used in comparison to a self- etching technique. Mazzoni et al. (26) found that there are no differences in the activities of MMP-2 and MMP-9 after treatment with different etch-and-rinse or self-etch adhesives, including XenoV. They also noted that MMPs have been considered as having a major role in the degradation of poorly resin-infiltrated hybrid layers. We chose XenoV, a self-etch adhesive for the present study, based on those findings and on the facts that self-etch bonding is less sensitive to the technique applied, that it is easy to work with, and that it may be more compatible with dentin.

Cavity preparation is another important parameter. The current study was designed to evaluate the marginal seals of non-beveled class II preparations. A non-beveled protocol is quite common for studies that primarily investigate clinical bond strengths to dentin, under the controversial premise that beveling the enamel margins increases the surface area and may increase the marginal seal (26, 27) and fracture resistance (28), while reducing the occurrence of micro-cracks (29). Therefore, restorations placed on beveled enamel in class II preparations have the potential to exhibit even

higher marginal seals than that those shown in the present study.

The main advantages of SDR bulk-fill flowable resin are its low shrinkage on polymerization (14, 30), its self-leveling characteristic and its stress-relieving properties during polymerization, that would allow the placement of 4-mm bulk increments and the use of light-curing without requiring multiple packing or pushing steps. These physical properties have clinical value. They increase the efficiency, simplify the restorative technique and decrease operating time. Nonetheless, SDR bulk-fill flowable resin bonded with XenoV did not yield a perfect gingival seal in the current study.

CONCLUSION

Within the limitations of the present *in vitro* study, the following conclusion can be drawn about bulk-fill flowable resin composite Surefil SDR. It provides poor sealing of the gingival margins located below the CEJ in class II restorations compared to gingival margins above the CEJ. Further studies are needed in order to clarify the high rate of dye penetration associated with its use.

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