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Laboratory Research

Marginal Integrity of Bulk Versus Incremental Fill Class II Composite Restorations

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Clinical Relevance

Bulk-fill composites provide similar marginal performance to open-sandwich and incremental composites. *In vitro* use of World Dental Federation criteria can be a valid method for predicting clinical marginal performance of restorations.

SUMMARY

Bulk-fill composites have been introduced to facilitate the placement of deep direct resin composite restorations. This study aimed at analyzing the cervical marginal integrity of bulk-fill vs incremental and open-sandwich class II resin composite restorations after thermomechanical cycling using replica scanning electron microscopy (SEM) and ranking according to the World Dental Federation (FDI) criteria.

Box-only class II cavities were prepared in 91 maxillary premolars with the gingival margin placed 1 mm above and below the cemento-enamel junction. Eighty-four premolars were divided into self-etch and total-etch groups, then subdivided into six restorative subgroups (n=7): 1-Tetric Ceram HB (TC) was used incrementally and in the open-sandwich technique with 2-Tetric EvoFlow (EF) and 3-Smart Dentin Replacement (SD). Bulk-fill restoratives were 4-SonicFill (SF), 5-Tetric N-Ceram Bulk Fill (TN), and 6-Tetric EvoCeram Bulk Fill (TE). In subgroups 1-5, Tetric N-Bond self-etch and Tetric N-Bond total-etch adhesives were used, whereas in subgroup 6, AdheSE self-etch and ExciTE F total etch were used. One more group (n=7) was restored with Filtek P90 Low Shrink Posterior Restorative (P9) only in combination with its self-etch P90 System Adhesive. Materials were manipulated and light cured (20 seconds, 1600 mW/cm^2), and restorations were artificially aged by thermo-occlusal load cycling. Polyvinyl-siloxane impressions were taken and poured with epoxy resin. Resin replicas were examined by SEM (200×) for

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marginal sealing, and percentages of perfect margins were analyzed. Moreover, samples were examined using loupes (3.5×) and explorers and categorized according to the FDI criteria.

Results were statistically analyzed (SEM by Kruskal-Wallis test and FDI by chi-square test) without significant differences in either the replica SEM groups (p=0.848) or the FDI criteria groups (p>0.05). The best SEM results at the enamel margin were in TC+EF/total-etch and SF/total-etch and at the cementum margins were in SF/total-etch and TE/self-etch, while the worst were in TC/self-etch at both margins. According to FDI criteria, the best was TE/total-etch at the enamel margin, and the poorest was P9/self-etch at the cementum margin.

Groups did not differ significantly, and there was a strong correlation in results between replica SEM and FDI ranking.

INTRODUCTION

Adhesive bonding to tooth structure has been an integral part of modern restorative dental practice that obviously improves the biomechanical and esthetic quality outcomes of restorations.[1,2] An effective bonding to tooth structure would durably seal dentinal tubules and restoration margins, preventing microleakage with adverse consequences of postrestoration hypersensitivity, marginal discoloration, recurrent caries, and harmful effects on the pulp. Furthermore, it would eliminate the need for extension undercuts, thus conserving tooth structure.[3] The literature clearly indicates that all modern formulations of resin adhesives provide an initial satisfactory performance and a progressive gradual *in vivo* deterioration of bonding effectiveness regardless of the bonding approach.[4-6]

Increased patient motivation toward an esthetic, biocompatible, cost-effective, and clinically durable restoration has lead research toward improving the *in vivo* effectiveness and longevity of resin adhesive bonds to tooth structure in direct resin composite restorations, particularly at the cervical margins of class II cavities, where the problem of microleakage becomes more pronounced.[7-9] Clinically effective and durable bonds should resist stresses due to polymerization contraction as well as differences in values of the modulus of elasticity and thermal expansion coefficient between tooth structure and restorative materials. Furthermore, they should be able to survive a number of oral environmental challenges of endogenous collagenolysis, hydrolytic degradation, functional loading, thermal and pH cycling, and bacterial biochemical activities.[3,5,10-12]

Different resin adhesives, placement techniques, and resin composite materials have been suggested to improve the clinical reliability and to control the effect of polymerization contraction stresses. Shrinkage stresses that develop at tooth-restoration interfaces interfere with effective adhesive bonds to tooth structure and marginal sealing of direct composite restorations.[4,5,10-13]

A new generation of bulk-fill resin composites has been recently introduced. Some bulk-fill composites are indicated for use as posterior restorations, while others are used as underlining or base materials under suitable posterior composites. Manufacturers and a few reports indicate that bulk-fill composites provide reduced or relieved interfacial polymerization contraction stresses. Additionally, materials can be applied and light cured in bulk, leading to reduced restorative procedure time, minimized air void entrapment, and improved quality of the final restoration.[2,14,15]

Various *in vitro* tests of marginal adaptation have been widely used to predict the *in vivo* quality of restorations, but reports are inconsistent regarding their clinical relevance. These tests include dye penetration and microscopic marginal and interfacial analysis.[3,4,9,16] While low or moderate correlation was found between scanning electron microscopic (SEM) marginal analysis and clinical findings, no available systematic correlation exists between dye tracing and clinical findings of hypersensitivity, marginal discoloration, caries at restorations margins, and retention.[1] As an *in vitro* test, Heintze[16] suggested using loupes and explorers for the assessment of the marginal integrity of restorations and rating them according to the World Dental Federation (FDI) ranking criteria, which could provide a more clinically relevant testing for marginal integrity.[16,17]

This study was performed in order to comprehensively analyze the cervical marginal behavior of bulk-fill restorations. Replica SEM and simulation of clinical evaluation using FDI criteria were used in an attempt to provide a more clinically relevant study outcome. The null hypothesis was that bulk-fill resin composites provide similar marginal integrity compared to conventional incremental fill and open-sandwich composites. Furthermore, *in vitro*

Table 1: *Materials Used in This Study*

Material	Manufacturer	Lot Number	Description
Tetric Ceram HB	Ivoclar Vivadent	N03283	A light-curing fine-particle microhybrid material based on a moldable ceramic
Tetric EvoFlow	Ivoclar Vivadent	R36640	An incremental light-curing, flowable microhybrid composite
SDR Smart Dentin Replacement	Dentsply	1011002185	A bulk-fill flowable composite base material that allows the curing of layers up to 4 mm thick
SonicFill Composite	Kerr Corp	4252654	Bulk-fill low-shrinkage composite that allows the curing of layers up to 5 mm thick; uses sonic energy during insertion
Tetric N-Ceram Bulk Fill	Ivoclar Vivadent	R65898	Bulk-fill resin composite material that allows the curing of 4-mm-thick layers
Tetric EvoCeram Bulk Fill	Ivoclar Vivadent	R56348	Bulk-fill resin composite material that allows the curing of 4-mm-thick layers
Filtek P90 (Filtek LS), Low Shrink Posterior Restorative	3M ESPE	N 281586	A low-shrink silorane-based resin composite material
Tetric N-Bond Self-Etch	Ivoclar Vivadent	P48222	Light-cured, one-step all-in-one self-adhesive
Tetric N-Bond	Ivoclar Vivadent	R52704	Light-cured primer and adhesive, total-etch adhesive
AdheSE	Ivoclar Vivadent	69346	Two-bottle self-etch adhesive primer and bond
ExciTE F	Ivoclar Vivadent	R50336	Primer and adhesive, total-etch adhesive
P90 System Adhesive, Self-Etch Primer & Bond	3M ESPE	N 281586	Two-bottle self-etch primer and bond
Fine Etch, etchant	Spident	FE1242	37% phosphoric acid gel
Express VPS Impression Material	3M ESPE	N220759	Polyvinylsiloxane impression material

simulation of clinically ranking marginal integrity can provide clinically relevant results.

METHODS AND MATERIALS

A total of 91 human maxillary premolars (n=7/group) that showed no caries, cracks, or developmental defects were used in this study. Teeth were freshly extracted for orthodontic reasons, and their use in research was approved by the local biomedical research ethics committee.

Each premolar was wrapped coronally with wax 2 mm below the cemento-enamel junction (CEJ). An artificial periodontal membrane of about 0.25 mm was created by dipping each premolar once in gum resin (Anti-Rutsch-Lack, Wenko-Wenslaar, Hiden, Germany), followed by lancet trimming of the excess resin apically after resin hardening. Then teeth were embedded vertically in self-curing acrylic blocks to a level 2 mm below the CEJ (self-curing liquid and powder, Major.Ortho, Moncalieri, Italy).

On each premolar, class II mesial and distal box-only cavities were prepared with butt joint margins and 4-mm buccolingual dimensions. Access was gained through enamel with a round tungsten carbide bur (no. 1, HM 1010, Meisinger, Neuss, Germany), and the preparation was completed with a cylindrical diamond abrasive with a flat end (no. 835012, Meisinger); new burs and abrasives were used for each of five cavities. The preparations were performed using high-speed ranges under abundant air-water coolant. The buccolingual dimensions were measured using a digital caliper (Digital Vernier Caliper, Clarke TM International, Essex, UK) with an accuracy of 0.01 mm, the outline was marked with a pencil, and an axial depth of 1.5 mm was measured at the gingival floor using a graduated periodontal probe (1011 Duralite Color Rings, Nordent Manufacturing Inc, Elk Grove Village, IL, USA). In each tooth, the proximal gingival margin was placed 1 mm above the CEJ on one side and 1 mm below it on the other side of the tooth. Consequently, two restorations were inserted in each premolar using the same bonding agent, restorative material, and technique, the only difference being the location of the cervical margin.

According to the resin composite used, 84 specimens were randomly divided into six main study groups and then subdivided according to the bonding technique into self-etch and total-etch subgroups (n=7). Group 7, an additional group (n=7), was included; restored with Filtek P90 low-shrinkage silorane-based composite (3M ESPE, Seefeld, Germany); and bonded with its corresponding self-etch adhesive system. All materials are listed in Table 1 and were manipulated according to the manufacturers' instructions; study variables are displayed in

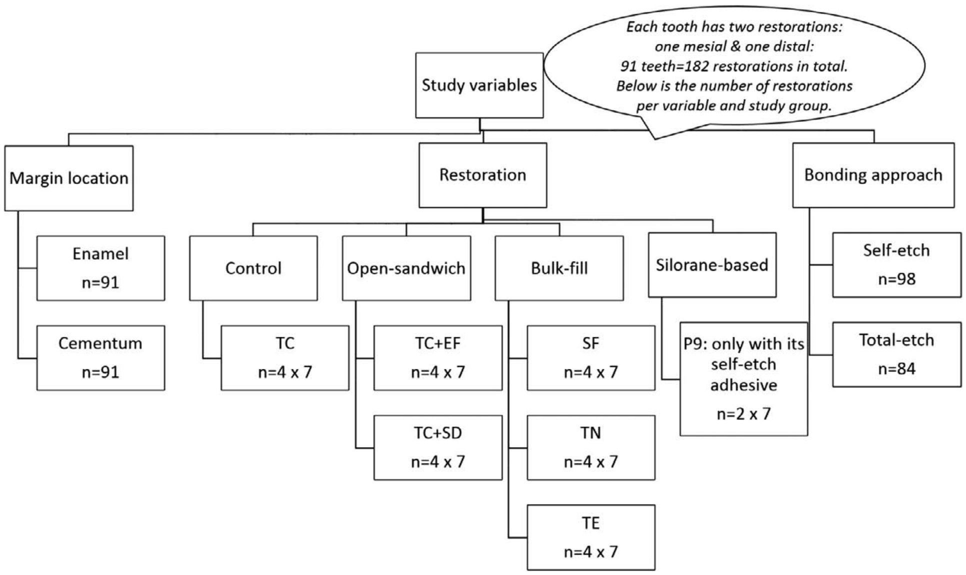

Figure 1. *Overview of the study variables. The abbreviations of the materials are as follows: TC = Tetric Ceram HB, EF = Tetric EvoFlow, SD = Smart Dentin Replacement, SF = SonicFill, TN = Tetric N-Ceram Bulk Fill, TE = Tetric EvoCeram Bulk Fill.*

Figure 1 and the study workflow is displayed in Figure 2.

During the bonding procedure and subsequent application and light curing of the restorative materials, a metallic matrix band attached to a universal matrix retainer (Tofflemire Retainer-Universal, Dentsply, Mount Waverley, VIC, Australia) was used. It was applied to each premolar to maintain the adaptation of the band to the cavity margins. For maximum and rapid curing conversion, the Ortholux Luminous Curing Light (3M Unitek, Monrovia, CA, USA) was used, which is a high-intensity LED of 1600 mW/cm^2 energy output with a wavelength of 430-480 nm and a peak of 455 $\pm$ 10 nm. All restorative materials were light cured from an occlusal direction. Each increment of restorative material, conventionally layered or bulk placed, was light cured for 20 seconds, while adhesives were light cured for 10 seconds before composite application, which is in agreement with the manufacturer's instructions. A summary of the various bonding procedures is presented in Table 2. Thereafter, resin composite restorations were inserted according to the assigned study groups.

In group 1, Tetric Ceram HB (TC) resin composite (Ivoclar Vivadent, Schaan, Liechtenstein) was inserted in horizontal increments of 2 mm each by using a metallic plastic instrument (stainless steel, G. Hartzell and Son, San Francisco, CA, USA) and light cured for 20 seconds until complete filling of the cavity. The plastic instrument was used to provide the proper anatomical form before light curing the most superficial increment.

In group 2, the open-sandwich technique was performed by inserting Tetric EvoFlow (EF, Ivoclar Vivadent, Schaan, Liechtenstein) as a base of approximately 2-mm thickness[18] under Tetric Ceram HB (TC+EF), followed by light curing for 20 seconds before incrementally inserting Tetric Ceram HB to completely fill the cavity in a similar manner to group 1.

In group 3, the open-sandwich technique was also utilized by applying SDR Smart Dentin Replacement (SD) bulk-fill flowable resin composite (Dentsply International, Milford, DE, USA) as a base of 4-mm thickness. SD was light cured for 20 seconds before incrementally inserting Tetric Ceram HB (TC+SD) as in the control group TC.

In group 4, SonicFill (SF), a sonic-activated bulk-fill composite system (Kerr Corp, Orange, CA, USA), was inserted into the cavity using the SonicFill Handpiece (Kavo, Biberach, Germany). The SonicFill handpiece automatically dispensed rheologically matched filling materials that are contained in SonicFill Unidose tips into the cavity by the action of sound and pressure under a frequency of 5-6 kHz. A MULTI flex coupling device connected the SonicFill Handpiece to the turbine hose of the dental unit. Initially, SF was inserted in a 5-mm-thick bulk of material and light cured for 20 seconds, and, when needed, a second, thinner horizontal increment was added to complete filling the cavity after reestablishing the occlusal anatomical features.

In group 5, Tetric N-Ceram Bulk Fill (TN; Ivoclar Vivadent) was used. A 4-mm-thick increment was inserted into the cavity using a plastic instrument (G. Hartzell and Son) and light cured for 20 seconds,

Table 2: *Summary of the Bonding Procedure*

Bonding System	Used With	Bonding Procedure
Tetric N-Bond Self-Etch (self-etch)	Tetric Ceram HB incremental Tetric Ceram HB underlined with Tetric EvoFlow Tetric Ceram HB underlined with SDR SonicFill Tetric N-Ceram Bulk Fill	After preparation, cavity was water washed and air-dried; thick layers of Tetric N-Bond Self-Etch were applied to the enamel and dentin surfaces of the preparation and brushed in for 30 s. Excess bonding agent was air thinned and light cured for 10 s.
Tetric N-Bond (total etch)	Tetric Ceram HB incremental Tetric Ceram HB underlined with Tetric EvoFlow Tetric Ceram HB underlined with SDR SonicFill Tetric N-Ceram Bulk Fill	After preparation, cavity was water washed and air-dried, etched for 15 s, and washed with vigorous water spray, and excess moisture was removed. Thick layers of bonding agent were applied to the enamel and dentin using an application brush, air thinned, and light cured for 10 s.
AdheSE (self-etch)	Tetric EvoCeram Bulk Fill	After preparation, cavity was water washed and air-dried. One drop of each primer and adhesive was dispensed individually. Primer was massaged to enamel and dentin for 30 s with a microbrush, air thinned, and light cured for 10 s.
Excite F (total etch)	Tetric EvoCeram Bulk Fill	After preparation, cavity was water washed and air-dried, etched for 15 s, and washed with vigorous water spray, and excess moisture was removed. Thick layers of bonding agent were applied to the enamel and dentin by application brush, and excess adhesive was dispersed with air and light cured for 10 s.
P90 System Adhesive (self-etch)	Filtek P90 (Low Shrink Posterior Restorative System)	Cavity was washed and dried. The self-etch primer was massaged to the surfaces of enamel and dentin for 15 s, air thinned evenly, and light cured for 10 s. Then the adhesive was applied to the entire area of the cavity, air thinned, and light cured for 10 s.

followed by a second increment to completely fill the cavity which was contoured and light cured.

In group 6, Tetric EvoCeram Bulk Fill (TE; Ivoclar Vivadent) was applied in a similar manner to group 5 with different bonding agents: AdheSE (Ivoclar Vivadent), a self-etch adhesive, and Excite F (Ivoclar Vivadent), a total-etch bonding agent, were used in this group.

In group 7, Filtek P90 (P9), a silorane-based composite (3M ESPE), was applied in a similar manner to group 1. P90 System Adhesive (3M ESPE), a self-etch adhesive system, was solely used in this group, according to the recommendations of the manufacturer (Table 2).

After completion of the restorations, gross marginal overhangs were removed by a surgical scalpel blade (no. 15, Swann-Morton, Sheffield, UK). Afterward, restorations were finished and polished using Sof-Lex XT 13-mm-size discs (Sof-Lex XT Finishing and Polishing System, 3M ESPE, St Paul, MN, USA), starting with a courser grit descending down to a superfine grit. The discs, mounted on the Sof-Lex finishing and polishing disc mandrel, were used in a slow-speed range under abundant air-water spray. Following finishing and polishing, the margins of the restorations were carefully inspected using loupes (3.5×) for complete removal of overhangs.

All samples were artificially aged by thermal and occlusal load cycling. Specimens were thermocycled for 5000 cycles in water baths between 5 ± 2°C and 55 ± 2°C at a dwell time of 30 seconds in each bath and a transfer time of 15 seconds between baths (Thermocycling machining, Proto-Tech, El Segundo, CA, USA). Then specimens were subjected to intermittent vertical occlusal loading between 25 and 100 N at 20 cycles/min (20 Hz) for 1000 cycles using the Chewing simulator CS4.2 (SD Mechanotronik GMBH, Westernham, Germany) with a vertically directed round-end piston of 5-mm diameter that touched the occlusal surface at the internal cuspal inclines.

Replica SEM

After artificial aging, polyvinyl-siloxane impressions (Excite, 3M ESPE) were taken of the cervical margins of all restorations mesially and distally. The impression material was injected around the tooth in one direction until the exposed part was completely covered. Impressions were poured with

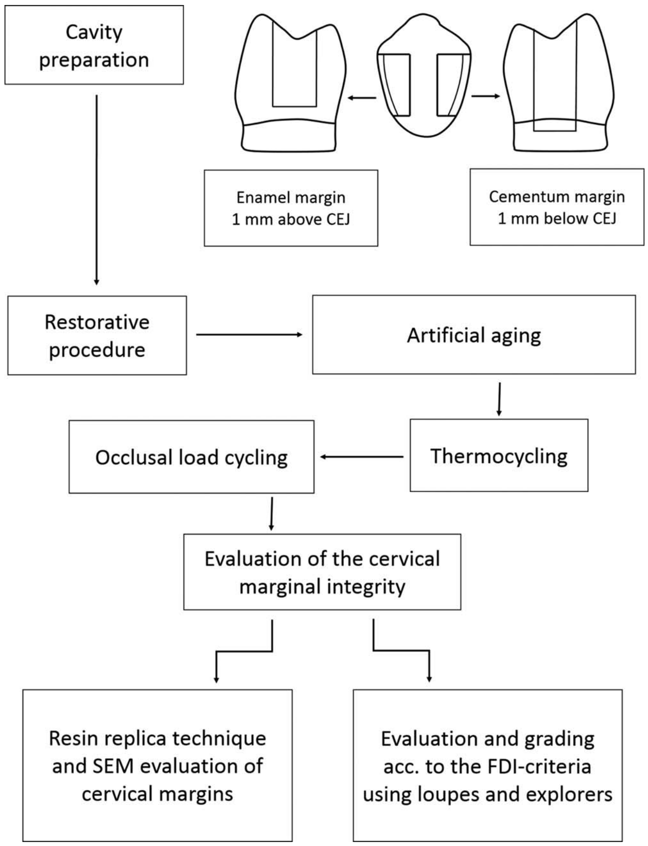

Figure 2. *Work flow of the specimen preparation for replica SEM and FDI ranking.*

an epoxy resin (Epoxy Cure Epoxy System, Buehler, Lake Bluff, IL, USA) for producing resin replicas for the SEM marginal assessment.

After drying at room temperature for 24 hours, replicas were removed from the impressions and trimmed at their cervical bases (Wassermann Trimmer, Hamburg, Germany). Replicas were glued at their bases on a metallic holder and gold sputter coated (25 nm) and examined under SEM at 200× (Stereozoom 250 Microscope, Luxo Microscopes, Elmsford, NY, USA). The quality of the marginal seal at the gingival margins of restorations was categorized into three scores following the methodology of Aschenbrenner and others[19]:

1. Perfect margin: The margin appears with smooth and uninterrupted tooth-restoration continuity.
2. Marginal gap: A distinct gap exists at the tooth-restoration margin.
3. Nonassessable margin: Does not fit the previous two categories accounting for imperfections in the impression material or the epoxy resin.

Images were analyzed with image analysis software (SigmaScan Pro 5.0 image measuring software), and the percentages of perfect margins were recorded.

FDI Ranking

The quality of the margins was assessed with the aid of loupes (3.5×) and two dental explorers with tip diameters of 150 and 250 μm. These explorers were specially prepared for this study by MEDSY dental explorers (MEDSY 560-1, MEDSY, Maniago, Italy). The marginal quality was ranked according to the FDI criteria, as suggested by Hickel and others[17]:

Category 1: Harmonious outline, no gaps, no white marginal lines
Category 2: Small marginal gaps <150 μm indicated by the presence of white lines or small ditching removable by polishing (slight)
Category 3: Marginal gap <250 μm indicated by definite gaps or defects not removable by polishing (major)
Category 4: Gaps >250 μm indicated by base/dentin exposed (severe)
Category 5: Ditching or marginal fracture (larger irregularities)

All samples were evaluated by the same two investigators after conforming to one single reading for each margin. Training on marginal ranking using FDI criteria was performed during the pilot study.

For the SEM results, the statistical analysis was performed with the Shapiro-Wilk confidence test, which proved that values were not normally distributed. Means and standard deviations were calculated, and the statistical analysis was carried out using the Kruskal-Wallis test. For the FDI ranking results, statistical analysis was performed using the chi-square test, while the Spearman correlation coefficient was calculated for correlating the two assessment results (IBM SPSS Statistics 19).

RESULTS

Replica SEM

Figure 3 displays representative SEM images (200×) of the resin replica for each category of margin: perfect margin, marginal gap, and nonassessable margin. The SEM evaluation of the cervical marginal seal was presented quantitatively as mean percentages of perfect margins of all groups in Table 3. None of the test groups showed 100% perfect margins regardless of the test material, bonding technique, or location of the gingival margin.

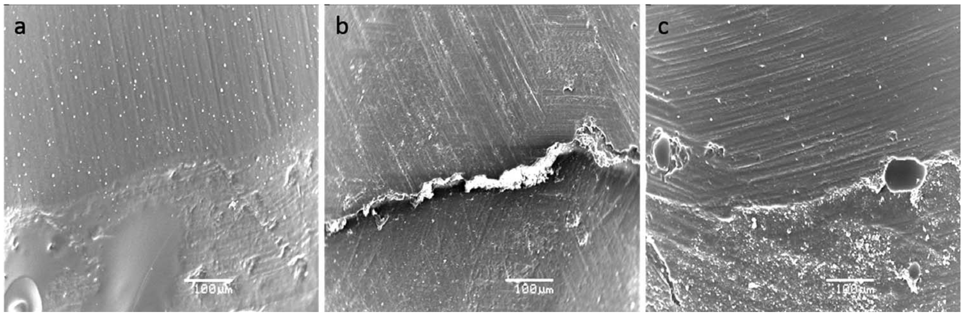

Figure 3. *SEM images (200×) of the resin replica showing a perfect margin (a), a marginal gap (b), and a non-assessable margin (c).*

Statistical analysis revealed no significant difference between the groups (p=0.848). The marginal seal generally trended better at enamel margins than at cementum margins and total-etch groups trended slightly better marginal integrity than self-etch ones, although there was no significant difference between the groups. The values of perfect margins at the enamel sides ranged from 85.6% to 94.9%, while at the cementum sides, they ranged from 70% to 93.3%.

FDI Ranking

The results of the FDI categories in terms of frequencies and percentages for all five categories are presented in Table 4. The chi-square categorical test was applied to compare the groups. The quality of cervical margins ranged from category 1 to category 3 FDI criteria among the study groups. No group consisted completely of category 1 but was rather a mixture of categories. None of the test specimens showed a cervical marginal gap of category 4 or 5.

There was no significant difference between the groups (p>0.05). Enamel margins showed generally better marginal quality than cementum margins. The best marginal quality was found in group TE/total etch at enamel margins. Category 3, the major gap, was found only at cementum margins in TC/self-etch, TC/total etch, TC+EF/self-etch, TC+SD/self-etch, and P9/self-etch. The Spearman rank correlation coefficient (r=–0.632, p=0.001) showed a significantly inverse correlation between the mean percentages of perfect margins of replica SEM and the mean values of FDI ranking (p<0.05; Figure 4).

DISCUSSION

A core issue for a clinically effective and durable resin composite restoration is to maintain tight and leakproof tooth restoration margins.[3,4] Although *in vitro* testing of restorations is an important screening, it does not rule out the clear significance of analyzing the clinical effectiveness of restorations. Lab testing shows different degrees of clinical relevance.[3,16,19] A more clinically relevant testing of marginal sealing necessitates the simulation of the oral environmental factors, including temperature changes, masticatory forces, pH fluctuations, and others.[3,4,16]

A number of studies have listed the pros and cons of different *in vitro* marginal sealing tests, especially toward the validity in predicting the clinical performance of restorations margins.[16] Dye penetration testing is lacking clinical relevance and interstudy comparability. In contrast, the replica SEM method is a well-established procedure that allows for qualitative and quantitative evaluation of margin analysis. Moreover, it can be applied for *in vitro* as well as *in vivo* screening of restorations.[20] Epoxy resin was reported as an adequate material for replicating details of silicone impressions in the indirect study of dentin surfaces.[16,21] An advantage of this qualitative and quantitative method is that

Table 3: *Mean Values of Perfect Margin Percentage (PMP; %) of Replica Scanning Electron Microscopy (SEM) and Standard Deviation (SD)[a]*

Groups	Mean PMP at Enamel	SD	Mean PMP at Cementum	SD
TC/self-etch	85.6	14.9	70.0	21.5
TC/total etch	91.9	11.3	82.3	22.1
TC+EF/self-etch	94.4	14.7	88.7	19.3
TC+EF/total etch	94.9	13.6	88.3	20.1
TC+SD/self-etch	91.4	14.7	79.3	25.9
TC+SD/total etch	93.0	18.5	88.0	20.8
SF/self-etch	93.1	12.4	90.1	17.2
SF/total etch	94.6	9.9	93.3	17.8
TN/self-etch	94.1	15.5	86.0	24.0
TN/total etch	94.1	15.5	81.4	23.5
TE/self-etch	93.7	16.6	91.0	23.8
TE/total etch	92.7	19.3	76.9	29.3
P9/self-etch	93.7	16.6	89.4	28.0

[a] *No significant difference between the groups was observed (p>0.05).*

Table 4: *The Results of the World Dental Federation (FDI) Categories. C1 (Category 1), C2 (Category 2), C3 (Category 3), C4 (Category 4), and C5 (Category 5) Were Presented in Terms of Frequencies and Percentages Between Brackets. The Chi-Square Categorical Test Was Applied to Compare the FDI Ranking Results Between the Groups*[a]

Groups	At Enamel Margins (n=7/Group)					At Cementum Margins (n=7/Group)				
	C1	C2	C3	C4	C5	C1	C2	C3	C4	C5
TC/self-etch	4 (57.1)	3 (42.9)	0 (0)	0 (0)	0 (0)	3 (42.9)	3 (42.9)	1 (14.2)	0 (0)	0 (0)
TC/total etch	5 (71.4)	2 (28.6)	0 (0)	0 (0)	0 (0)	3 (42.9)	3 (42.9)	1 (14.2)	0 (0)	0 (0)
TC+EF/self-etch	5 (71.4)	2 (28.6)	0 (0)	0 (0)	0 (0)	5 (71.4)	1 (14.2)	1 (14.2)	0 (0)	0 (0)
TC+EF/total etch	5 (71.4)	2 (28.6)	0 (0)	0 (0)	0 (0)	4 (57.1)	3 (42.9)	0 (0)	0 (0)	0 (0)
TC+SD/self-etch	5 (71.4)	2 (28.6)	0 (0)	0 (0)	0 (0)	3 (42.9)	2 (28.6)	2 (28.6)	0 (0)	0 (0)
TC+SD/total etch	4 (57.1)	3 (42.9)	0 (0)	0 (0)	0 (0)	5 (71.4)	2 (28.6)	0 (0)	0 (0)	0 (0)
SF/self-etch	4 (57.1)	3 (42.9)	0 (0)	0 (0)	0 (0)	4 (57.1)	3 (42.9)	0 (0)	0 (0)	0 (0)
SF/total etch	5 (71.4)	2 (28.6)	0 (0)	0 (0)	0 (0)	5 (71.4)	2 (28.6)	0 (0)	0 (0)	0 (0)
TN/self-etch	5 (71.4)	2 (28.6)	0 (0)	0 (0)	0 (0)	3 (42.9)	4 (57.1)	0 (0)	0 (0)	0 (0)
TN/total etch	5 (71.4)	2 (28.6)	0 (0)	0 (0)	0 (0)	5 (71.4)	2 (28.6)	0 (0)	0 (0)	0 (0)
TE/self-etch	4 (57.1)	3 (42.9)	0 (0)	0 (0)	0 (0)	3 (42.9)	4 (57.1)	0 (0)	0 (0)	0 (0)
TE/total etch	6 (85.8)	1 (14.2)	0 (0)	0 (0)	0 (0)	3 (42.9)	4 (57.1)	0 (0)	0 (0)	0 (0)
P9/self-etch	5 (71.4)	2 (28.6)	0 (0)	0 (0)	0 (0)	3 (42.9)	2 (28.6)	2 (28.6)	0 (0)	0 (0)

[a] *No significant difference between the groups was observed ($p>0.05$).*

samples can be retested at different study levels, allowing for monitoring restorations over a longer time span.[9,16,19,21,22] Points of weakness in the procedure of the replica technique include the accuracy of the impression relative to the type of bonding agent used, a lack of detailed description of impression taking, and a weak to moderate correlation to clinical findings.[16]

Heintze[16] reported that *in vitro* testing of restoration margins employing a sharp explorer and a magnifying loupe, similar to actual clinical examination, can provide more clinically significant outcomes,[16,17] thus allowing testing at different study stages in addition to saving time and cost.

In the current study, both replica SEM and clinical simulation ranking using the FDI criteria for marginal integrity of restorations were employed in an attempt to provide better prediction for clinical marginal behavior of the test restorations. Our pilot study, as well as previous studies, showed less importance of immediate testing. For this reason, testing was done only after artificial aging by thermoload cycling.[3,4,8,14,22,23]

El-Damanhoury and Platt[2] reported a significant reduction in polymerization shrinkage stress with comparable curing efficiency at 4 mm for some bulk-fill composites, supporting their potential use in posterior teeth. In the current study, a high-intensity LED light-curing unit (1600 mW/cm^2) was used, producing a rapid and high degree of conversion which could lead to greater curing contraction stresses and expose the tested cervical bonded interfaces to increased challenges.[24,25]

Regarding the effect of margin location, the replica SEM results showed that none of the groups could provide 100% perfect enamel or cementum margins regardless of the restorative material or bonding approach used. Although previous studies indicated significantly better marginal integrity at enamel than at nonenamel margins,[22,26] our results found

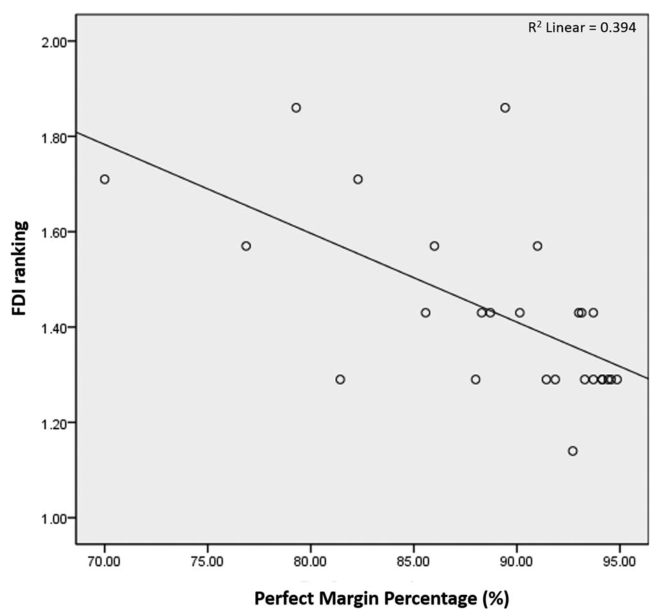

Figure 4. *Graph showing the inverse correlation between the mean perfect margin percentage (PMP; %) of replica SEM and the mean values of FDI ranking ($p<0.05$).*

only insignificantly better marginal integrity at enamel than nonenamel (cementum) margins. This, in part, is in agreement with the findings of Roggendorf and others,[14] who reported different levels of significance in marginal adaptation between enamel and nonenamel margins. They used the replica SEM testing method after thermomechanical cycling of class II composite restorations with and without SD base. In six of their studied groups, enamel margins showed only insignificantly better marginal adaptation than nonenamel margins, two groups showed significantly better adaptation of enamel margins, while two groups showed significantly better adaptation of nonenamel margins. This reflects the apparent impact of the respective restorative material and/or bonding system used on the quality of the outcome.

Because of the increased number of variables and groups of our study and the limited availability of extracted maxillary premolars for orthodontic reasons, the investigators had to decrease the sample size to a low but acceptable sample size (n=7) per group. However, increasing the sample size could have provided a more consistent statistical outcome.

Takahashi and others[22] found a statistically significant higher percentage of continuous enamel margins than dentin margins. Variations in findings can be related to differences in study design and materials. Manhart and Trumm[26] studied the marginal integrity of resin composite restorations in class II cavities after thermoload cycling using the replica SEM. They obtained higher percentages of a "perfect margin" that ranged from 95.9% to 99.6% in enamel and 85.9% to 96.0% in dentin. Sabatini and others[27] studied the effect of preheating and the use of flowable resin liners on the formation of cervical cementum marginal gaps in class II cavities using replica SEM. They found no significant effect on cervical gap formation between their test groups.

There was no clear effect of adhesives in the current study, as the percentages of perfect margin did not differ significantly between the self-etch and total-etch groups. In contrast, Takahashi and others[22] had significantly higher percentages of continuous dentin margins with self-etch than with total-etch adhesives, and an insignificant difference in effect at enamel margins was reported. On the other hand, Roggendorf and others[14] found a significantly higher percentage of continuous margins with total-etch adhesives than with self-etch adhesives at dentin margins with an insignificant difference in effect at enamel margins. Variation in results can be related to materials and testing protocol variations.

The similar marginal sealing quality of bulk and layered resin composites showed in the current study can be explained by previous reports indicating reduced polymerization shrinkage stresses[2] and hence improved marginal behavior of bulk-fill composites.[1,14,15] It is apparent that the initial flowability of SF composite induced by the sonic energy on insertion, as well as the low volumetric shrinkage and high filler loading, compensated for bulk curing by reducing polymerization contraction stresses. This was coupled with adequate resistance to aging by thermoload cycling.[28,29]

Our results showed that using a 2-mm-thick increment of conventional flowable composite did not significantly affect the marginal integrity, differing from Fabianelli and others,[30] who found that using the open-sandwich technique in class II resin composite restorations provided significantly better marginal seal.[30] It was also reported that using an intermediate flowable resin composite with a low modulus of elasticity may partially absorb polymerization contraction stresses in restricted constraints of class II cavities.[23] Differences in restorative materials, flowable liners, bonding systems, and testing procedures may explain variations in results.

Similar to our study, Malstrom and others[18] assessed class II sandwich restorations above and below the CEJ. They found that when margins were located above the CEJ, the use of a 2-mm-thick gingival increment of flowable composite provided significantly less marginal leakage than when 0.5-mm- and 1-mm-thick increments were applied. Nevertheless, de Goes and others[31] suggested that light curing through a thin gingival increment of flowable composite might confirm maximum conversion of the oxygen-inhibited surface molecules of the adhesive layer, thus improving the bond strength. However, this contradicts the common application techniques of composite restorations in class II cavities even with the use of bulk-fill flowable composites.

The present study did not find a significant effect of using silorane-based composite P90 on cervical marginal sealing with either enamel or cementum margins. It was used only with its self-etch adhesive system in order to follow the instructions of the manufacturer as well as other reports.[32,33] On the other hand, Mahmoud and Al-Wakeel[32] found that the use of P90 with its adhesive system significantly improved marginal adaptation compared to Tetric Ceram/Excite in dentin cavities. This was the case immediately after polymerization after one month and one year of water aging and thermal cycling without occlusal load cycling. Such a variation in effect can be related to the difference in cavity configuration and testing methodology.

Simulating the clinical assessment of marginal adaptation using FDI criteria did not reveal any significant differences between groups, in accordance with results obtained from replica SEM assessment. This is in agreement with the findings of Hayashi and others,[34] who reported that explorer tip diameter had a significant effect on detecting horizontal gaps. In our study, explorer tip diameters of 150 and 250 μm were used according to the recommendation of Hickel and others.[17] Moreover, the inverse correlation between the mean percentages of perfect margins and the mean values of FDI ranking indicates that using loupes and explorers for evaluating marginal sealing by FDI criteria can provide a valid laboratory test for predicting clinical outcomes. Additional research is recommended to correlate *in vitro* results to actual clinical findings using this method. Nevertheless, the results of this study supported the null hypothesis that bulk-fill restoration cervical marginal integrity does not deteriorate and that *in vitro* FDI ranking of marginal sealing can give clinically relevant information on the marginal behavior of restorations.

CONCLUSIONS

Under the circumstances of this investigation, the following conclusions can be drawn:

1. Marginal integrity was not significantly influenced by the use of bulk-fill materials, bonding techniques, or variation in the location of cervical margins.
2. There was an inverse correlation between percentage of perfect margins in replica SEM and marginal ranking according to the FDI criteria, indicating the validity of *in vitro* testing of marginal integrity using this method.

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Regulatory Statement

This study was conducted in accordance with all the provisions of the local human subjects oversight committee guidelines and policies of: University of Dammam. The approval code for this study is: 110/2012.

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.

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