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Effects of Total and Selective Bonding on Marginal Adaptation and Microleakage of Class I Resin Composite Restorations *In Vitro*

PR Schmidlin • T Huber
TN Göhring • T Attin • A Bindl

Clinical Relevance

Within the limitations of the current study, the use of glass ionomer liners improves the margin quality of Class I resin composite restorations and reduces leakage.

*Patrick R Schmidlin, PD Dr med dent, senior research associate, Department of Preventive Dentistry, Periodontology and Cariology, Center for Dental Medicine, University of Zürich, Zürich, Switzerland

Thomas Huber, med dent, doctorand, Department of Preventive Dentistry, Periodontology and Cariology, Center for Dental Medicine, University of Zürich, Zürich, Switzerland

Till N Göhring, PD Dr med denta, senior research associate, Department of Preventive Dentistry, Periodontology and Cariology, Center for Dental Medicine, University of Zürich, Zürich, Switzerland

Thomas Attin, Prof Dr med dent, Department of Preventive Dentistry, Periodontology and Cariology, Center for Dental Medicine, University of Zürich, Zürich, Switzerland

Andreas Bindl, PD Dr med dent, senior research associate, Department of Preventive Dentistry, Periodontology and Cariology, Center for Dental Medicine, University of Zürich, Zürich, Switzerland

*Reprint request: Plattenstrasse 11, CH 8032, Zürich, Switzerland; e-mail: patrick.schmidlin@zzmk.uzh.ch

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SUMMARY

This study assessed the marginal integrity and microleakage of standardized Class I resin composite restorations when placed with either "total" or "selective bonding" techniques.

Sixty standardized Class I cavities comprising the main fissure system were prepared (9 mm length and 7 mm width). Cavity depth was set at 2.5 mm. In cavities where a glass ionomer liner was placed, the cavity was deepened by an additional 0.5 mm. In "total bonding" specimens, enamel and dentin were conditioned using a four-step adhesive system (Syntac Classic). In teeth with "selective bonding," a chemical curing conventional glass ionomer cement (GIC; Ketac Fil) and light-curing resin-modified glass ionomer liner (RMGI; Vitrebond) or three-step adhesive bonding liner (Syntac) were applied. The cavity margins of the latter specimens were finished with water-spray, acid-etched and a bonding agent was applied. All restorations were

placed in two oblique increments. Totally bonded ceramic inlays (Cerec) served as the control. All specimens were subjected to thermo-mechanical loading (1.2 Mio cycles) and marginal quality and microleakage were assessed.

The highest percentage of margins rated as "perfect" was found in selective bonding samples with glass ionomer liners and totally bonded inlay restorations. All the other groups showed significantly decreased marginal quality (*p*<0.05). The same results were found for the microleakage assessment.

The authors of the current study concluded that the application of a GIC liner significantly improved the overall marginal adaptation of direct Class I restorations. The use of an adhesive bonding agent for cavity sealing as currently used is not recommended.

INTRODUCTION

Marginal integrity is crucial for the predictable, long-term clinical results of adhesively placed direct restorations.[1] A major problem for these restorations is polymerization shrinkage, which may initiate failure of the composite–tooth interface, resulting in interfacial gaps.[2-3] Hampered marginal quality can lead to microleakage, postoperative sensitivity, marginal discoloration and secondary caries.[4] The stress generated during polymerization of the resin composite restorations is influenced by several factors related to material, technique, cavity preparation and their respective interactions.[5] Thus, strategic changes in material selection and technical procedures to reduce stress may directly influence the quality of adhesively bonded restorations.

For the "total bonding" concept, the finishing line and the entire cavity's inner surface are conditioned with phosphoric acid and/or an acidic primer and covered with the adhesive. The restoration material is usually incrementally placed and polymerized onto it. The adhesive layer is usually sufficiently thick to absorb polymerization shrinkage stresses.[6] In general, by carefully curing the increments of composites inside a low configuration factor cavity, the clinician can maintain stresses at a low level using this technique.[7]

When the configuration factor is higher (for example, in Class I or retentively prepared Class V cavities), shrinkage stresses increase polymerization stresses, which puts the marginal integrity of the restoration at risk. Under such conditions, use of the "selective bonding" concept, where restorations are bonded to the cavity margins only, may be indicated.[8] With this approach, the surfaces that compensate for the volumetric shrinkage of the restorative material are: a) the occlusal surface and b) the inner unbonded surface of the restoration.

Among these two approaches, the use of a conventional or resin-modified glass ionomer cement to line the cavity floor has been recommended. This primarily reduces the volume of the resin composite material. In addition, the liner claims to act as a stress-absorbing layer between the shrinking composite and the dentin, and it reduces polymerization contraction stresses at the cavity finishing lines by increasing the free composite surfaces.[9-12] However, comparative data assessing different materials and strategies under standardized conditions are still scarce.

It was the aim of the current study to evaluate the restoration margin quality and microleakage of different bonding procedures in standardized Class I restorations. The following techniques and materials were used:

- "*Total bonding*" using a three-step adhesive system and a resin composite or a ceramic inlay (control) that was luted with the same resin composite material.
- "*Selective bonding*" using either a light or a chemical cured glass-ionomer liner and a resin composite to reduce the ratio of bonded to unbonded surface.
- In a *cavity sealing* approach, which also aims to reduce the bonded surface, the dentinal cavity areas were sealed with a three-step adhesive system, and the enamel margins were consecutively finished under water spray.

The null hypothesis tested is that there is no difference in terms of marginal quality and microleakage when comparing the different materials and techniques applied.

METHODS AND MATERIALS

Tooth Selection, Cavity Preparation and Restoration Procedure

Human molars free of decay, stored in 0.1 mol/L thymol solution, were mounted centrally to roughened specimen carriers (SEM mounts, Baltec AG, Balzers, Liechtenstein) with superglue (Renfert Sekundenkleber Nr 1733, Dentex AG, Zürich, Switzerland) and embedded with chemically-curing acrylic resin (Paladur, Heraeus Kulzer GmbH, Wehrheim, Germany). Dentin fluid pressure was stimulated according to Krejci and others.[13]

Standardized Class I cavities were prepared using 80 µm diamond burs (Intensiv SA, Grancia, Switzerland) under water-cooling. Subsequently, the cavities were finished using a 25 µm diamond bur (Intensiv SA). The cavity size was standardized in a mesio-distal direction to a length of 9 mm and a width in the bucco-oral direction of 7 mm. The depth was set at 2.5 mm (Figure 1). In specimens where a glass ionomer liner was applied,

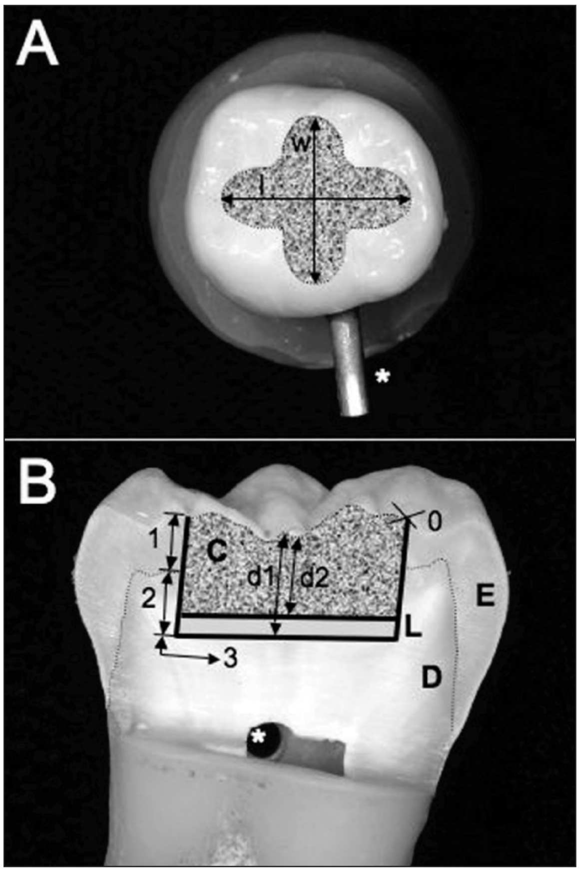

Figure 1. *Schematic drawing illustrating tooth embedding and restoration dimensions. Standardized Class I cavities comprising the main fissure system were prepared (panel A: view from occlusal; length (l): 9 mm and width (w): 7 mm). Panel B represents a mesio-distal section (C: resin composite; L: liner; E: enamel; D: dentin). Cavity depths were set at 2.5 mm (d2). In cavities where a glass ionomer liner was placed, the cavity was deepened by an additional 0.5 mm (d1-d2). The extension of the penetration (microleakage scores) are also marked (0: no penetration; 1: within the enamel; 2: within the dentin of the axial wall; 3: within the pulpal floor).*

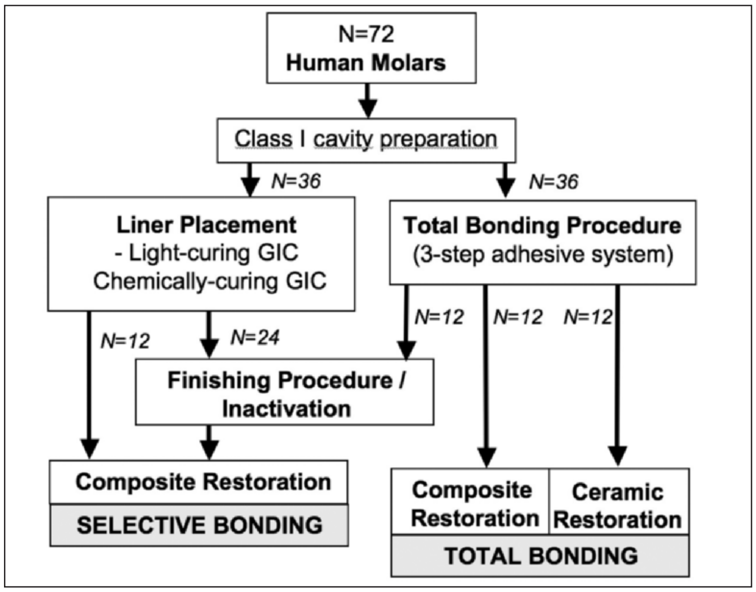

Figure 2. *Flow chart of the study depicting the different treatment groups and specimen numbers used.*

the cavity was deepened by an additional 0.5 mm. The different treatment groups, materials and protocols are summarized in Figure 2 and Table 1.

In the "total bonding" groups, enamel was etched with 35% phosphoric acid (Ultraetch, Ultradent, South Jordan, UT, USA) for 30 seconds and rinsed with water spray for 20 seconds. After carefully drying the cavity with air, a self-conditioner was applied for 15 seconds and gently air-dried before applying a second primer (Syntac Adhesive, Ivoclar Vivadent) for 20 seconds. After gentle air application, unfilled bonding resin (Heliobond, Ivoclar Vivadent) was applied for 20 seconds and light-cured for 40 seconds (Optilux 500, Demetron Kerr Inc, Danbury, CT, USA). In the "selective bonding" groups, either a glass ionomer liner or the three-step adhesive system was applied as described above. After light curing the liner or the bonding materials, cavity finishing lines were prepared using finishing diamond rotary instruments (Intensiv SA, Viganello, Switzerland). Only at this time point was the enamel etched and the bonding agent applied and air-thinned without light curing. The restoration procedures for all groups followed the same protocol: the hybrid resin composite material was placed in two oblique layers (Tetric A2, Ivoclar Vivadent, Schaan, Liechtenstein). Each increment was indirectly light-cured for 60 seconds (Optilux 500, Demetron Kerr Inc), respectively.

In the control group, a ceramic inlay was machined from Mark II ceramic (Vita Zahnfabrik, Bad Säckingen, Germany) using a CAD/CAM system (Cerec 3, Sirona, Bensheim, Germany). The inlays were etched for 60 seconds with a 4.9% hydrofluoride gel (Vita Ceramics Etch, Vita, Bad Säckingen, Germany), rinsed with water for 20 seconds, dried and treated for another 60 seconds with silane (Monobond S, Ivoclar Vivadent). After drying with air, Heliobond (Ivoclar Vivadent) was applied and thinned with air. The tooth cavities were prepared as for *ad modum* "total bonding" (see above), that is, the enamel was acid etched and the dentin conditioned using the three-step adhesive System (Syntac). The inlays were seated with the identical resin composite (Tetric) using an ultrasonic insertion technique and light-cured from the occlusal for 2 x 60 seconds mesially and distally, respectively (1000 mW/cm^2).

Contouring, finishing and polishing of the restorations were performed under a stereomicroscope (Stemi 1000, Carl Zeiss AG, Oberkochen, Germany) at 12x magnification. Forty 8 µm diamond burs (Intensiv SA), flexible abrasive discs (Sof-Lex, 3M ESPE, Seefeld,

Table 1: *Different Treatment Groups, Materials and Protocols*

Substrate BONDING PRINCIPLE *Material* (manufacturer)	**Component** (pH)–LOT	**Composition**	**Application Protocol**
ENAMEL—etching	Ultraetch	35% Phosphoric acid	Apply for 30 seconds, rinse for 40 seconds, air-dry
Bonding	Heliobond G26999	BisGMA, (1-methylethylidene)bis [4,1-phenyleneoxy(2-hydroxy-3 1-propanediyl)] bismethacrylate), TEGDMA, UDMA (urethanedi-methacrylate: 1,6-dimethacryl-ethyl-oxy-carbonylamino-2,4,4-trimethylhexane)	Apply for 20 seconds air dry
Dentin TOTAL BONDING *Syntac Classic* (Ivoclar Vivadent, Schaan, Liechtenstein)	Primer G27368	Maleic acid, TEGDMA (triethyleneglycol dimethacrylate), water, acetone	Apply for 20 seconds, air-thin
	Adhesive G05424	Polyethyleneglycol dimethycrylate, glutaraldehyde, water	Apply for 20 seconds, air-thin
	Heliobond G26999	(see enamel)	Apply for 20 seconds, air-thin
SELECTIVE BONDING *Syntac Classic*			Inactivation by finishing with water
Liner			
Glass ionomer cement[a] SELECTIVE BONDING			Inactivation by finishing with water
Ketac Fil Plus (GIC) chemically curing (3M ESPE, Seefeld, Germany)	Aplicap 276121	Calcium-alumino-fluoro-silicate glass, copolymer of acrylic and maleic acid, tartaric acid, water	Mix for 10 seconds
Vitrebond[a] *(RMGI)* Resin-modified, light-curing (3M ESPE, Seefeld, Germany)	Powder/Liquid 20051108	Powder: Fluoro-alumino-silicate glass Liquid: Caphorquinone and co-initiator; acrylic-itaconic acid copolymer with Pendant methacryloxy groups; 2-hydroxy-ethyl-methacrylate (HEMA), water	Mix the composition of the reactive liquid and powder to liquid ratio of 2.5:1; light cure

Germany), abrasive polishing brushes (Occlubrush, Hawe Neos, Bioggio, Switzerland) and diamond polishing paste (Vita Karat) were used under water-cooling.

Thermomechanical Loading and SEM Analysis

Impressions of the restorations were made using polyvinylsiloxane of low viscosity (President Light Body, Coltène, Altstätten, Switzerland) to assess baseline marginal quality. The impressions were cast with resin (Stycast 1266, Emerson & Cuming, Westerlo, Belgium) for later comparison with replicas made after the teeth had been thermomechanically loaded.

Caries-free palatal cusps were used as antagonists. The test specimens were loaded in the center of the occlusal surface in a computer-controlled masticator (CoCoM 2, PPK) for 1.2 Mio cycles (five-year equivalent) with 49 N at 1.7 Hz and simultaneous thermal stress with temperature changes of 5°C and 50°C.[14] After the loading phase, replicas were made and examined, together with baseline replicas by SEM (Amray 1810/T, Amray Inc, Bedford, MA, USA) at 15 kV and a working distance of 20–30 mm, to achieve comparable contrasts. The researcher was carefully trained in the established procedures for the evaluation of marginal adaptation and was blinded to group allocation of the various specimens. A modified image analysis program (NIH Image 1.62, National Institutes of Health, Bethesda, MD, USA) was used to assess the quality of the total length of the margins on multiple images at a magnification of 200x. All the restorations were examined for "perfect margins" (no gaps, no interruption of continuity), non-continuous "imperfect" margins (open gaps due to adhesive or cohesive failure; restoration or enamel fractures related to restoration margins) and expressed as a percentage of the total margin length.

Microleakage Assessment

The apices of the embedded teeth were sealed with sticky wax, and the samples were coated with two consecutive layers of transparent nail varnish up to 1 mm from the restoration margins. The samples were then immersed in 0.5% fuchsin solution (Fluka, Buchs, Switzerland) for 20 hours. After thoroughly rinsing with distilled water, the samples were air-dried and

Table 2: *SEM Evaluation of the Margins (median values; interquartile ranges in brackets)*

	Total Bonding		Selective Bonding		
Liner	-	-	AS	GIC-LC	GIC-CC
Filling	Composite	Ceramic Inlay	Composite	Composite	Composite
Perfect Margin					
Before Loading	85 (22) ^{A,B}	95 (14) ^{A,B}	65 (10) ^{C}	95 (9) ^{A,B}	96 (7) ^{A}
After Loading	42 (23) ^{A}	71 (27) ^{B}	31 (11) ^{A}	90 (15) ^{B}	98 (14) ^{B}
Gap					
Before Loading	8 (18) ^{A,B}	5 (13) ^{B}	30 (18) ^{A}	4 (7) ^{B}	3 (3) ^{B}
After Loading	40 (21) ^{A}	19 (21) ^{A,B}	53 (19) ^{A}	9 (13) ^{B}	9 (11) ^{B}
Filling Fractures					
Before Loading	0 (1) ^{A}	0 (0) ^{A}	0 (0) ^{A}	0 (0) ^{A}	0 (1) ^{A}
After Loading	3 (5) ^{A}	0 (0) ^{A}	1 (6) ^{A}	0 (2) ^{A}	0 (2) ^{A}
Enamel Fractures					
Before Loading	2 (9) ^{A}	0 (0) ^{A}	4 (10) ^{A}	0 (3) ^{A}	0 (3) ^{A}
After Loading	11 (15) ^{A}	3 (17) ^{A,B}	14 (14) ^{A}	0 (3) ^{A}	4 (4) ^{A,B}

Same superscripts represent values showing statistically significant difference.
AS: Adhesive system; GIC: glass ionomer cement; LC: light-cured; CC: chemically cured

Table 3: *Microleakage Assessment*

	Total Bonding		Selective Bonding		
Liner	-	-	AS	GIC-LC	GIC-CC
Filling	Composite	Ceramic Inlay	Composite	Composite	Composite
Score (N)					
0	6	11	1	15	16
1	4	11	2	1	2
2	5	1	2	5	5
3	9	1	19	1	1
Mean	1.7	0.7	2.6	0.8	0.6
Median	**2**	**1**	**3**	**0**	**0**
IQR	2.5	1	0	2	1.5

embedded in epoxy resin (Struers, Copenhagen, Denmark). Two parallel longitudinal sections were made parallel to the occlusal plane by using a kerosene-cooled low-speed diamond saw (Isomet, Buehler, Lake Bluff, IL, USA). Digital photographs of each section were obtained at 20x (1280 x 1024 resolution) under a stereomicroscope (Olympus, Tokyo, Japan). Photographs were taken at 3.2x and 6.4x (Leica Dialux 20 and ProgRes C14, Jenoptik, Jena, Germany) and electronically captured and evaluated (Image Access, Imagic, Glattbrugg, Switzerland). The degree of leakage at the restoration margin was determined based on an ordinal ranking system (0-no leakage—3) as follows:

1) leakage limited to the enamel;
2) leakage reaching the dentin but limited to the lateral axial wall;
3) leakage along the full length of the lateral axial wall, reaching the pulpo-axial surface.

Two readings were taken per slice (at both lateral axial walls), but only the higher leakage score was used for further analyses.

Data Presentation and Analysis

Statistical analysis was performed with StatView (Version 4.5, Abacus Concepts Inc, Piscataway, NJ, USA). The mean values and standard deviations were calculated and Student's paired t-test was used for statistical analyses. The normal distribution was analyzed using the Kolmogorov–Smirnov test. The level of significance was set at 95%.

For the microleakage evaluation, a score frequency table was presented.

RESULTS

Excellent marginal quality after thermo-mechanical loading was observed in all teeth with a GIC liner, followed by the ceramic inlay samples following the "total bonding" approach (Table 2). A significantly decreased percentage of margins rated as "perfect" was found in adhesively placed Class I restorations, irrespective of whether a total or selective bonding approach was used ($p \leq 0.05$). Therefore, the null hypothesis had to be rejected for the latter groups. In analogy, "gap" rating revealed the same tendency. Restoration fractures were rarely found in all treatment groups. The greatest number of enamel fractures were found in adhesively sealed samples in the selective approach and the totally bonded specimens, whereas the other groups exhibited almost no enamel fractures ($p \leq 0.05$).

The results of the microleakage assessment are shown in Table 3. Samples with the glass ionomer liner showed the least leakage. However, the ceramic inlay control group showed the least leakage scores extending into dentin. Almost complete leakage was found in the cavity sealing approach.

DISCUSSION

Polymerization shrinkage of direct resin composite restorations remains a major problem in contemporary operative dentistry. The configuration factor (C-factor), which is the ratio of the bonded to unbonded surface area, plays a pivotal role in the development of contraction stresses and, thus, the adaptation of the resin composite to the bonded cavity walls. An increase in the C-factor has been associated with an increase in the development of shrinkage stresses. The developed stress is proportional to the volume of the resin composite cured. The authors of the current study used standardized high C-factor Class I cavities prepared in natural human molars using a two-increment oblique layering technique. It must be acknowledged, however, that, despite standardized preparation geometry, small volume differences in the cavity due to anatomical tooth variations must be anticipated. Other stress contributing factors, including visco-elastic properties of the resin composite material and irradiation intensity, were controlled by choosing one restoration material, comparable increment volume and technique, and constant light-curing settings.

Regarding the restoration material used in the current evaluation, low-shrinkage resin composites were shown to have reduced microleakage in Class I cavities as compared to hybrid resin composites, which were used in the current study.[15] However, application of the two-increment technique was shown to reduce microleakage scores; whereas, the restoration placement in one increment (bulk) did not.[15] This was attributed to the assumption that internal stresses developed when the composite material is placed in bulk are already high, thus the fatigue applied in the restoration interface did not cause a higher degree of leakage. However, all resin composites of different shrinkage potential of the latter study showed a significant amount of microleakage when applied in a total bonding approach. This was also observed in the current study—when restorations were bonded to all cavity surfaces, shrinkage led to a decreased marginal integrity and high microleakage scores. In contrast, when the inlay was placed in order to reduce the total volume of shrinkable material, marginal quality was significantly improved and leakage scores decreased.

The current study also showed that the use of a glass ionomer liner in a selective bonding approach significantly improved the marginal integrity as compared to totally bonded direct restorations. This can be attributed to a higher degree of elastic deformation during the early stage of setting of the liner material, which can relieve contraction stress. Recently, Ratih and others demonstrated that the use of a glass ionomer liner was able to significantly reduce gap formation and outward fluid flow in direct restorations when used as a liner material.[16] On the other hand, glass ionomer reduces polymerization contraction stresses by increasing the free composite surfaces.[11-12] However, the clinical evidence is still controversial. Van Dijken studied the clinical performance of Class I restorations in a six-year study.[17] Restorations with a poly-acid modified resin liner were compared to totally bonded direct restorations. The latter study found no statistically significant difference in clinical performance between the two methods. Based on this finding, it was questioned whether "selectively bonded" laminate restorations, including a base material with more elastic behavior, which may result in better adaptation to the dentin, reflected more optimal clinical durability, as was suggested by laboratory findings. It must be taken into account that the latter *in vivo* study collected no quantitative data concerning the quality of the restoration margins or microleakage. Notably, both the marginal (peripheral) seal and the internal dentinal seal are important to the longevity of resin-based restorations. Therefore, laboratory investigations should, nevertheless, focus on ideal restorative materials and techniques to ensure optimal restoration quality and long-term success.

Sealing and lining the cavity with an adhesive bond, as used in the current investigation, has failed to improve restoration quality. Leakage was a general observation. One reason might be that the modulus of elasticity of sealed dentin does not represent a stress-breaking layer under the loaded resin composite, as it may stiffen the dentin. To date, little attention has been given to this topic in the literature. It has been shown, however, that resin infiltration may increase the elastic modulus of bovine dentin.[18] Another reason for this observation may be that the bonding potential of the adhesive was not adequately inactivated by water contamination during the finishing procedure of the margins. Therefore, enough free radicals and leaching soluble bonds might have been available for co-polymerization with the resin composite material, resulting in an increased C-factor. The latter aspect *per se*, however, cannot explain the results of the current study. An important factor with adhesive bonding agent layers is the possibility of the advocated decrease in bond-strength and increased nanoleakage over time in the presence of thermo mechanical loading, both of which have been shown *in vitro* and *in vivo*.[19-20]

CONCLUSIONS

This evaluation showed that glass ionomer liners improved the margin quality of restorations and reduced leakage. The use of an adhesive bonding agent for cavity sealing, as used in the current laboratory evaluation, is not recommended.

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References

1. Kramer N, Lohbauer U & Frankenberger R (2000) Adhesive luting of indirect restorations *American Journal of Dentistry* **13(Special No)** 60D-76D.
2. Botha CT & de Wet FA (1994) Polymerisation shrinkage around composite resin restorations—an *in vitro* study *The Journal of the Dental Association of South Africa* **49(5)** 201-207.
3. Griffiths BM, Naasan M, Sherriff M & Watson TF (1999) Variable polymerisation shrinkage and the interfacial micropermeability of a dentin bonding system *The Journal of Adhesive Dentistry* **1(2)** 119-131.
4. Krejci I & Lutz F (1991) Marginal adaptation of Class V restorations using different restorative techniques *Journal of Dentistry* **19(1)** 24-32.
5. Peutzfeldt A & Asmussen E (2004) Determinants of *in vitro* gap formation of resin composites *Journal of Dentistry* **32(2)** 109-115.
6. Bouillaguet S (2004) Biological risks of resin-based materials to the dentin-pulp complex *Critical Reviews in Oral Biology and Medicine* **15(1)** 47-60.
7. Gonzalez-Lopez S, Lucena-Martin C, de Haro-Gasquet F, Vilchez-Diaz MA & de Haro-Munoz C (2004) Influence of different composite restoration techniques on cuspal deflection: An *in vitro* study *Operative Dentistry* **29(6)** 656-660.
8. Krejci I & Stavridakis M (2000) New perspectives on dentin adhesion—differing methods of bonding *Practical Procedures and Aesthetic Dentistry* **12(8)** 727-32.
9. Davidson CL & Abdalla AI (1993) Effect of thermal and mechanical load cycling on the marginal integrity of Class II resin composite restorations *American Journal of Dentistry* **6(1)** 39-42.
10. Kemp-Scholte CM & Davidson CL (1990) Complete marginal seal of Class V resin composite restorations effected by increased flexibility *Journal of Dental Research* **69(6)** 1240-1243.
11. Feilzer AJ, de Gee AJ & Davidson CL (1987) Setting stress in composite resin in relation to configuration of the restoration *Journal of Dental Research* **66(11)** 1636-1639.
12. Lutz E, Krejci I & Oldenburg TR (1986) Elimination of polymerization stresses at the margins of posterior composite resin restorations: A new restorative technique *Quintessence International* **17(12)** 777-784.
13. Krejci I, Kuster M & Lutz F (1993) Influence of dentinal fluid and stress on marginal adaptation of resin composites *Journal of Dental Research* **72(2)** 490-494.
14. Gohring TN, Besek MJ & Schmidlin PR (2002) Attritional wear and abrasive surface alterations of composite resin materials *in vitro Journal of Dentistry* **30(2-3)** 119-127.
15. Yamazaki PC, Bedran-Russo AK, Pereira PN & Swift EJ Jr (2006) Microleakage evaluation of a new low-shrinkage composite restorative material *Operative Dentistry* **31(6)** 670-676.
16. Ratih DN, Palamara JE & Messer HH (2006) Minimizing dentinal fluid flow associated with gap formation *Journal of Dental Research* **85(11)** 1027-1031.
17. van Dijken JW (2003) A 6-year clinical evaluation of Class I poly-acid modified resin composite/resin composite laminate restorations cured with a two-step curing technique *Dental Materials* **19(5)** 423-428.
18. Yasuda G, Inage H, Takamizawa T, Kurokawa H, Rikuta A & Miyazaki M (2007) Determination of elastic modulus of demineralized resin-infiltrated dentin by self-etch adhesives *European Journal of Oral Science* **115(1)** 87-91.
19. Frankenberger R, Pashley DH, Reich SM, Lohbauer U, Petschelt A & Tay FR (2005) Characterisation of resin-dentine interfaces by compressive cyclic loading *Biomaterials* **26(14)** 2043-2052.
20. Hashimoto M, Ohno H, Kaga M, Endo K, Sano H & Oguchi H (2000) *In vivo* degradation of resin-dentin bonds in humans over 1 to 3 years *Journal of Dental Research* **79(6)** 1385-1391.