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The Effects of Cavity Preparation and Composite Resin on Bond Strength and Stress Distribution Using the Microtensile Bond Test

SSL Braga • LRS Oliveira • RB Rodrigues • AA Bicalho • VR Novais
S Armstrong • CJ Soares

Clinical Relevance

The biomechanical performance of composite resins is strongly influenced by the type of cavity preparation used. Using flat surface preparation to test different composite types may underestimate the effect of C-factor, stress, and shrinkage of composite resins.

SUMMARY

Objectives: To evaluate the effect of flowable bulk-fill or conventional composite resin on bond strength and stress distribution in flat or mesio-occlusal-distal (MOD) cavity preparations using the microtensile bond strength (μTBS) test.

Methods: Forty human molars were divided into two groups and received either standardized MOD or flat cavity preparations. Restorations were made using the conventional composite resin Z350 (Filtek Z350XT, 3M-ESPE, St Paul, MN, USA) or flowable bulk-fill (FBF) composite resin (Filtek Bulk Fill Flowable, 3M-ESPE). Postgel shrinkage was measured using the strain gauge technique (n=10). The Z350 buildup was made in two increments of 2.0 mm, and the FBF was made in a single increment of 4.0 mm. Six

Stella Sueli Lourenço Braga, DDS, MSc, PhD student, Department of Operative Dentistry and Dental Materials, School of Dentistry, Federal University of Uberlandia, Minas Gerais, Brazil

Laís Rani Sales Oliveira Schliebe, DDS, MSc, PhD student, Department of Operative Dentistry and Dental Materials, School of Dentistry, Federal University of Uberlandia, Minas Gerais, Brazil

Renata Borges Rodrigues, DDS, MS, PhD student, Department of Operative Dentistry and Dental Materials, School of Dentistry, Federal University of Uberlandia, Minas Gerais, Brazil

Aline Arêdes Bicalho, DDS, MS, PhD, professor, Health Technical School, Federal University of Uberlandia, Minas Gerais, Brazil

Veridiana Resende Novais, DDS, MS, PhD, professor, Department of Operative Dentistry and Dental Materials, School of Dentistry, University of Uberaba, Minas Gerais, Brazil

Steve Armstrong, DDS, PhD, professor and chair, Department of Operative Dentistry, College of Dentistry, University of Iowa, Iowa City, IA, USA

*Carlos José Soares, DDS, MS, PhD, professor and chair, Department of Operative Dentistry and Dental Materials, School of Dentistry, Federal University of Uberlandia, Minas Gerais, Brazil

*Corresponding author: Avenida Pará, 1720, Bloco 4L, Anexo A, Sala 42, Campos Umuarama, Uberlândia–Minas Gerais, Brazil CEP 38400-902; e-mail: carlosjsoares@ufu.br

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rectangular sticks were obtained for each tooth, and each section was used for μTBS testing at 1.0 mm/min. Polymerization shrinkage was modeled using postgel shrinkage data. The μTBS data were analyzed statistically using a two-way analysis of variance (ANOVA), and the postgel shrinkage data were analyzed using a one-way ANOVA with Tukey post hoc test. The failure modes were analyzed using a chi-square test (α=0.05).

Results: Our results show that both the type of cavity preparation and the composite resin used affect the bond strength and stress distribution. The Z350 composite resin had a higher postgel shrinkage than the FBF composite resin. The μTBS of the MOD preparation was influenced by the type of composite resin used. Irrespective of composite resin, flat cavity preparations resulted in higher μTBS than MOD preparations (*p*<0.001). Specifically, in flat-prepared cavities, FBF composite resin had a similar μTBS relative to Z350 composite resin. However, in MOD-prepared cavities, those with FBF composite resin had higher μTBS values than those with Z350 composite resin. Adhesive failure was prevalent for all tested groups. The MOD preparation resulted in higher shrinkage stress than the flat preparation, irrespective of composite resin. For MOD-prepared cavities, FBF composite resin resulted in lower stress than Z350 composite resin. However, no differences were found for flat-prepared cavities.

Conclusions: FBF composite resin had lower shrinkage stress than Z350 conventional composite resin. The μTBS of the MOD preparation was influenced by the composite resin type. Flat cavity preparations had no influence on stress and μTBS. However, for MOD preparation, composite resin with higher shrinkage stress resulted in lower μTBS values.

INTRODUCTION

Research in the field of adhesive dentistry strives for improvements in composite restorations to increase restoration longevity in tooth-preserving operative procedures. The use of a variety of composite resins with different mechanical properties makes it difficult to analyze the stress distribution at the interface between the tooth and the restoration.[1] Several variables affect the mechanical behavior of the restorations to be studied; therefore, a systematic understanding of the distribution of stress patterns involved in adhesion failure is important for correct interpretation of results. Laboratory bond testing of adhesive restorations using the microtensile bond strength (μTBS) test is the most common method to obtain information about the adhesion between restorative material and tooth structure.[2] The μTBS test is considered to be reliable because of its versatility and reliability *in vitro*.[3] However, this test method is time-consuming and technically demanding, requiring great care during specimen preparation and handling.[3]

During the preparation of samples for μTBS, polymerization of the composite resin produces shrinkage stress. This is influenced by restorative technique, resin elastic modulus, polymerization rate, and configuration of the cavity or "C-factor," which is defined as the ratio between bonded and unbonded composite resin surface area.[4-9] Shrinkage stresses from composite resin cause structural deformation and interfacial integrity failures, decreasing the bond strength between composite resin and tooth.[10] To reduce shrinkage stress, the use of an incremental technique is recommended, which promotes a smaller ratio of bonded to unbonded areas in each composite resin layer, achieving a lower C-factor during polymerization of each layer.[11]

The filling technique and type of composite resin can have a great impact on the adhesion of composite resin with the restoration, in particular in cavities with a high C-factor.[7] Laboratory testing for μTBS in constrained class II cavities are clinically relevant. In high C-factor cavities, the stress relief due to flow is severely limited, and the polymerization shrinkage stress might exceed the bond strength.[9]

New composite resins have been developed to minimize the deleterious clinical effects of polymerization shrinkage.[7,12,13] The use of bulk-fill resin allows a single increment of 4 mm. This thicker increment is possible due to modifications that increase the translucency of the bulk-fill composites, enabling greater light transmission.[14] In addition, formulation of these materials allows modulation of the polymerization reaction by the use of particular stress-relief monomers and more reactive photoinitiators.[12] These features decrease the undesirable effects of polymerization shrinkage.[7,13] To test different adhesive systems on the effects of polymerization shrinkage stress and adhesion, the μTBS test is the most commonly used method for researchers and manufacturers; however, the results of these tests are often difficult to interpret as limited attention has been given to the type of the composite resin used during this testing.

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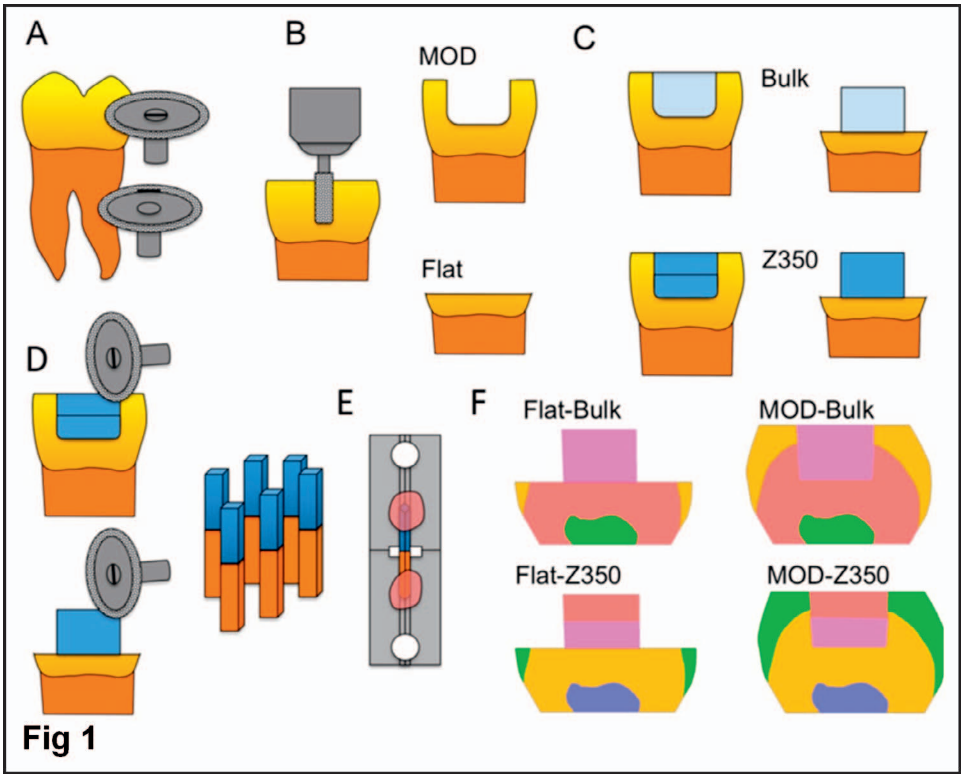

Figure 1. *Stepwise schematic of experimental design. (A): Sectioning of teeth at root and crown. (B): Teeth preparation: MOD, mesio-occlusal-distal preparation; flat, flat surface preparation. (C): Restorations were restored with each composite resin type: bulk, Filtek bulk-fill composite resin (bulk) or incremental filling using Filtek Z350XT (Z350; n=10). (D): Six sticks of restored teeth were obtained for each tooth. (E): Each section was subjected to the μTBS test using Geraldeli's device. (F): Preprocessing of the finite element method.*

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The aim of this study was to evaluate the bond strength and stress distribution in flat or mesio-occlusal-distal (MOD) cavity preparations using the same adhesive strategy with flowable bulk-fill or conventional composite resins, as determined using the μTBS test. Therefore, we tested the null hypothesis that the type of cavity preparation or composite resin does not influence bond strength or stress distribution as determined using the μTBS test.

METHODS AND MATERIALS

Forty extracted, intact human third molars that were caries free were used with approval from the University Ethics Committee in Human Research (No. 1.451.872). Teeth were embedded in a polystyrene resin (Cristal, Piracicaba, SP, Brazil) up to 2.0 mm below the cervical line to simulate alveolar bone and to ease manipulation.[15] The teeth were cleaned using a rubber cup and fine pumice water slurry and randomly distributed into four groups of 10 teeth. Two cavity preparations were defined: the flat preparation was generated by midcoronal cutting using a precision saw machine (Isomet 1000, Buehler, Lake Bluff, IL) resulting in a flat surface; the MOD preparation had an intercuspal width of 4.5 mm and was prepared with a diamond bur (No. 3099, KG Sorensen, Barueri, SP, Brazil) in a high-speed hand piece with copious air-water spray using a cavity preparation machine.[16] The depth of the cavities was the same for both types of preparation (4 mm in depth; Figure 1). A silicone mold was used for composite resin placement on flat cavity preparations. For MOD cavities, the prepared tooth was inserted in a metallic device that simulated proximal teeth, and a unimatrix with an elastic ring (TDV, Pomerode, SC, Brazil) was used in the proximal area. The self-etching adhesive system (ClearFil SE Bond, Kuraray, Japan) was used according to the manufacturer's instructions for all groups. Each type of restoration was made using two different composite resins: Filtek Z350XT (Z350; 3M-ESPE, St Paul, MN, USA) and Filtek bulk-fill flowable (FBF; 3M-ESPE; Table 1). The Z350 composite resin was placed in two horizontal increments for both types of cavity preparation, whereas the FBF composite resin was placed in a single increment. Each increment was light cured for 20 seconds using a multipeak light source with 1200 mW/cm^2 exitant irradiance (Bluephase G2, Ivoclar Vivadent, Amherst, NY, USA) from the occlusal direction closest to the cavity or to the composite resin increment.

μTBS Test

The specimens were sectioned buccolingually into slabs of 1-mm thickness under water cooling using a

Table 1: *Composite Resin Composition*

Material	Filtek Bulk Fill	Filtek Z350XT
Code	FBF	Z350
Shade	A2	A2
Composite resin type	Bulk-fill flowable	Nanofilled composite resin
Increment size and light activation time	4.0 mm/40 s	2.0 mm/20 s
Organic matrix	UDMA, BISGMA, EBPADMA, Procrylat resin	Bis-GMA, Bis-EMA, UDMA, TEGDMA
Filler	Silane-treated ceramic and YbF_3	Silica and zirconia nanofillers, agglomerated zirconia-silica nanoclusters
Filler % wt/vol	64/42.5	82/60
Manufacturer	3M-ESPE (St Paul, MN, USA)	3M-ESPE (St Paul, MN, USA)

Abbreviations: Bis-GMA, bisphenol-A glycidyl methacrylate; Bis-EMA, ethoxylated bisphenol-A dimethacrylate; UDMA, urethane dimethacrylate; EBPADMA, ethoxylated bisphenol A dimethacrylate; TEGDMA, triethylene glycol dimethacrylate.

low-speed diamond saw (Isomet, Buehler). Each slab was then sectioned mesiodistally to produce 1.0 mm × 1.0 mm cross-section sticks (six sticks per tooth). The ends of the specimens were fixed to a Geraldeli's device (Odeme, Joinvile, SC, Brazil) using cyanoacrylate glue (Super Bonder Flex Gel, Henkel Loctite Adesivos Ltda, Itapevi, SP, Brazil) to cover all gripping surfaces of each specimen.[17,18] Each specimen was then subjected to a tensile load at a cross-head speed of 1 mm/min using a microtensile machine (Microtensile ODEME, Luzerna, SC, Brazil). The cross-sectional area of each stick was measured to the nearest 0.01 mm using a digital caliper (Mitutoyo CD15, Mitutoyo Co, Kawasaki, Japan), and the μTBS in MPa was calculated by dividing the fracture load by the surface area. Each tooth was treated as a statistical unit by averaging the μTBS of all six samples from one tooth.

Following the μTBS test, specimens were examined with a stereomicroscope (Mitutoyo, Tokyo, Japan) at 40× magnification. The fractured surfaces were classified as adhesive failure (I), cohesive failure in composite resin (II), cohesive failure in dentin (III), or mixed failure (IV).

Finite Element Analysis

Residual stress in the tooth was calculated using a digitized buccolingual cross section with similar dimensions and conditions as those used for the μTBS test. The digitized buccolingual cross section of an intact molar with similar dimensions and conditions as those for the μTBS test was used as a reference for construction of the models. Coordinates were obtained using ImageJ software (public domain, Java-based image processing and analysis software developed at the National Institutes of Health, Bethesda, MD, USA).[19] Only the cervical portion of the root was simulated since the rest of the root did not affect the coronal stress distribution.[20] A simplified boundary condition was assumed at the cut plane of the root (fixed zero displacements in both horizontal and vertical directions).

The elastic modulus of enamel was 84 GPa and Poisson's ratio 0.30; the dentin elastic modulus was 18 GPa and the Poisson's ratio 0.23.[21] The elastic modulus of the restorative materials was 14.4 GPa for Z350 and 10.1 GPa for FBF.[13] The Poisson's ratio was chosen to be the same for all composite resins at 0.24.[20] The finite element analysis was performed using MSC.Mentat (preprocessor and postprocessor) and MSC.Marc (solver) software (MSC Software Corporation, Santa Ana, CA, USA). The total number of finite element analyses models was four for the different restorative materials and cavity type. A plane strain condition was assumed for the tooth cross sections. Polymerization shrinkage was simulated by thermal analogy. Temperature was reduced by 1°C, while the linear shrinkage value (postgel shrinkage) was entered as the coefficient of linear thermal expansion.

Modified von Mises equivalent stress was used to express the stress conditions using compressive-tensile strength ratios of 37.3 and 3.0 for the enamel and dentin,[21] respectively, and 6.25 for composite resin.[13] Stress values were recorded at the integration points of each element and node along material interfaces at either aspect (tooth and restoration). The stress values at the interface between composite resin and dentin at two depths in the two-dimensional model correlated with the elastic modulus and postgel shrinkage values at the same depths of the laboratory test restorations. The mean values of the top 5% of stresses were determined for the dentin/composite resin–isolated nodes at the interface and correlated with μTBS values.

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Table 2: *Summary of μTBS Values in Flat- or MOD-Prepared Samples Using Filtek Z350XT or Filtek Bulk Fill Composite Resin*[a]

Group	Conventional Composite Resin (Filtek Z350XT)		Bulk Fill Composite Resin (Filtek Bulk Fill)	
Preparation	Mean (SD)	95% Confidence Interval	Mean (SD)	95% Confidence Interval
Flat preparation	45.8 ± 9.0^{Aa}	(39.4-52.2)	49.2 ± 7.3^{Aa}	(44.0-54.4)
MOD preparation	31.6 ± 7.8^{Bb}	(26.0-37.2)	38.5 ± 10.8^{Ba}	(30.8-46.2)

[a] *The mean, standard deviation, and 95% confidence interval of MPa values are provided for each type of preparation and composite resin that was used. n=10 teeth per group. Two-way ANOVA was used to analyze differences between groups. Superscript uppercase letters indicate a significant difference between cavity preparations, and superscript lowercase letters indicate a significant difference between composite resins (p<0.05).*

Statistical Analysis

The μTBS test data were assessed for normal distribution (Shapiro-Wilk) and equality of variances (Levene test), followed by parametric statistical tests. Two-way analysis of variance (ANOVA) was performed with the study factors represented by the composite resin (Z350 and FBF), cavity preparation (flat and MOD), and their interactions. Multiple comparisons were made using the Tukey post hoc test. The data of failure mode were subjected to the chi-square test. All tests employed a 0.05 level of statistical significance, and all statistical analyses were carried out with Sigma Plot version 13.1 (Systat Software Inc, San Jose, CA, USA).

RESULTS

We used the μTBS test to assess the effects of cavity preparation and composite resin on the bond strength and stress distribution. Two-way ANOVA of μTBS values revealed a statistically significant difference between the composite resins ($p<0.001$), the cavity preparation ($p=0.001$), and the interaction between composite resins and cavity preparations ($p=0.004$; Table 2). Irrespective of composite resin type, flat preparations had significantly higher μTBS values than MOD preparations. For MOD-prepared samples, FBF composite resin had significantly higher μTBS values than Z350. However, flat-prepared samples showed no difference in μTBS values between FBF or Z350 composite resins.

We also measured the effects of cavity preparation and type of composite resin on stresses in the restoration. Preparations using the Z350 composite resin resulted in higher stress on composite resin buildup, irrespective of the type of cavity preparation (Figure 2). Flat-prepared cavities resulted in lower stresses at the dentin/composite resin interface relative to MOD-prepared cavities (Figure 3A). Within flat cavity preparations, each of the composite resins showed similar stresses at the dentin/composite resin interface. However, in MOD-prepared cavities, the Z350 composite resin resulted in higher stresses at the dentin/composite resin interface compared with MOD-prepared samples with FBF composite resin (Figure 3B). All groups showed similar failure patterns based on fracture mode distributions as represented in Figure 4. Adhesive failures were prevalent for all groups. Therefore, the cavity preparation and type of composite resin used affect the stress at the interface between dentin and composite resin.

DISCUSSION

The results of our study demonstrate that the type of cavity preparation and type of composite resin affect μTBS and stress distribution. Further, our results also show that each preparation can be influenced by the type of composite resin used. Thus, we reject our null hypothesis that the type of cavity preparation or composite resin does not influence bond strength or stress distribution. Clinically, it is common to find structural loss in posterior teeth, resulting in the formation of large cavities. However, most studies use flat surfaces for testing bond strength, which does not resemble this clinical situation in the oral cavity.[22,23] Therefore, the present study was undertaken to obtain a more clinically relevant idea of the effects of cavity preparation and different composite resins used on (restoration) bond strength.

Restoration bond strength is affected by several factors, with composite resin polymerization shrinkage stress considered to play an important role.[8,24,25] A useful strategy to quantify the stress located at the bonded interface is finite element analysis. Sufficient polymerization that results in adequate mechanical properties associated with favorable bonding is mandatory for the best clinical performance of the composite resin restoration. Previous studies of large MOD restorations have shown that the type of composite resin and filling technique may influence the bond strength value of large MOD restorations.[15] Polymerization stress can be affected by bond strength and elastic modulus values. Bond strength values are indirectly related to polymerization shrinkage stresses,[26,27] while elastic modulus values of the composite resin are directly related to

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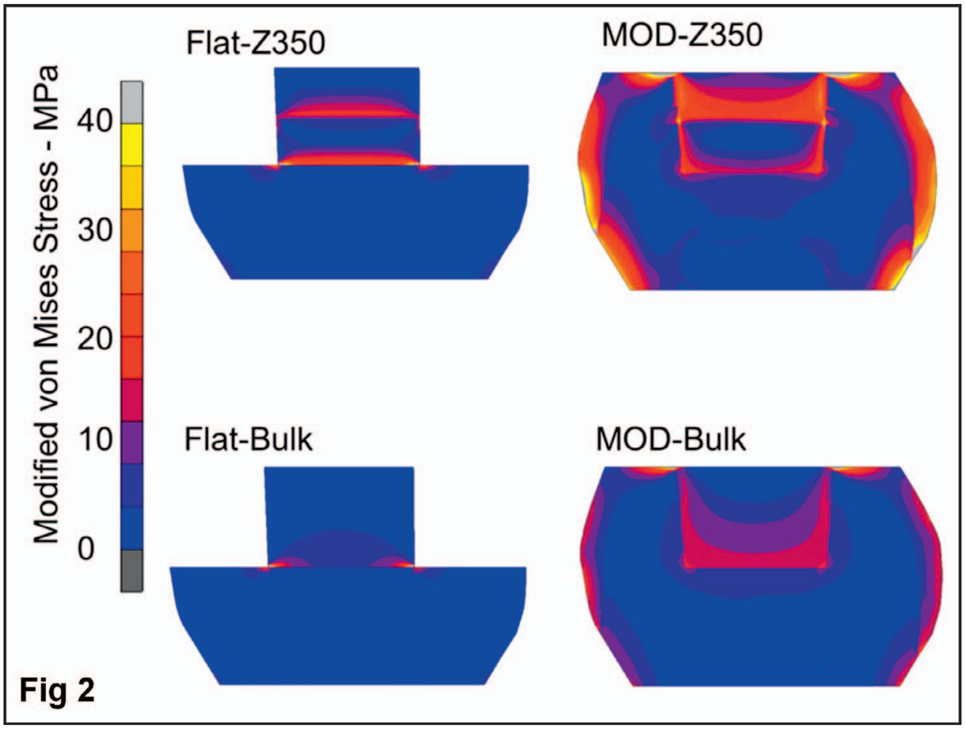

Figure 2. *Stress distributions of the two composite resins, each as calculated by finite element analysis (modified von Mises equivalent stresses; MPa).*

higher stresses in the remaining tooth structure and at the tooth/restoration interface. Materials with high elastic modulus deform less when they are stressed and produce more rigid restorations. This increases the effect of polymerization shrinkage, resulting in residual shrinkage stresses.[28] Thus, when polymerization contraction is restricted by bonding to the cavity walls, a composite resin with a high elastic modulus will result in higher shrinkage stress.[29] FBF composite resin has a lower filler content, which results in a lower elastic modulus and lower postgel shrinkage compared with Z350 composite resin.[13] In this study, Z350 showed higher stress, irrespective of cavity preparation, because of its higher elastic modulus and higher postgel shrinkage. Further, flat cavity preparations resulted in lower stresses at the dentin/composite resin interface than MOD cavity preparations. The free constrain of the composite resin on flat surface releases the shrinkage stress that compromises bond

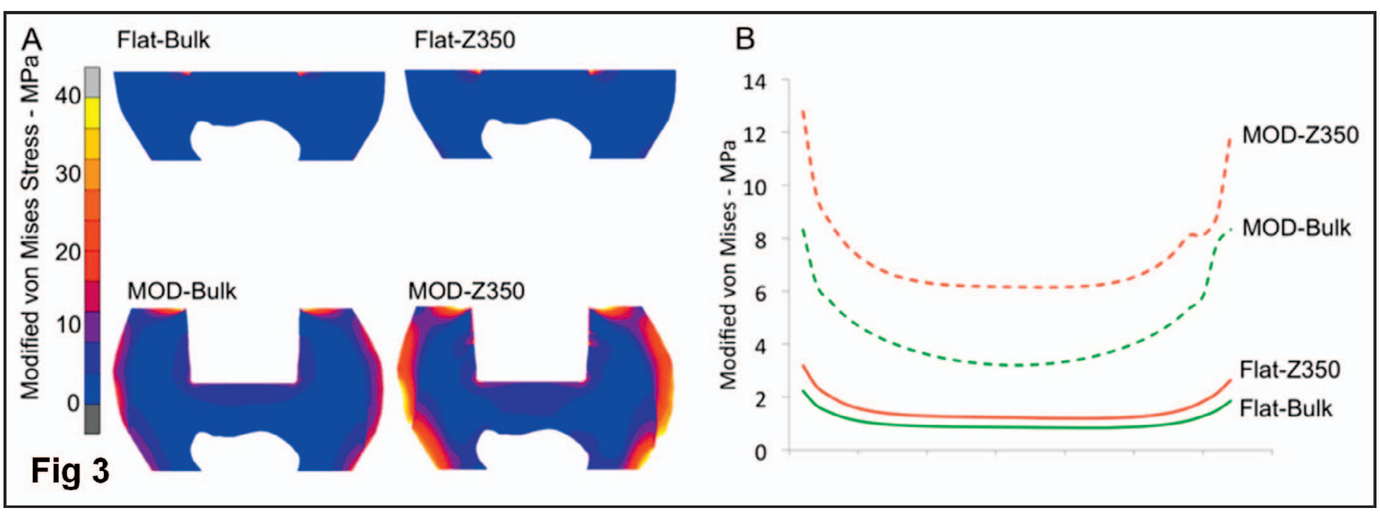

Figure 3. *The Z350 composite resin results in a higher stress distribution irrespective of the type of preparation used. (A): Stress distributions in flat- or MOD-prepared cavities using FBF or Z350 composite resin. (B): Stress along at the dentin/composite resin interface for each group in A calculated by finite element analysis (modified von Mises equivalent stresses; MPa).*

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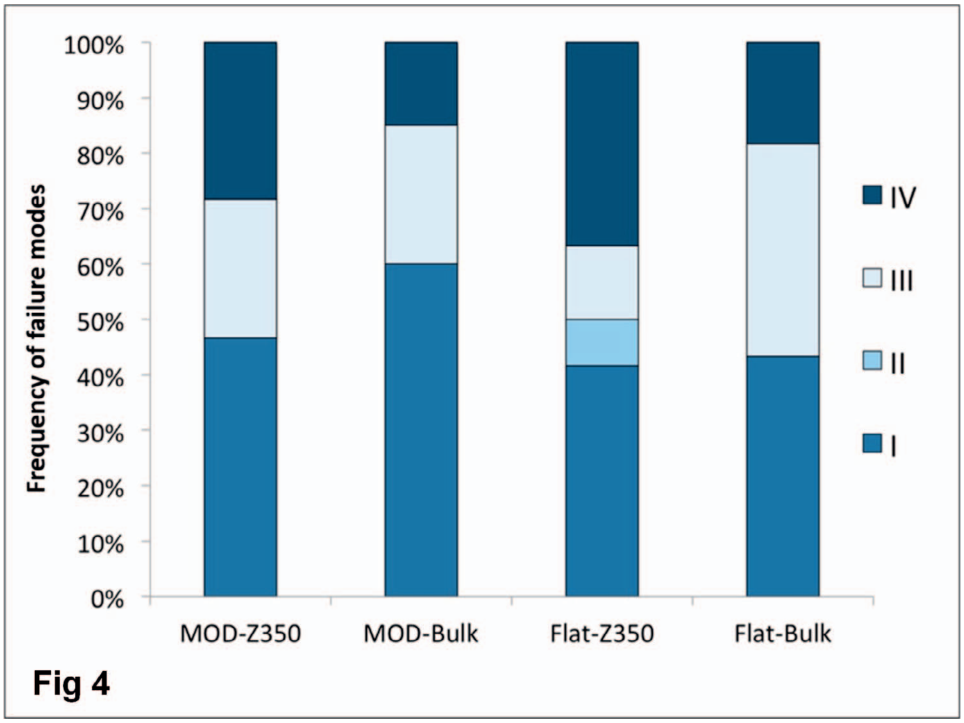

Figure 4. *Frequency of failure mode for flat- or MOD-prepared cavities using FBF (bulk) or Z350 composite resin. Fractured surfaces were classified as follows: I, adhesive failure; II, mixed failure; III, cohesive failure in dentin; IV, cohesive failure in composite resin.*

integrity. Similar to previous reports, our study has confirmed that shrinkage stress is influenced by the elastic modulus of resin, polymerization rates, restorative techniques, and cavity configuration.[23] The horizontal incremental filling used in the MOD cavities joining buccal and lingual walls increased the shrinkage stresses.[30] This stress is initially transferred to the interface, resulting in decreasing μTBS.

Bond strength values tend to decrease directly with the number of walls in the cavity.[6,31] In this study, the bond strength values for flat-prepared cavities were higher than the MOD-prepared cavities, regardless of the type of material that was used. In flat preparations, surrounding walls are absent, contributing to a lower C-factor[11]; thus, composite resin increments deform without restriction of the proximal walls, reducing the residual shrinkage stress, which may be why bond strength values were higher for cavities that underwent the flat preparation in our study. The expected magnitude of stress might be estimated through the ratio of the bonded to the unbonded areas, also known as the configuration factor.[32] The higher the C-factor, the higher the stress level generated; this aspect was observed in the MOD cavity tested in the present study. On the contrary, a higher ratio of unbonded to bonded walls, represented by the flat cavity tested in this study, would be responsible for lower values of stress as shrinkage would freely occur at the unbonded surface areas. In addition, without proximal walls, the increments may receive light energy more effectively, since insufficient curing is associated with lower bond strength and mechanical properties.[33]

In MOD-prepared cavities, FBF composite resin had higher bond strength values than Z350 composite resin. FBF has lower postgel shrinkage and lower elastic modulus. Consequently, shrinkage stress was lower in cavities restored with FBF composite. This is a principal factor to explain the better performance of FBF in MOD cavities. In addition, FBF has better adaptation to the pulp floor of the cavity, generating a more effective union of the Z350 conventional composite resin.[6] The FBF composite resin has a lower filler content and higher translucency,[13] allowing higher light transmission within the material and better photoactivation characteristics than Z350.[6]

The μTBS values were dependent on both the cavity preparation and composite resin type in this study. Therefore, our study highlights the importance of determining how materials were tested when comparing the μTBS results using different adhesive systems within and between laboratories. In addition, the findings of this study demonstrate that in constrained cavities, the use of an FBF composite resin may be a good strategy to produce better interface integrity.

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CONCLUSION

Within the limitations of this study design, we conclude that composite resins and cavity preparations, and the interaction between composite resins and cavity preparations, influence the stress distribution at the restoration/tooth interface and, consequently, the measured bond strength. Flat preparations resulted in lower shrinkage stress and significantly higher μTBS values relative to MOD preparations. FBF composite resin had significantly higher μTBS values than Z350 composite resin when tested using MOD preparation. MOD preparation Z350 resulted in higher stresses at the dentin/composite resin interface. The use of MOD preparations for the treatment of cavities will better reproduce clinical conditions when testing for bond strength using the μTBS test.

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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 Ethics Committee in Human Research. The approval code for this study is 1.451.872.

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 presented in this article.

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References

1. Poitevin A, De Munck J, Van Landuyt K, Coutinho E, Peumans M, Lambrechts P, & Van Meerbeek B (2008) Critical analysis of the influence of different parameters on the microtensile bond strength of adhesives to dentin *Journal of Adhesive Dentistry* **10(1)** 7-16.
2. Betamar N, Cardew G, & Van Noort R (2007) Influence of specimen designs on the microtensile bond strength to dentin *Journal of Adhesive Dentistry* **9(2)** 159-168.
3. Pashley DH, Carvalho RM, Sano H, Nakajima M, Yoshiyama M, Shono Y, Fernandes CA, & Tay F (1999) The microtensile bond test: a review *Journal of Adhesive Dentistry* **1(4)** 299-309.
4. Kumagai RY, Zeidan LC, Rodrigues JA, Reis AF, & Roulet JF (2015) Bond strength of a flowable bulk-fill resin composite in class II MOD cavities *Journal of Adhesive Dentistry* **17(5)** 427-432.
5. Labella R, Lambrechts P, Van Meerbeek B, & Vanherle G (1999) Polymerization shrinkage and elasticity of flowable composites and filled adhesives *Dental Materials* **15(2)** 128-137.
6. Van Ende A, De Munck J, Van Landuyt K, & Van Meerbeek B (2016) Effect of bulk-filling on the bonding efficacy in occlusal class I cavities *Journal of Adhesive Dentistry* **18(2)** 119-124.
7. Van Ende A, De Munck J, Van Landuyt KL, Poitevin A, Peumans M, & Van Meerbeek B (2013) Bulk-filling of high C-factor posterior cavities: effect on adhesion to cavity-bottom dentin *Dental Materials* **29(3)** 269-277.
8. Van Ende A, Mine A, De Munck J, Poitevin A, & Van Meerbeek B (2012) Bonding of low-shrinking composites in high C-factor cavities *Journal of Dentistry* **40(4)** 295-303.
9. Yoshikawa T, Sano H, Burrow MF, Tagami J, & Pashley DH (1999) Effects of dentin depth and cavity configuration on bond strength *Journal of Dental Research* **78(4)** 898-905.
10. Versluis A, Douglas WH, Cross M, & Sakaguchi RL (1996) Does an incremental filling technique reduce polymerization shrinkage stresses? *Journal of Dental Research* **75(3)** 871-878.
11. Park J, Chang J, Ferracane J, & Lee IB (2008) How should composite be layered to reduce shrinkage stress: incremental or bulk filling? *Dental Materials* **24(11)** 1501-1505.
12. Fronza BM, Rueggeberg FA, Braga RR, Mogilevych B, Soares LE, Martin AA, Ambrosano G, & Giannini M (2015) Monomer conversion, microhardness, internal marginal adaptation, and shrinkage stress of bulk-fill resin composites *Dental Materials* **31(12)** 1542-1551.
13. Rosatto CM, Bicalho AA, Verissimo C, Braganca GF, Rodrigues MP, Tantbirojn D, Versluis A, & Soares CJ (2015) Mechanical properties, shrinkage stress, cuspal strain and fracture resistance of molars restored with bulk-fill composites and incremental filling technique *Journal of Dentistry* **43(12)** 1519-1528.
14. Bucuta S, & Ilie N (2014) Light transmittance and micromechanical properties of bulk fill vs. conventional resin based composites *Clinical Oral Investigations* **18(8)** 1991-2000.
15. Bicalho AA, Pereira RD, Zanatta RF, Franco SD, Tantbirojn D, Versluis A, & Soares CJ (2014) Incremental filling technique and composite material—part I: cuspal deformation, bond strength, and physical properties *Operative Dentistry* **39(2)** E71-E82.
16. Soares CJ, Fonseca RB, Gomide HA, & Correr-Sobrinho L (2008) Cavity preparation machine for the standardization of *in vitro* preparations *Brazilian Oral Research* **22(3)** 281-287.
17. Raposo LH, Armstrong SR, Maia RR, Qian F, Geraldeli S, & Soares CJ (2012) Effect of specimen gripping device, geometry and fixation method on microtensile bond strength, failure mode and stress distribution: laboratory and finite element analyses *Dental Materials* **28(5)** e50-e62.
18. Soares CJ, Soares PV, Santos-Filho PC, & Armstrong SR (2008) Microtensile specimen attachment and shape—finite element analysis *Journal of Dental Research* **87(1)** 89-93.
19. Schneider CA, Rasband WS, & Eliceiri KW (2012) NIH Image to ImageJ: 25 years of image analysis *Nature Methods* **9(7)** 671-675.

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20. Versluis A, & Versluis-Tantbirojn D (2011) Filling cavities or restoring teeth? *Journal of the Tennessee Dental Association* **91(2)** 36-42.

21. Watts DC, el Mowafy OM, & Grant AA (1987) Temperature-dependence of compressive properties of human dentin *Journal of Dental Research* **66(1)** 29-32.

22. Bravis T, Pilecki P, Wilson RF, Fenlon M, Watson TF, & Foxton RM (2012) Effect of loading on the microtensile bond strength and microleakage of a self-etching and etch-and-rinse adhesive in direct class II MOD composite restorations *in vitro Dental Materials Journal* **31(6)** 924-932.

23. He Z, Shimada Y, & Tagami J (2007) The effects of cavity size and incremental technique on micro-tensile bond strength of resin composite in class I cavities *Dental Materials* **23(5)** 533-538.

24. Armstrong S, Geraldeli S, Maia R, Raposo LH, Soares CJ, & Yamagawa J (2010) Adhesion to tooth structure: a critical review of "micro" bond strength test methods *Dental Materials* **26(2)** e50-e62.

25. El-Sahn NA, El-Kassas DW, El-Damanhoury HM, Fahmy OM, Gomaa H, & Platt JA (2011) Effect of C-factor on microtensile bond strengths of low-shrinkage composites *Operative Dentistry* **36(3)** 281-292, doi: 10.2341/10-105-L.

26. Boaro LC, Goncalves F, & Braga RR (2010) Influence of the bonding substrate in dental composite polymerization stress testing *Acta Biomaterialia* **6(2)** 547-551.

27. Isaac SZ, Bergamin AC, Turssi CP, Amaral FL, Basting RT, & Franca FM (2013) Evaluation of bond strength of silorane and methacrylate based restorative systems to dentin using different cavity models *Journal of Applied Oral Science* **21(5)** 452-459.

28. Versluis A, Tantbirojn D, Pintado MR, DeLong R, & Douglas WH (2004) Residual shrinkage stress distributions in molars after composite restoration *Dental Materials* **20(6)** 554-564.

29. Bicalho AA, Valdivia AD, Barreto BC, Tantbirojn D, Versluis A, & Soares CJ (2014) Incremental filling technique and composite material—part II: shrinkage and shrinkage stresses *Operative Dentistry* **39(2)** E83-E92.

30. Soares CJ, Bicalho AA, Tantbirojn D, & Versluis A (2013) Polymerization shrinkage stresses in a premolar restored with different composite resins and different incremental techniques *Journal of Adhesive Dentistry* **15(4)** 341-350.

31. Bakhsh TA, Sadr A, Shimada Y, Mandurah MM, Hariri I, Alsayed EZ, Tagami J, & Sumi Y (2013) Concurrent evaluation of composite internal adaptation and bond strength in a class-I cavity *Journal of Dentistry* **41(1)** 60-70.

32. 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.

33. Price RB, Doyle G, & Murphy D (2000) Effects of composite thickness on the shear bond strength to dentin *Journal Canadian Dental Association* **66(1)** 35-39.

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