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Cervical Interfacial Bonding Effectiveness of Class II Bulk Versus Incremental Fill Resin Composite Restorations

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Clinical Relevance

When cervical margins of Class II cavities are inevitably located in cementum, bulk-fill and silorane based restorations might be preferable. When possible, restorations should be bonded using a total-etch approach.

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SUMMARY

Cervical interfacial bonding quality has been a matter of deep concern. The purpose of this study was to analyze microtensile bond strength (MTBS) and cervical interfacial gap distance (IGD) of bulk-fill vs incremental-fill Class II composite restorations. Box-only Class II cavities were prepared in 91 maxillary premolars (n = 7) with gingival margin placement 1 mm above the cementoenamel junction at one side and 1 mm below it on the other side. Eighty-four maxillary premolars were divided into self-etch and total-etch groups and further subdivided into six restorative material subgroups used incrementally and with an open-sandwich technique: group 1, Tetric Ceram HB (TC) as a control; group 2, Tetric EvoFlow (EF); group 3, SDR Smart Dentin Replacement (SDR); group 4, SonicFill (SF); group 5, Tetric N-Ceram Bulk Fill (TN); and group 6, Tetric EvoCeram Bulk Fill (TE). Groups 2-6 were bulk-fill restoratives. Tetric N-Bond Self-Etch (se) and Tetric N-Bond total-etch (te) adhesive were

used in subgroups 1–5, whereas AdheSE (se) and ExciTE F (te) were used in subgroup 6. In an additional group, Filtek P90 Low Shrink Restorative (P90) was used only with its corresponding self-etch bond. The materials were manipulated, light-cured (1600 mW/cm^2), artificially aged (thermal and occlusal load-cycling), and sectioned. Two microrods/restoration (n = 14/group) were tested for MTBS at a crosshead-speed of 0.5 mm/min (Instron testing machine). Fracture loads were recorded (Newtons), and MTSBs were calculated (Megapascals). Means were statistically analyzed by the Kruskal-Wallis test, Conover-Inman post hoc analysis for MTBS (multiple comparisons), and Mann-Whitney U test for IGD. The ends of the fractures were examined for failure mode. One microrod/restoration (n = 7/group) was investigated by scanning electron microscopy (×1200) for IGD.

MTBS values for SF/te, P90 in enamel, and TC+SDR/te in enamel and cementum were significantly higher compared with those for the control TC/te and TC/se in cementum. Most of the failures were mixed. IGDs were generally smaller at enamel margins, and the smallest IGDs were found in P90 at both enamel and cementum margins. Bulk-fill and silorane-based composites might provide better cervical interfacial quality than incremental-fill restorations.

INTRODUCTION

A strong challenge for resin composite restorations is their questionable adaptability to cavity walls and margins, particularly in the long-term scale of clinical service. This lack of adaptability is due to the inherent limitations of polymerization shrinkage and resultant shrinkage stresses, the mismatch in the coefficients of thermal expansion and contraction, the mismatch of the moduli of elasticity to that of the tooth structure, and the long-term chemical instability of the restorative material and adhesive joints in clinical service. These factors compromise the effectiveness of tooth-restoration interfacial bonding.[1-3]

The clinical reliability and longevity of intracoronal adhesive restorations in stress-bearing areas in the posterior teeth depend on the ability of these materials to sustain polymerization contraction stress. Moreover, such restorations should be able to endure complex chemical and mechanical oral environmental challenges, such as endogenous collagenolysis, hydrolytic degradation, functional loading, thermal and pH cycling, and bacterial biochemical activities. Currently, no single *in vitro* test can simultaneously simulate all of these parameters.[2-7]

Recent investigations have shown that the initial bonding effectiveness of contemporary adhesives is quite favorable regardless of the approach used. However, in terms of long-term clinical service, the bonding effectiveness of tooth restoration interfacial joints is questionable.[7]

The correlation between *in vitro* and *in vivo* data revealed that, currently, the best-validated method for assessing adhesion durability involves the aging of biomaterials that are bonded to either enamel or dentin. The literature shows that artificial aging can be carried out by storage in water for different periods, thermal cycling, and/or occlusal load cycling.[7]

A durable and reliable bond between the restoration and the remaining tooth structure should uniformly seal the interfaces against the microleakage of fluids, molecular movements, and ingresses of bacteria and nutrients that may lead to postrestoration hypersensitivity, marginal discoloration, recurrent caries, and adverse pulpal consequences.[2,7-11] Furthermore, the bond should be able to reinforce the remaining tooth structure by effectively cross-linking the discontinuity and efficiently transferring and distributing the functional reactionary stresses throughout the restorative complex that is formed by the remaining tooth structure, the restoration, and the adjoining bonds.[5,6] The effectiveness of bonded interfaces has long been investigated using assessments of microleakage and bond strength.[7,12]

One of the weakest parts in Class II composite restorations is leakage at the gingival margin of the proximal boxes. This leakage is due to the absence of enamel at the gingival margins, which implies a less stable and less uniform cementum-dentin substrate for bonding. This conjecture is supported by the findings of Ferrari and others, who experimentally demonstrated the presence of an outer layer of 150–200 μm that is partially formed by cementum and located below the cementoenamel junction (CEJ) and does not allow for the microretention of adhesive materials.[10,11]

The orientation of dentinal tubules can negatively affect the quality of hybridization and, thus, favor leakage in resin-based restorations that are placed in deep interproximal boxes.[11] Different techniques and materials have been introduced to improve the performance of resin composite materials and the quality of interfacial bonding to the tooth structure. These techniques and materials include the introduction of nonmethacrylate silorane-based composites, nanofiller technology, and modifications of the triethyleneglycol dimethacrylate diluents and photoinitiators.[13] Recently, Smart Dentin Replacement has been marketed as a flowable bulk-fill base with reduced polymerization contraction stresses.[14-17] Furthermore, the SonicFill resin composite system uses sonic energy to provide bulk-fill resin composite restorations and has been reported to improve performance and reliability.[18,19]

Therefore, this study was designed to assess the effectiveness of these materials and techniques by investigating MTBS, failure modes, and interfacial gaps at the cervical interfaces of artificially aged Class II direct composite restorations. The null hypothesis was that the bulk-fill resin composites would not significantly affect the MTBS or the interfacial gaps.

METHODS AND MATERIALS

For this study, 91 caries-free human maxillary premolars that were freshly extracted for orthodontic reasons were used, and seven premolars were used for each study group. Only the teeth that were free of caries and exhibited no cracks or developmental defects were selected for the study. The teeth were collected after approval was obtained from the local biomedical research ethics committee.

Each tooth was covered coronally with wax to a level of 2 mm below the CEJ and then dipped in gum resin once (Anti-Rutsch-Lack, Wenko-Wenslaar, Hiden, Germany). After the gum resin dried, the excess apical resin was trimmed with a lancet to produce a uniform thickness of gum resin of approximately 0.25 mm that simulated the periodontal membrane. The teeth were then embedded in self-curing acrylic blocks in a vertical orientation to a level of 2 mm below the CEJ (Self-curing liquid and powder Major.Ortho, Major Prodotti Dentari S.p.A., Moncalieri, Italy).

Class II mesial and distal box-only cavities were created on each tooth using a round tungsten-carbide bur (No. 1, HM 1010, Meisinger, Neuss, Germany) to gain access through the enamel, and a cylindrical diamond abrasive with a flat end (No. 835012, Meisinger) was used to complete the preparation. New burs and abrasives were used after the creation of every five cavities. The preparations were performed using high-speed ranges under abundant air-water coolant.

The cavities were prepared with standardized dimensions such that the buccolingual dimension was 4 mm. Measurements were taken with digital calipers (Digital Vernier Caliper, Clarke International, Essex, England) with an accuracy of 0.01 mm, and a pencil was used to mark the outline. On each tooth, the gingival margin of the cavity was positioned 1 mm above the CEJ on the proximal side and 1 mm below the CEJ on the other side, and the axial pulpal depth was 1.5 mm as measured at the gingival wall using a graduated periodontal probe (1011 Duralite ColorRings, Nordent Manufacturing Inc, Elk Grove Village, IL, USA). All cavity margins were butt joint to deliver comparable results with previous experiments.[15]

The 84 samples were randomly divided into six study groups according to the resin composite restoration used. Each group was then subdivided into two subgroups according to whether a self-etch (se) or a total-etch (te) adhesive system was used. For comparison purposes, an extra group of seven teeth (group 7) was added and restored with a low-shrinkage silorane-based composite with its corresponding self-etch adhesive system. All study materials are listed in Table 1, and the study variables are shown in Figure 1.

A metallic matrix band tied to a universal matrix retainer (Tofflemire Retainer-Universal, Dentsply, Mount Waverley, Australia) was applied to each tooth so that the cervical end of the band extended beyond the gingival cavity margin. The matrix was tightened and the band was finger supported at its cervical end against the tooth surface to avoid an undue pressure of the fingertip. This was done to prevent the creation of gross marginal discrepancies during material insertion and curing that might compromise the results.

All study materials were used according to the manufacturers' instructions. A high-intensity output light curing unit (Ortholux Luminous Curing Light, 3M Unitek, Monrovia, CA, USA) was used to provide maximum conversion of the test resin composite restorative materials and adhesives upon curing. Each restorative material increment was light-cured for 20 seconds, and the adhesives were light-cured for 10 seconds from an occlusal direction. The Ortholux Luminous Curing Light is a fast-curing cordless light-emitting diode (LED) light with an output energy of 1600 mW/cm^2 (independent of the battery power level) that provides a wavelength of

Table 1: *Materials Used in the Study*

Material	Manufacturer	Lot No.	Description
Tetric Ceram HB	Ivoclar Vivadent, Schaan, Liechtenstein	N03283	Light-cured fine-particle microhybrid material based on a moldable ceramic
Tetric EvoFlow	Ivoclar Vivadent, Schaan, Liechtenstein	R36640	Incremental light-cured, flowable, microhybrid composite
SDR Smart Dentin Replacement	Dentsply, Milford, DE, USA	1011002185	Bulk-fill flowable composite base material that allows the curing of layers up to 4-mm thick
SonicFill Composite	Kerr, Orange, CA, USA	4252654	Bulk-fill low-shrinkage composite that allows the curing of layers up to 5-mm thick and uses sonic energy during insertion
Tetric N-Ceram Bulk Fill	Ivoclar Vivadent, Schaan, Liechtenstein	R65898	Bulk-fill resin composite material that allows the curing of 4-mm-thick layers
Tetric EvoCeram Bulk Fill	Ivoclar Vivadent, Schaan, Liechtenstein	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, Seefeld, Germany	N 281586	Low-shrink silorane-based resin composite material
Tetric N-Bond Self-Etch	Ivoclar Vivadent, Schaan, Liechtenstein	P48222	Light-cured, one-step all-in-one self-adhesive
Tetric N-Bond	Ivoclar Vivadent, Schaan, Liechtenstein	R52704	Light-cured primer and adhesive, total-etch adhesive
AdheSE	Ivoclar Vivadent, Schaan, Liechtenstein	69346	Two bottle self-etch adhesive primer and bond
ExciTE F	Ivoclar Vivadent, Schaan, Liechtenstein	R50336	Primer and adhesive, total-etch adhesive
P90 System Adhesive, Self-Etch Primer & Bond	3M ESPE, Seefeld, Germany	N 281586	Two bottle self-etch primer and bond
Fine Etch, etchant	Spident, Incheon, Korea	FE1242	37% phosphoric acid gel

430–480 nm and a peak of 455 ± 10 nm. The details of the bonding procedures are presented in Table 2.

In groups 1–5, Tetric N-Bond Self-Etch adhesive (Ivoclar Vivadent, Schaan, Liechtenstein) was used for the se-subgroups, and Tetric N-Bond (Ivoclar Vivadent), a total-etch adhesive, was used in the te-subgroups. After the bonding procedure, the composite restorations were inserted according to the assigned study groups.

In group 1, Tetric Ceram HB (TC) resin composite (Ivoclar Vivadent) was inserted in horizontal increments of approximately 2-mm thickness each using a metallic plastic instrument (stainless steel, G. Hartzell & Son, Concord, CA, USA). Each increment was light-cured for 20 seconds before inserting the next increment until the cavity was completely filled. Before curing the most superficial increment, the plastic instrument was used to provide the proper occlusal anatomic form, then light-cured for 20 seconds.

In group 2, the open-sandwich technique was used, and Tetric EvoFlow (EF) (Ivoclar Vivadent) was used in a horizontal increment as a base of

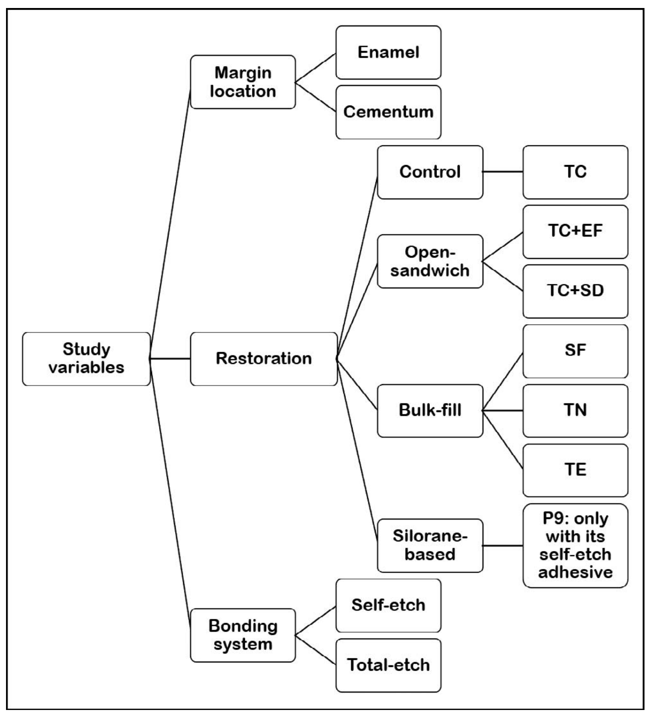

Figure 1. *Overview of the study variables.*

Table 2: *Summary of the Bonding Procedures*

Bonding System	Material 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 Smart Dentin Replacement SonicFill restorations Tetric N-Ceram Bulk Fill	Cavity was water-washed and air-dried after preparation, 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 Tetric N-Bond Self-Etch was dispersed with a strong stream of air 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 Smart Dentin Replacement SonicFill restorations Tetric N-Ceram Bulk Fill	Cavity was water-washed and air-dried after preparation, etched for 15 s, and washed with vigorous water spray. Excess moisture was removed. Thick layers of Tetric N-Bond 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	Cavity was water-washed and air-dried after preparation. One drop of primer and one drop of adhesive were dispensed individually. Primer was applied to the enamel and dentin for 30 s with a microbrush. Adhesive was applied with a microbrush and air dispersed with a strong air stream and light-cured for 10 s.
Excite F (total-etch)	Tetric EvoCeram Bulk Fill	Cavity was water-washed and air-dried after preparation, etched for 15 s, and washed with vigorous water spray. Excess moisture was removed. Thick layers of Excite-F bond were applied to the enamel and dentin using an application brush. Excess adhesive was dispersed with a strong stream of 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 applied to the enamel and dentin and massaged into the entire surface for 15 s. A gentle stream of air was applied until the primer was spread into an even film. The primer was light-cured for 10 s, then the adhesive was applied to the entire area of the cavity and a gentle stream of air was applied until the bond was spread into an even film, then light-cured for 10 s.

approximately 2 mm under the Tetric Ceram HB (Ivoclar Vivadent) (TC + EF), followed by light-curing for 20 seconds. TC was then incrementally inserted until the cavity was completely filled in a manner similar to group 1.

In group 3, the open-sandwich technique was used with SDR Smart Dentin Replacement (SDR) bulk-fill flowable resin composite (Dentsply International, Milford, DE, USA) as a base under TC (TC + SDR). A compule tip gun was used to eject the SDR into the cavity to form a base of approximately 4-mm thickness before light-curing for 20 seconds. The rest of the cavity was then incrementally filled with TC.

In group 4, SonicFill (SF), a Sonic-Activated Bulk Fill Composite System (Kerr, Orange, CA, USA) was applied using the SonicFill Handpiece (Kavo, Biberach, Germany). The handpiece was used to automatically dispense rheologically matched filling materials contained in SonicFill Unidose tips into the cavity via the action of sound and pressure. The SonicFill Handpiece works at a frequency of 5–6 kHz and was connected to the turbine hose of the dental unit through a multi-flex coupling device. The material was inserted in a first bolus of approximately 5-mm thickness and light-cured from the occlusal direction for 20 seconds. A second, thinner horizontal increment was then inserted to completely fill the cavity and was light-cured for 20 seconds after reestablishing the occlusal anatomic features as mentioned previously.

In group 5, Tetric N-Ceram Bulk Fill (TN) was used (Ivoclar Vivadent). An increment of approximately 4-mm thickness was inserted into the cavity using a plastic instrument (G. Hartzell & Son) and light-cured from the occlusal direction for 20 seconds. A second increment of TN was inserted until the cavity was completely filled, anatomically contoured, and light-cured from the occlusal direction.

In group 6, Tetric EvoCeram Bulk Fill (TE) was used (Ivoclar Vivadent) in a manner similar to that used for group 5. However, AdheSE (Ivoclar Vivadent), a self-etch adhesive, or Excite F (Ivoclar Vivadent), a total-etch adhesive, were used in this group following the recommendations of the manufacturer.

In group 7, Filtek P90 (P90), a silorane-based composite (3M ESPE, Seefeld, Germany) was applied using a plastic instrument in increments of approximately 2.5-mm thickness. Each increment was light-cured for 20 seconds. Before the light-curing of the last increment, the occlusal anatomic features were reestablished. Only the P90 System Adhesive, a self-etch adhesive, was used in this group following the instructions of the manufacturer.

After the restorations were completed, a surgical scalpel blade (No. 15, Swann-Morton, Sheffield, England) was used to remove the gross marginal overhangs. Finishing and polishing were performed with 13-mm Sof-Lex XT discs (Sof-Lex XT Finishing and Polishing System, 3M ESPE, St. Paul, MN, USA) beginning with the coarser grit disc and ending with the superfine grit. The discs were mounted on a Sof-Lex finishing and polishing disc mandrel and were used at a slow speed range under abundant air-water spray.

All samples were exposed to artificial aging via thermal and occlusal load-cycling. The test specimens were placed in mesh bags and subjected to thermocycling for 5000 cycles in water baths between 5 ± 2°C and 55 ± 2°C with a dwell time of 30 seconds in each bath and a transfer time of 15 seconds between baths (Thermocycling machine, Proto-Tech, El Segundo, CA, USA). The specimens were then submitted to intermittent vertical occlusal loads between 25 and 100 N at 20 cycles/minute (20 HZ) for 1000 cycles using the chewing simulator CS4.2 (SD Mechatronik GmbH, Westernham, Germany) with a round-end piston that was 5 mm in diameter and touching the tooth and restorations at the buccal and lingual internal cuspal inclines.

After aging, a sawing machine (Isomet 5000 Linear precision saw, Buehler Ltd, Lake Bluff, IL, USA) was used at the lowest blade speed with water lubrication to section the teeth. Each tooth was serially sectioned longitudinally approximately 3–4 mm short of the acrylic block base in the mesiodistal direction to produce slabs that were approximately 0.8-mm thick and that contained restorations. An additional buccolingual longitudinal cut was made in the center of the tooth next to the axial walls of the restorations to approximately 1 mm short of the end of the acrylic block. After machine sawing, the samples were hand-split into two longitudinal proximal halves. The rods containing the restorations in both halves were cut apically short of the root apices using a needle-shaped diamond abrasive at high speed with an abundant air-water spray. Before, during, and after the cutting procedure, the rods with restorations at the gingival margins in the enamel were identified and separated from those with gingival cementum margins using a magnifying lens. Two microrods per restoration (n = 14/group) were tested for MTBS, and one microrod of each restoration (n = 7/group) was used to assess the cervical IGD under a scanning electron microscope (SEM) (×1200). The details of the work flow are shown in Figure 2.

MTBS

During the MTBS testing, each microrod was measured at the bonding interface in the buccolingual direction using a digital caliper (Clarke International). Each microrod was then fixed to a modified microtensile testing device (ie, an attachment jig) that allowed for loading in the vertical direction. Two layers of bonding agent (Tetric N-Bond) were applied to the two sides of the testing device, the microrod was longitudinally seated in line with the testing load direction, and the bonding agent was light-cured. A flowable composite was applied to each end of the microrod and light-cured to ensure strong rod-fixing. After that, an hourglass shape was produced at the bonded interface in the mesiodistal direction using a needle diamond abrasive in the high-speed range under abundant air-water coolant. The mesiodistal side of the microbar was measured using a digital caliper to the nearest 0.01 mm. The surface area of the bonded interface of each rod was calculated. The samples were subjected to microtensile testing at a crosshead speed of 0.5 mm/min using a universal testing machine (Instron 8871 Universal Testing Machine, Instron, Shakopee, MN, USA). The fracture loads were obtained in newtons and divided by the surface areas of bonding, thereby obtaining microtensile bond strength values in megapascals. Immediately after testing, all samples were examined under a stereomicroscope (Stereozoom 250 Microscope, Luxo Microscopes, Elmsford, NY, USA) at ×40 magnification to determine the failure mode. The failure modes were categorized as follows:

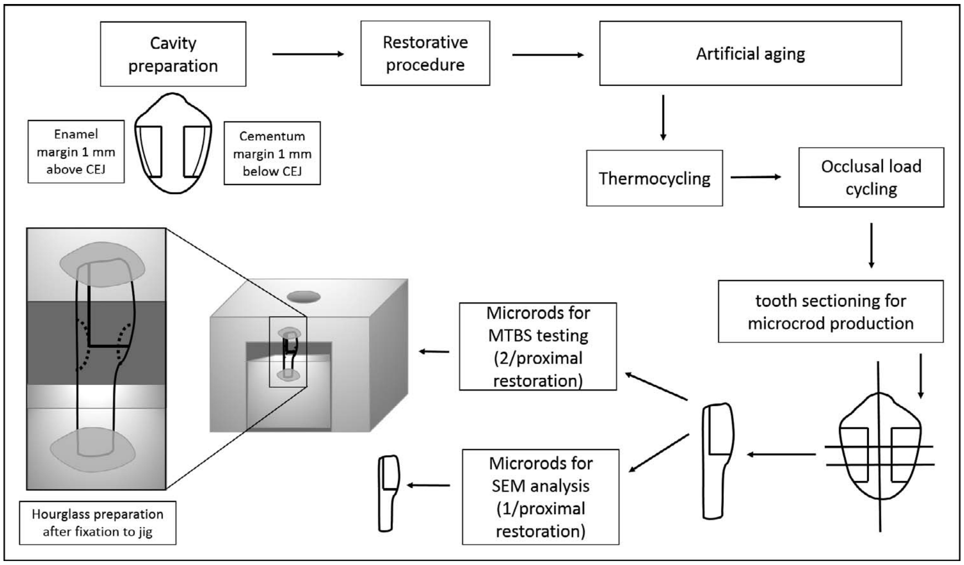

Figure 2. *Work flow of the microrod prepration for microtensile bond strength and intercial gap distance testing.*

a. Adhesive failure along the tooth/restoration interface
b. Cohesive failure in the resin involving the resin composite material and/or the bonding layers
c. Cohesive failure of the tooth
d. Mixed failure involving adhesive fracture and cohesive fracture in the composite with or without fracture in the tooth.

SEM examinations (×500) were performed on two of the failed microrods from each study group.

All data analysis for MTBS was conducted using R 3.0.2.[20] MTBS values were subjected to the Shapiro-Wilk confidence test, which proved that data were not normally distributed. Therefore, comparisons between groups for differences in MTBS were performed using a nonparametric Kruskal-Wallis test followed by a Conover-Inman post hoc test for pairwise comparisons. In addition, a Bonferroni correction was applied to correct for multiple comparisons. Differences with p values <0.05 were considered significant. All pretest failures were recorded as zero but were not included for the statistical analysis. For the statistical testing, only one out of two microrods per restoration was randomly chosen to avoid considering microrods from the same restoration as independent samples as proposed by Eckert and Platt.[21] Statistical analyses with randomly chosen

Table 3: Mean MTBS values, SD, minimum, maximum, and medians

Group	MTBS Values (MPa) at Enamel Margin						MTBS Values (MPa) at Cementum Margin					
	N	Mean	SD	Min	Max	Median	N	Mean	SD	Min	Max	Median
TC/se	14	14.7	4.1	6.8	20.4	14.8	12	7.6	4.0	2.2	17.4	7.0
TC/te	14	15.8	3.6	9.6	22.4	17.1	13	7.6	2.7	3.2	11.8	7.9
TC+EF/se	13	18.9	4.2	8.0	24.4	19.6	12	9.5	3.5	3.7	13.8	10.2
TC+EF/te	13	20.5	6.5	12.8	37.8	20.4	13	12.6	3.9	8.6	22.7	11.5
TC+SDR/se	14	13.8	4.3	1.9	18.0	15.0	12	12.7	8.6	3.7	38.5	10.5
TC+SDR/te	14	24.2	9.5	12.0	48.4	25.1	13	23.2	15.4	5.4	57.9	21.7
SF/se	14	13.1	2.0	10.8	18.0	12.4	13	10.8	3.6	5.8	18.5	11.2
SF/te	14	23.8	5.2	17.1	34.7	23.4	13	14.0	2.1	10.3	17.1	13.2
TN/se	13	16.2	8.2	3.3	37.0	16.8	13	7.6	3.8	1.6	13.2	6.4
TN/te	14	15.9	8.5	5.6	35.0	15.1	12	9.6	4.9	3.5	18.6	10.0
TE/se	12	13.6	5.7	6.1	21.3	13.9	12	9.4	3.6	5.1	16.4	8.6
TE/te	12	12.0	5.6	2.6	19.4	13.0	12	8.6	2.2	6.2	12.2	7.8
P90/se	14	23.6	4.1	12.5	28.0	24.6	13	18.6	7.9	9.1	32.2	17.3

Abbreviations: EF, Tetric EvoFlow; Max, maximum; Min, minimum; MTBS, microtensile bond strength; P90, Filtek P90 Low Shrink Restorative; SD, standard deviation; SDR, SDR Smart Dentin Replacement; se, self-etch; SF, SonicFill; TC, Tetric Ceram HB; te, total-etch; TE, Tetric EvoCeram Bulk Fill; TN, Tetric N-Ceram Bulk Fill.

Table 4: *Significantly Different Groups With* p<*0.05 in More Than 80% of Statistical Comparisons of Randomly Chosen Microrods (One Microrod per Restoration)*

Significantly Different Groups (>80% With *p*<0.05)		
P9/se/enamel	vs	SF/se/cementum
P9/se/enamel	vs	TC+EF/se/cementum
P9/se/enamel	vs	TC/se/cementum
P9/se/enamel	vs	TC/te/cementum
P9/se/enamel	vs	TE/se/cementum
P9/se/enamel	vs	TE/te/cementum
P9/se/enamel	vs	TN/se/cementum
P9/se/enamel	vs	TN/te/cementum
SF/te/enamel	vs	SF/se/cementum
SF/te/enamel	vs	TC+EF/se/cementum
SF/te/enamel	vs	TC/se/cementum
SF/te/enamel	vs	TC/te/cementum
SF/te/enamel	vs	TE/se/cementum
SF/te/enamel	vs	TE/te/cementum
SF/te/enamel	vs	TN/se/cementum
SF/te/enamel	vs	TN/te/cementum
TC/EF/se/enamel	vs	TC/se/cementum
TC+EF/se/enamel	vs	TC/te/cementum
TC+EF/te/enamel	vs	TN/se/cementum
TC+EF/te/enamel	vs	TC/se/cementum
TC+EF/te/enamel	vs	TC/te/cementum
TC+EF/te/enamel	vs	TE/te/cementum
TC+EF/te/enamel	vs	TN/se/cementum
TC+SD/te/cementum	vs	TC/te/cementum
TC+SD/te/enamel	vs	TC/se/cementum
TC+SD/te/enamel	vs	TC/te/cementum
TC+SD/te/enamel	vs	TE/se/cementum
TC+SD/te/enamel	vs	TE/te/cementum
TC+SD/te/enamel	vs	TN/se/cementum
TC+SD/te/enamel	vs	TN/te/cementum

Abbreviations: EF, Tetric EvoFlow; MTBS, microtensile bond strength; P90, Filtek P90 Low Shrink Restorative; SDR, SDR Smart Dentin Replacement; se, self-etch; SF, SonicFill; TC, Tetric Ceram HB; te, total-etch; TE, Tetric EvoCeram Bulk Fill; TN, Tetric N-Ceram Bulk Fill.

samples were repeated 10,000 times. Groups were considered significantly different when more than 80% of the repetitions showed p values <0.05.

IGD

To study the cervical interfacial micromorphology, one microrod from each restoration (n=7/group) was randomly selected and processed for SEM examination of the cervical interfaces (×1200) in a manner similar to the technique used by Duarte and others.[22] The widest interfacial gap in each specimen was measured and recorded in microns.[22] Statistical analysis was performed using the Kruskal-Wallis nonparametric test and post hoc Mann-Whitney U test in IBM SPSS Statistics 21 (IBM Corporation, Armonk, NY, USA).

RESULTS

MTBS

Table 3 shows the mean MTBS values, standard deviations, minimum, maximum, and median of the samples in each group. Table 4 shows significantly different groups with $p<0.05$ in more than 80% of comparisons. In all study groups, the mean MTBS values were higher at the enamel than at the cementum margins, but there was no statistical significance. At the enamel margins, the highest mean MTBS values were 24.2 ± 9.5 MPa for TC+SDR/te, 23.8 ± 5.2 MPa for SF/te and 23.6 ± 4.1 MPa for P90/se. At the cementum margins, the highest values were 23.2 ± 16.1 MPa for TC+SDR/te, 18.6 ± 7.9 MPa for P90/se, and 14.0 ± 2.1 MPa for SF/te; the lowest values at the cementum margins were 7.6 ± 4.0 MPa for TC/se, 7.6 ± 2.7 MPa for TC/te, and 7.6 ± 3.8 MPa for TN/se. All test restorations, with the exception of the TE, exhibited better mean bond strength values when tested with the total-etch rather than the self-etch bonding approach. TC+SDR/te at the enamel and cementum exhibited significantly higher MTBS values than control group TC/te and TC/se at cementum margins ($p<0.05$).

Similarly, SF/te at enamel margins exhibited significantly better mean values than the control group TC/te and TC/se at cementum margins ($p<0.05$). Furthermore, P90 exhibited significantly higher values than the control group TC/te and TC/se at cementum margins ($p<0.05$).

In contrast, TN and TE and TC+EF/se and TC+EF/te exhibited MTBS values that were not significantly different from those of the control group TC/te and TC/se ($p>0.05$) at enamel and cementum. However, at the enamel margins, TC+EF/te exhibited a significantly higher value than the control group TC at cementum.

Study of the failure modes of the failed ends of the microrods revealed that they were either mixed, adhesive, or cohesive failures in the resin composites. No cohesive failures in the tooth structures were observed in any of the tested samples. Most of the failures were mixed fractures. No cohesive failures in the resin were observed in TC+EF/se,

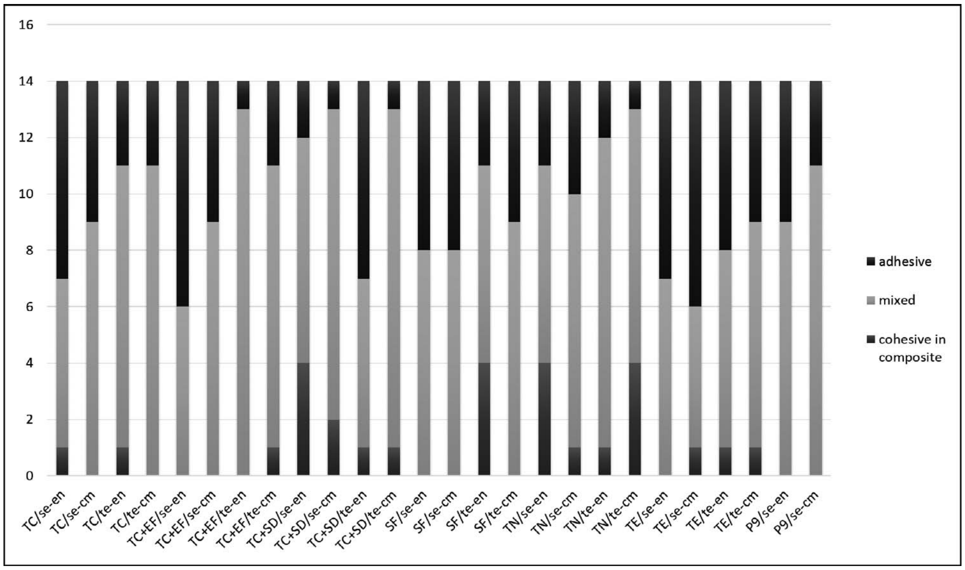

Figure 3. *Graph of the adhesive, mixed, and cohesive failure modes of microrods upon microtensile bond strength testing.*

SF/se, or P90, regardless of cervical margin location (Figures 3 and 4).

IGD

SEM examination of the cervical interfaces of the restorations revealed different areas of perfect cervical interfacial bonding zones and gaps that varied with the different restoration and bonding techniques. Table 5 presents the mean IGD and standard deviations of the different study groups. Figure 5 illustrates the statistically significant ($p<0.05$) difference in interfacial gap distances between P90 at the enamel and cementum margins and the control group TC/se at the cementum margins. The bulk-fill composites did not significantly improve the adaptations compared with the control group TC ($p>0.05$; Table 5).

DISCUSSION

In vitro testing of the effectiveness of interfacial tooth restoration bonds has long been performed in marginal sealing and MTBS studies to predict the clinical reliability of these bonds. Artificial aging via immersion in different media for different periods and thermal and occlusal load cycling has been used to mimic oral environmental conditions.[7,11,12,23,24]

In this study, the samples were tested for MTBS after thermal and load cycling because our pilot study and previous reports indicated that the results of immediate testing of restorations are less signif-

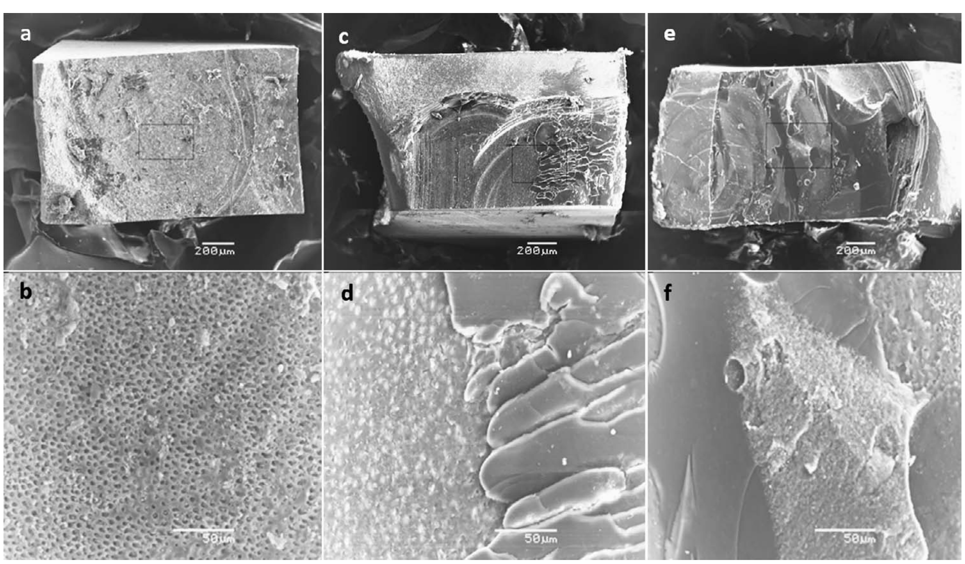

Figure 4. *Scanning electron microscope images (×40; x500) of the different failure modes: adhesive failure (a, b), mixed failure (c, d), and cohesive failure (e, f).*

Table 5: Mean Values of the Interfacial Gap Distances and Standard Deviation (SD)

Group	Mean Gap Distance at Enamel Margin (μm)[a]	SD	Mean Gap Distance at Cementum Margin (μm) [a]	SD
TC/se	7.3[b]	5.6	15.5[a]	8.4
TC/te	3.4[b]	4.3	9.5	6.7
TC+EF/se	9.1	6.1	16.3[a]	5.0
TC+EF/te	6.1[b]	4.3	13.4	7.0
TC+SD/se	8.8	6.9	12.6	6.2
TC+SD/te	6.4[b]	4.7	8.4	6.7
SF/se	6.9[b]	6.5	11.4	5.2
SF/te	6.8[b]	6.1	14.0	5.2
TN/se	8.7	7.8	18.4[a]	2.8
TN/te	6.7[b]	5.9	14.4	5.8
TE/se	6.8[b]	5.3	14.6	7.3
TE/te	9.9	4.6	14.9	5.7
P9/se	2.5[b]	2.9	7.7[y]	3.8

Abbreviations: EF, Tetric EvoFlow; MTBS, microtensile bond strength; P90, Filtek P90 Low Shrink Restorative; SD, standard deviation; SDR, SDR Smart Dentin Replacement; se, self-etch; SF, SonicFill; TC, Tetric Ceram HB; te, total-etch; TE, Tetric EvoCeram Bulk Fill; TN, Tetric N-Ceram Bulk Fill.
[a] Different letters indicate significant difference ($p<0.05$).

icant.[25] Bulk-fill resin composites that have been reported to exhibit reduced polymerization contraction stress were tested.[14-19]

Maxillary premolars with proximal box-only preparations were used to simulate cuspal deflections with challenging interfacial stresses on occlusal cyclic loading.[26] The testing of Class II box-only restorations provides higher C-factors that lead to greater polymerization contraction stresses compared with bonding to flat dentin surfaces.[27-30] High-intensity LED curing (1600 mW/cm^2) was used to rapidly provide a high degree of conversion to increase the challenging polymerization contraction stresses.[18,31-34] Therefore, the specimens were confronted with challenges of rapid intense contraction and thermal and occlusal load fluctuation stresses.

In this study, the modified testing device (ie, an attachment jig) used by El Zohairy and others[35] was

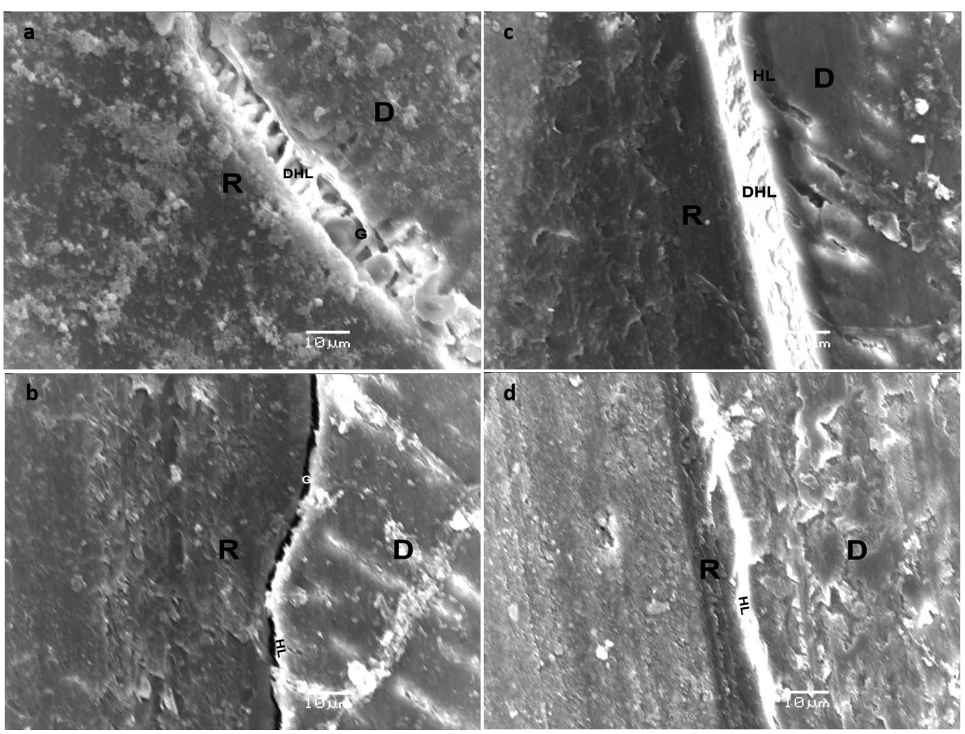

Figure 5. *Scanning electron microscope images (×1200) of the interfacial gap distance (IGD): interfacial gap in TC/te at the cementum margin (a), in TC+EF/se at the cementum margin (b), in TC+SDR at the cementum margin (c) and in P90/se at the enamel margin (d). Abbreviations: D, dentin; DHL, disrupted hybrid layer; EF, Tetric EvoFlow; G, gap; HL, hybrid layer; P90, Filtek P90 Low Shrink Restorative; R, resin; SDR, SDR Smart Dentin Replacement; se, self-etch; TC, Tetric Ceram HB; te, total-etch.*

used for MTBS testing. The microrod production and hourglass shape preparations were the least traumatic and minimized pretest failures. The numbers of microrods that have been used in MTBS vary widely between studies.[12,23,27,28] In the current MTBS testing, two microrods were used in each restoration, and 14 microrods per group were tested in either the enamel or cementum margins. For the evaluation of MTBS values, only one out of two microrods was randomly chosen for multiple comparisons to avoid treating microrods obtained from the same restoration as independent samples as recommended by Eckert and Platt.[21] For this reason, the number of samples considered at each comparison was restricted to seven, which constitutes a limitation of the current study.

All pretest failures were recorded and given a value of zero megapascals but were not included in the multiple statistical analyses, which is similar to the approach of Takahashi and others,[25] who recorded all pretest failures but did not include any in their statistical analyses. They used the freehand technique to prepare hourglass shapes; this technique can be traumatic and increase the pretest failures. However, this trauma was avoided in the preparation of our microrods.[21]

MTBS studies have been reported to effectively and reliably discriminate between adhesive bonding systems. Additionally, MTBS studies have also stated correlations between retention and many influencing factors, such as the diameter of the stick, the type of testing device, trimming into an hourglass shape, the handling of pretest failures, and the artificial aging technique.[11,21] The lack of adequate consistency between MTBS studies and the desire to clearly understand the correlation between a particular bond strength test and clinical performance have prompted recommendations to clarify the specimen fabrication details.[21,36-39] In the current study, microrods were trimmed into hourglass shapes before MTBS testing to concentrate the stresses at the sites of bonding and to correlate failures to bonding interfaces with fewer incidences of cohesive failures, although this practice may have generated stress concentrations and increased pretest failures.[39]

The higher MTBS values at the enamel margins compared with the cementum margins found in all study groups were not significant, regardless of the bonding technique. This can be explained by similarity in effectiveness of the adhesives/restorations used at both enamel and cementum margins. This is contrary to the reports that the cementum at the outer part of the interface and the orientation of the dentinal tubules in the deep proximal cavities might interfere with proper micromechanical interlocking and effective hybridization.[11]

Takahashi and others[25] studied MTBS in Class II restorations in molars that were restored after thermo-load cycling using Scotchbond Multipurpose, Adper Scotchbond1, Clearfil SE, and Clearfil Tri-S and incrementally placed resin composite Clearfil AP-X at the enamel and dentin margins. They found statistically significant differences among all groups at the enamel and dentin margins.[25] The differences in the materials and test protocol might explain the variations in the results between studies.

Findings in this study showed that EF liner did not significantly improve MTBS and that SDR combined with total-etch bonding produced an MTBS that was significantly higher than that of the control group TC regardless of margin location or bonding approach. This is in agreement with previous findings that confirmed that the effects of flowable liners on MTBS are specific to the material and the bonding system.[27,28,40,41]

Our results did not confirm that the use of total-etch bonding produced significantly higher MTBS values than those achieved by self-etch bonding in all comparisons. Although in terms of stability and degradation resistance, the total-etch bonding technique has been reported to produce more reliable resin-dentin hybrid layers than self-etch adhesives, particularly at the enamel margin,[2,7,11,24,28] reliability also seems to be affected by the performance of the specific adhesive bonding/restorative material.

SDR is a bulk-fill base with a modified methacrylate resin (a polymerization modulator), a slow polymerization rate, and a filler loading of 68 wt% that produces significantly lower polymerization contraction stresses than those produced by conventional flowable composites.[14,15] Therefore, combining the benefits of SDR with the superior performance of total-etch bonding may have provided the best resistance to challenging stresses, which would explain the results.

Similarly, the superior performance of SF/te at the enamel margins can be explained by the combination of the benefits of total-etching and the heavily filled (83.5 wt%) material with the reduced polymerization contraction (1.6%) and contraction stresses.[19]

The use of the P90 with its corresponding adhesive system provided the second-highest MTBS results, compared with the control group TC, at the cementum regardless of the bonding approach. This finding may be related to the low contraction stresses of this low-shrinkage silorane-based material[42,43] and is probably related to a superior resistance of this material to thermo-load cycling relative to that of methacrylate-based composites. It has been reported that the reduced polymerization shrinkage of silorane composite results in significantly less stress at the bonding interface and reduces the need for a very strong adhesive.[42-44]

Interfacial gap distance measurements of microrods have been previously performed. Duarte and others[22] used 1-mm thick slices obtained by sectioning restored human third molar teeth for SEM assessment of the interfacial gap distances in class V restorations. Heintze[12] also reported this method. Loguercio and others[45] used 0.8 mm^2 cross-sectional area sticks of resin composite bonded to dentin to measure interfacial gaps (×400) using light microscopy.

Results of the interfacial gap distance measurements were in agreement with MTBS results, where better results were obtained by P90 at both enamel and cementum margins. At enamel margins, IGD did not significantly differ from the control TC, from TC+SDR/te, or from SF. On the contrary, at cementum margins, P90 did differ significantly from all other study groups and showed the least gaps.

Variations in cervical micromorphologic patterns related to the presence of gaps and differential appearances of resin-dentin interdiffusion along the respective cervical interfaces of the test restorations confirm the multifactorial nature of adhesive joint effectiveness, degradation, and debonding.[1-3,7] The effectiveness of the adaptation of the silorane-based composite has previously been reported in other studies.[45] The reduced shrinkage silorane-based resins and improved resistance to bonding degradation of the Filtek P90 System Adhesive explain the significantly better adaptation at the enamel and cementum margins relative to the control group TC at the cementum margin.

Although the null hypothesis that bulk-fill resin composites do not significantly affect MTBS can partially be rejected based on the results of the current study, the results also confirm that the use of these resins does not affect the cervical interfacial gaps.

CONCLUSIONS

The following conclusions can be made based on comparisons to the incrementally applied control group TC. In the open-sandwich restorations, the use of SDR with the total-etch approach significantly improved the MTBS values, whereas the conventional flowable composite EF did not. SF with total-etch and P90 at enamel significantly improved MTBS relative to TC at cementum, whereas TN and TE did not. The cervical interfacial adaptation of P90 at both enamel and cementum margins was significantly better than that of TC at the cementum margins when bonded by the self-etch approach.

When cervical margins of Class II cavities are inevitably located in cementum, bulk-fill and silorane based restorations might be preferable. When possible, restorations should be bonded using a total-etch approach.

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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 the University of Dammam institutional review board. The approval code for this study is 110/2012.

Conflict of Interest

The authors of this manuscript certify that they 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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