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Fracture Resistance and Marginal Adaptation of Capped and Uncapped Bulk-fill Resin-based Materials

HN Al-Nahedh • Z Alawami

Clinical Relevance

Resistance to marginal ridge fracture of class II restorations restored with some bulk-filled resin based composites can be significantly improved by capping with conventional composites and by higher radiant exposure.

SUMMARY

Objectives: This study tested the fracture resistance of capped and uncapped bulk-fill composite restorations and compared them to a conventional composite. Also, the effect of different radiant exposure was investigated.

Methods and Materials: Flowable and high-viscosity bulk-fill composites (SureFil SDR, Filtek Bulk-Fill Posterior, and Tetric N-Ceram Bulk-Fill) and a nanohybrid resin composite (Filtek Z350 XT) were used. Standardized class II cavities were prepared on extracted premolars, and different restoration protocols were used. In protocol 1 (control), restoration was applied using a layering technique; in protocol 2, restoration was applied in bulk with a capping layer; in protocol 3, restoration was applied in bulk without a capping layer; and in protocol 4, restoration was applied in bulk without a capping layer, and the light curing time was extended. After thermocycling, the restorations were examined for marginal gaps and then subjected to the fracture resistance test using a universal testing machine. Statistical analysis was carried out using two-way analysis of variance (ANOVA) followed by one-way ANOVA at a significance level of $\alpha = 0.05$.

Results: A statistically significant difference in the fracture resistance of the tested materials and protocols was detected. Filtek Bulk-Fill Posterior achieved the highest fracture resistance values regardless of the protocol used, and its results were comparable to those of Filtek Z350. SDR and Tetric N-Ceram Bulk-Fill achieved their highest strengths when a capping layer was added. Tetric N-Ceram Bulk-Fill showed improvement in fracture resistance with extended light curing, while SDR and Tetric N-Ceram Bulk-Fill achieved similar results with the addition of a capping layer.

*Hend N Al-Nahedh, BDS, MSD, associate professor, Department of Restorative Dental Sciences, College of Dentistry, King Saud University, Riyadh, Saudi Arabia

Zainab Alawami, BDS, MSD, restorative specialist, Dentistry Division, Eastern Province, Ministry of Health, Eastern, Saudi Arabia

*Corresponding author: PO Box 60169, Riyadh 11545, Saudi Arabia; e-mail: h_nahed@yahoo.com

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The uncapped bulk-fill group showed more gap-free margins than the capped group.

Conclusion: The new high-viscosity bulk-fill composite restorations seem to have adequate fracture resistance. However, the results are material dependent, and some materials perform better with a capping layer and extended light curing.

INTRODUCTION

Resin-based composite (RBC) technology has undergone tremendous developments, producing restorative materials with excellent durability, wear resistance, and esthetics. Controlling the filler architecture through the incorporation of nanotechnology has resulted in dramatic improvements in these materials.[1] The first formulation of RBC was chemically activated, but the generations that followed are photoactivated composites.[1] One of the main problems encountered with resin composites is polymerization shrinkage. This is a reduction of the resin volume that occurs during the polymerization process. This shrinkage, coupled with other factors, such as the RBC modulus of elasticity and restoration confinement within the tooth structure, leads to the development of internal stress within the cavity, which is referred to as polymerization shrinkage stress.[1,2] Polymerization shrinkage stress has been associated with the development of marginal discrepancies, microleakage, postoperative sensitivity, and cusp deflection/enamel microcracks.[2,3] The incremental placement technique was introduced in an attempt to overcome some of the consequences of polymerization shrinkage stress.[4] Other strategies have been proposed in an effort to reduce polymerization shrinkage stress, such as use of different light-curing modes, the use of flowable RBC as an intermediate liner, and the development of new low-shrinkage monomers.[5-7]

Currently, the incremental placement technique is considered the standard of care in cavity preparations exceeding 2 mm. This technique was adopted to ensure sufficient light-curing exposure of the entire increment and to relieve, to some extent, part of the polymerization shrinkage stresses generated during light curing.[8] There are, however, some disadvantages associated with the incremental filling technique. In addition to the technique's requiring a longer time for placement and being labor intensive, there is the possibility of entrapping voids and/or contamination between the layers.[9] Bulk-fill RBCs reduce some of the problems associated with conventional RBC materials occurring with the incremental filling technique.

The bulk-fill RBCs are a newly introduced category of direct resin-based restorative material advocated for use in posterior restorations. They can be applied and cured in a single layer of up to 4 or 5 mm, offering a faster restoration procedure.[10-12] With regard to their mechanical properties, the bulk-fill materials fall between conventional RBCs and flowable RBCs.[13] In general, when compared to conventional RBCs, the bulk-fill RBCs show inferior mechanical properties values.[14] There are two types of bulk-fill materials: flowable and high viscosity. Some manufacturers recommend adding a capping layer of 2 mm to the bulk-fill materials; others report that their materials do not require the addition of a capping layer. The indication for the addition of a capping layer can be attributed to the modulus of elasticity, indentation modulus, and measured hardness values of these materials.[13]

The composite-to-composite bonding during composite layering occurs by the formation of primary covalent bonds between the residual C=C bonds of the previously placed layer and the C=C bonds of the newly applied layer, development of interpenetrating networks, secondary bonding, and mechanical interlocking.[15] It is also believed that the oxygen-inhibited layer increases the bond strength between RBC increments.[16] Having a good bond between the RBC layers is crucial since adequate mechanical properties depend largely on the integrity between layers.[17] For the capping layer of bulk-fill RBCs, manufacturers usually advocate the use of any type of RBC; however, there are some concerns with regard to the bond strength between different types of composites. The microfilled RBC material associations show lower shear bond strength compared to hybrid/hybrid resin and hybrid/nanofiller resin associations. In addition, some materials show higher shear bond strength than others.[18]

The mechanical properties of RBC materials are impacted by the resin material composition, filler content, and coupling process. In addition, the inherent flaws present in RBC also influence mechanical properties. The use of the newly available bulk-fill RBC material is advocated to save time due to their ability to cure in thicker layers. However, several studies have reported low mechanical properties of some bulk-fill material, and caution is advocated when using these materials in areas of high occlusal load.[13,14] Furthermore, there is a lack of information in the literature about the fracture resistance of bulk-filled RBC restorations and the

Table 1: *Resin Composite Materials Used in the Study*

Materials/Shade	Lot Number	Material Type	Resin Matrix	Filler
SDR Universal shade	1501000007	Flowable bulk-fill composite	Modified UDMA, di-methacrylate resin, di-functional diluents, EBPADMA, and TEGDMA	Filler content consists of barium and strontium alumino-fluoro-silicate glasses. Filler loading 68% by weight, 47.3% by volume. Inorganic filler particles range from 20 nm to 10 μ.
Tetric N-Ceram Bulk Fill Shade IVB (European trade name is Tetric EvoCeram Bulk-Fill)	T47219	Packable hybrid bulk-fill composite	Bis-GMA, Bis-EMA, and UDMA	Filler content consists of barium glass, prepolymer, ytterbium trifluoride, and mixed oxide. Filler loading 75% to 77% by weight, 53% to 55% by volume. Inorganic filler particle size is between 0.04 and 3 μm, mean particle size is 0.6 μm.
Filtek Bulk Fill Posterior Restorative Shade A2	N682081	Packable nanofilled bulk-fill composite	ERGP-DMA, diurethane-DMA, and 1,12-dodecane-DMA	Filler content consists of nonagglomerated/nonaggregated 20-nm silica filler and 4- to 11-nm zirconia filler, aggregated zirconia/silica cluster filler, and ytterbium trifluoride filler agglomerate 100-nm particles. Filler loading 76.5% by weight, 58.4% by volume.
Filtek Z350 XT (3M ESPE), A2 Body shade (North American trade name is Filtek Supreme Ultra)	N677462	Nanohybrid paste composite	Bis-GMA, UDMA, TEGDMA, PEGDMA, and Bis-EMA	Filler content consists of nonagglomerated/nonaggregated 20-nm silica filler and 4- to 11-nm zirconia filler and aggregated zirconia/silica cluster filler. Filler loading 78.5% by weight, 63.3% by volume.

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

efficacy of capping bulk-filled materials with conventional RBCs.

The aims of the study were to compare the fracture resistance (or loads at fracture) of different capped and uncapped resin-based bulk-fill restorative materials in deep class II cavity preparations, to compare the fracture resistance of different bulk-fill composite restorations, to compare the fracture resistance of bulk-fill restorations to conventional nanohybrid RBC restorations, and to investigate the effect of using different radiant exposures on fracture resistance of bulk-fill composite materials. The null hypotheses were that 1) there is no significant difference in fracture resistance between capped and uncapped bulk-fill materials, 2) there are no significant differences in the fracture resistance between the bulk-fill materials tested, 3) there is no significant difference in fracture resistance between bulk-fill materials and nanohybrid composites, and 4) the radiant exposure does not influence the fracture resistance of bulk-fill materials.

METHODS AND MATERIALS

The protocol for this study was registered and approved by the College of Dentistry Research Center in King Saud University (CDRC registration #PR 0037). Three commercially available bulk-fill materials were used in the study: one flowable and two high-viscosity RBCs. A conventional nanohybrid RBC was used as a control (Table 1). Each RBC material was used with its corresponding bonding agent (Table 2). Eighty intact maxillary premolars were collected after extraction and stored in 0.05% thymol solution at a temperature of 4°C. The teeth were examined under a light microscope (Microscope series 80, SWIFT Instruments International, SA, Tokyo, Japan) at 10× magnification to ensure that they were free of defects and fracture lines. The bucco-lingual dimension and crown length of the teeth at the interproximal areas were measured with a digital micrometer gauge (Mitutoyo, Kawasaki, Japan), and only teeth within a size range of less than 1 mm were selected. Later, they were stratified for tooth size and randomly distributed over the study groups (n=8) such that the variance of the mean measurements between groups was less than 5%. The sample size was estimated at $\alpha = 0.05$ with an expected standard deviation of 0.12[19] and a power of 0.95. The number of specimens for each material was estimated to be eight in each protocol.

Table 2: *Adhesive Systems Used in the Study*

Adhesive System	Lot Number	Application
Single Bond Universal	590863	Acid etching for 15 s; rinse and dry using cotton pellet and gentle blotting. Apply the adhesive and rub it in for 20 s. Gentle air drying for 5 s. Light cure for 10 s.
Prime&Bond NT	1307001099	Acid etching for 15 s; rinse and dry using cotton pellet and gentle blotting. Apply a generous amount of the adhesive and keep surface wet for 20 s. Gentle air drying for 5 s. Light cure for 10 s.
Tetric N-Bond	U34550	Acid etching for 15 s; rinse and dry using cotton pellet and gentle blotting. Apply a thick layer of adhesive and gently brush for 10 s. Gentle air drying until surface is evenly shiny. Light cure for 10 s.

Cavity Preparation

Under copious water irrigation, standardized class II occluso-distal cavities were prepared by one operator. To help standardize the preparations, the dimensions were confirmed using a periodontal probe and a digital micrometer with an accuracy level of up to 0.05 mm (Flexbar Tools, New York, NY, USA). The bucco-lingual width of the preparation was 2 mm with an occlusal depth of 2 mm; the distal box extended 6 mm gingivally, ending in dentin right below the cemento-enamel junction with a width of 3.5 mm at the marginal ridge; and the width of the gingival seat was 1 mm (Figure 1). The preparation was done using 1156 round-ended straight fissure carbide burs (Komet Dental, Lemgo, Germany). Each bur was replaced after four preparations.

Restoration Protocol

The teeth were randomly divided into 10 groups and restored by one operator. The restorative materials were placed with their respective bonding agents according to the manufacturers' instructions (Table 2).

Protocol 1 (control): Eight cavities were incrementally filled with Single Bond Universal/Filtek Z350 XT nanohybrid composite using a horizontal incremental placement technique with 2-mm layer thickness. Each layer was cured for 20 seconds.

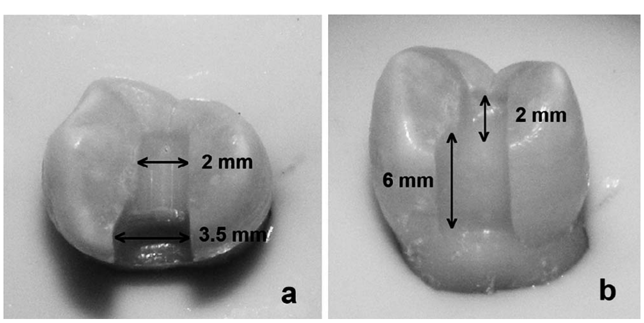


Figure 1. *Standard cavity preparation.*

Protocol 2 (capped): Twenty-four cavities were bulk-filled in 4-mm increments using different bulk-fill materials (Prime&Bond NT/SureFil SDR, Dentsply, Germany, Single Bond Universal/Filtek Bulk-Fill Posterior, 3M ESPE, USA, and Tetric N-Bond/Tetric N-Ceram Bulk-Fill, Ivoclar-Vivadent, Liechtenstein; n= 8) with the addition of a 2-mm capping layer using the Filtek Z350 XT composite without bonding agent. The first layer was cured for 20 seconds, and the second layer was cured for 10 seconds.

Protocol 3 (uncapped): Twenty-four cavities were restored with the three bulk-filled composite materials (n=8) in two increments: a 4-mm increment cured for 20 seconds and a 2-mm increment cured for 10 seconds.

Protocol 4 (extended light curing): Twenty-four cavities were restored with the three bulk-filled composite materials (n=8) in two increments: a 4-mm increment cured for 40 seconds and a 2-mm increment cured for 20 seconds.

A light-emitting diode light-curing unit was used (Bluephase G2, Ivoclar Vivadent AG, Schaan, Liechtenstein). The light-guide tip was placed in contact with the tooth cusps, and the distance was kept at 2 mm from the marginal ridge. Analysis and measurement of the irradiance values (1200 mW/cm^2), spectrum emission, and total energy delivered for each specimen were performed with the use of a MARC-RC device (BlueLight Analytics Inc, Halifax, NS, Canada). After restoring the teeth, excess material was removed, and finishing and polishing were done using diamond composite finishing burs (flame-shaped DOS1F, Brasseler, Savannah, GA, USA), Soflex polishing discs (3M ESPE, St Paul, MN, USA), a scalpel, and a number 12 blade.

Table 3: *Mean and Standard Deviation Values of the Mean Fracture Resistance (N) of the Different Groups*

Material	Type	N	Mean	Standard Deviation	Standard Error	95% Confidence Interval for Mean		Minimum	Maximum
						Lower Bound	Upper Bound		
Filtek Z350 XT	Control	8	67.55	15.66	3.25	60.9	74.2	42.59	83.91
SDR	Capped	8	68.95	2.59	0.91	58.04	79.86	65.30	72.61
	Uncapped	8	48.65	6.48	2.29	44.58	71.70	42.41	59.58
	Extended LC	8	51.81	10.52	3.72	48.24	75.35	36.84	60.48
Filtek Bulk Fill Posterior	Capped	8	74.52	4.13	1.46	70.00	79.04	65.78	78.71
	Uncapped	8	70.61	4.19	1.48	59.70	81.52	61.35	74.05
	Extended LC	8	70.10	7.21	2.55	59.19	81.02	57.72	80.60
Tetric N-Ceram Bulk Fill	Capped	8	71.50	2.11	0.75	60.59	82.42	66.98	73.93
	Uncapped	8	53.08	8.23	2.91	46.44	73.56	40.70	65.23
	Extended LC	8	63.10	7.10	2.51	56.97	84.09	57.48	78.38

Examination of Restoration Margins

After restoration, the teeth were stored in a distilled water solution at 37°C for two weeks. During this time, the teeth underwent thermocycling (Thermocycler 1106/1206, SD Mechatronik, Feldkirchen-Westerham, Germany) for 5000 cycles, with water baths between 5°C and 55°C, a dwell time of 30 seconds, and a transfer time of five seconds. Later, the marginal gaps along the restoration margins were measured using a digital microscope (HIROX Digital Microscope, Hirox Co Ltd, Tokyo, Japan) at a magnification of 150× to 200×. The restoration margins were divided into sections: the buccal and lingual margins divided into two sections, the gingival margin divided into three sections, and the interface between the composite layers was divided into two sections. An average reading for each section was taken in micrometers (μm), and the mean marginal gap was calculated.

Fracture Resistance Test

After the thermocycling and marginal examination were done, the teeth were embedded into a plastic ring 2.5 cm in diameter and 3 cm in length. An autopolymerizing resin (Orthoresin, DeguDent GmbH, Hanau, Germany) was used up to 3 mm below the cemento-enamel junction in order to be able to fit the specimens into the jig of the Instron machine.

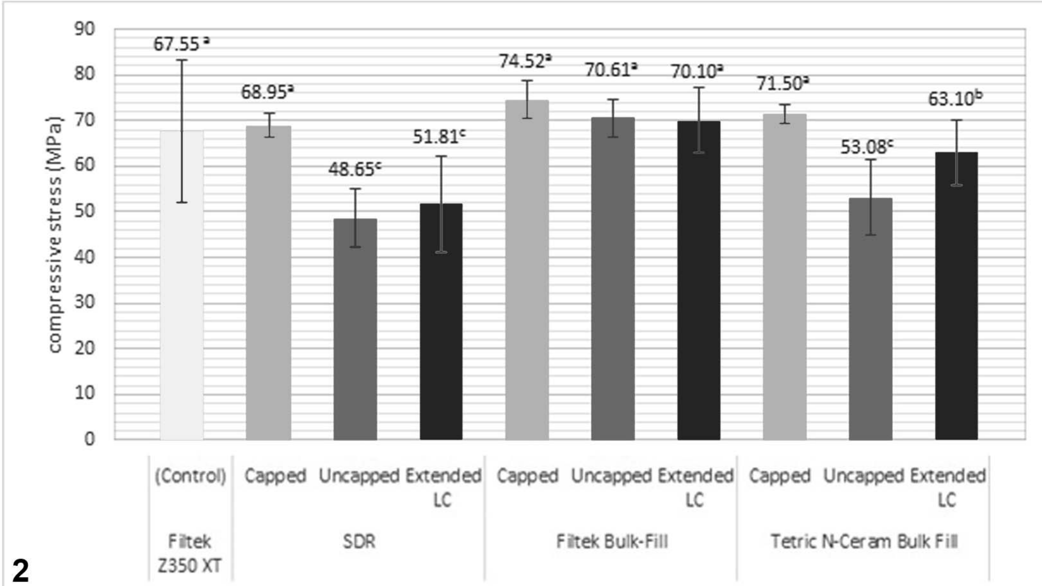
A flame-shaped diamond finishing bur was used to create a small flat area in the middle of the restoration's marginal ridge that was used as the point for force loading. Care was taken to ensure that the occluso-gingival length of the restoration was standardized at 6 mm. A universal testing machine (ElectroPuls E3000, Instron, Norwood, MA, USA) with a smooth, 0.5-mm tipped, round-ended stainless-steel rod attached to its upper member was used to fracture the specimens. They were subjected to a compressive axial loading with a crosshead speed of 1 mm/min. The failure loads of the restorations were determined and recorded in newtons (N). The fracture mode of each specimen was evaluated under a stereomicroscope (SMZ 1000, Nikon, Tokyo, Japan) at 3× magnification and photographed. It was classified into three groups: cohesive fracture of tooth structure, cohesive fracture of the filling material, and mixed fracture of both tooth structure and the filling material. In addition, three representative samples from each group were coated with gold-palladium and examined under a scanning electron microscope (JSM-6360LV, JEOL, Tokyo, Japan).

Statistical Analysis

The Kolmogorov-Smirnov normality test was carried out and satisfied. The statistical analysis was done using SPSS version 22.0 for Windows (IBM, Chicago, IL, USA). Two-way analysis of variance (ANOVA) and the Tukey honestly significant difference multiple comparisons test were carried out to compare the fracture resistance of different bulk-fill RBCs and determine the influence of the different protocols used. One-way ANOVA was carried out to compare the control with the bulk-fill groups prepared according to the manufacturers' instructions. The level of significance was set at $\alpha = 0.05$ for all tests.

RESULTS

The mean fracture loads of the different groups are presented in Table 3 and depicted in Figure 2. The two-way ANOVA revealed a statistically significant



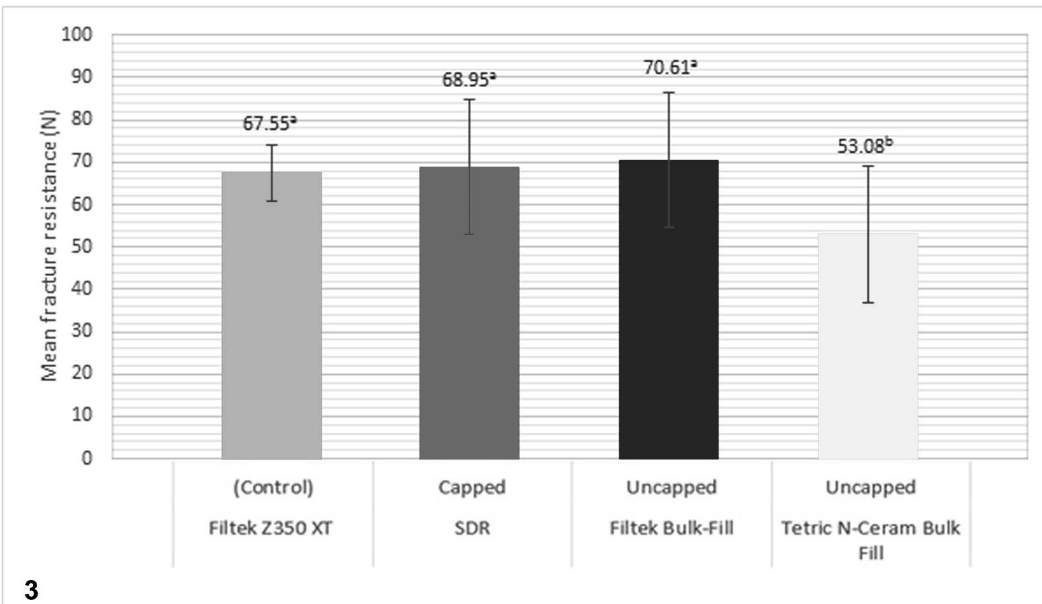


Figure 2. *Chart presenting the mean values of fracture resistance (N) of each material within the different protocols with standard deviation bars. Different superscript letters indicate statistical differences between the bulk-fill restorations and protocols.*

Figure 3. *Chart presenting the mean values of fracture resistance (N) and results of one-way analysis of variance comparing groups prepared following the manufacturers' instructions. Different superscript letters indicate statistical differences.*

difference among the experimental groups and among the different materials within the different protocols ($p<0.001$). Also, the interaction between material and protocol was highly significant ($p=0.0016$) (Table 4; Figure 2). The Filtek Bulk-Fill Posterior composite showed the highest fracture resistance values, while SDR showed the lowest values. Filtek Bulk-Fill Posterior was not affected by the different restoration protocols used. Capped SDR and Tetric N-Ceram bulk-fill groups showed significantly higher fracture resistance values than uncapped groups ($p<0.000$), and the capped SDR group was higher than the extended light cure group ($p<0.000$).

When taking into consideration the protocol effect for all of the bulk-fill materials' fracture resistance values, the statistically significant difference between Filtek Bulk-Fill Posterior and the other bulk-

Table 4: *Results of Two-Way Analysis of Variance Showing the Interaction Between the Different Materials and Protocols*

Source	Type III Sum of Squares	Degrees of Freedom	*F*-Value	Significance (*p*)
Intercept	44,423	1	1085.2062	0.000 (2.2e-16)
Material	124	2	1.5192	0.227
Protocol	93	2	1.1405	0.326
Material × protocol	807	4	4.9295	0.0016
Residuals	2579	63		

fill materials disappeared when a capping layer was used. Also, a significant difference between SDR and Tetric N-Ceram Bulk-Fill was seen only when a higher radiant exposure was used (p=0.02). The radiant exposure increase had no statistically significant effect on the fracture resistance values of bulk-fill restorations; nonetheless, there was a noticeable increase in the fracture resistance of Tetric N-Ceram Bulk-Fill composite, although the increase was not significant statistically (p=0.061).

The one-way ANOVA comparing the four groups that were prepared following the manufacturers' instructions revealed a significant difference (p=0.002) between them. Tetric N-Ceram Bulk-Fill mean fracture resistance was lower than the other bulk-fill materials. No statistically significant difference was found between the incrementally placed conventional nanohybrid RBC (control) and the Filtek Bulk-Fill Posterior or capped SDR bulk-fill composite groups (Table 5; Figure 3).

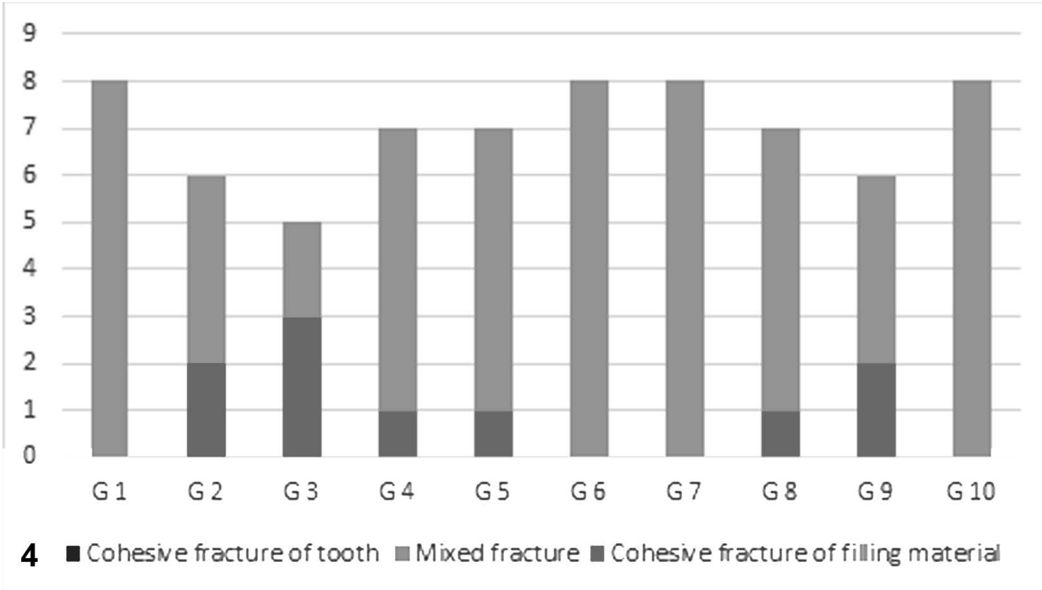
Examination of the fractured parts under a light microscope revealed that the fracture mode was mostly a mixed fracture of both tooth structure and the filling material (Figure 4). Severe fractures involving both composite and tooth structure were observed.

The mean marginal gap values for the tested groups are shown in Figure 5. Gaps were highest in the capped groups followed by the extended light cure groups, with uncapped groups demonstrating the fewest number of gaps. The enamel margins (buccal and lingual) showed lower marginal gap values compared to the dentin/cementum margin (gingival) in all tested groups. The gap values of gingival margin of the tested groups were similar to each other. Gaps between increments were found only in the control group and capped bulk-fill group. Figure 6 shows examples of some of the marginal gaps.

Macroscopic examination of the fractured specimens did not reveal any significant plastic deformation. The higher energy involved in fast fracture led to rough fracture surfaces and evidence of multiple crack planes (Figure 7a,b). Fractographic features, such as hackle lines, radial marks, and rip marks, were easily found on the fractured surfaces. Localized crushing at the point of contact was clearly evident at the surface and subsurface (Figure 7c). Also, in many specimens, a semiellipse was observed around the fracture origin. Crack lines started at the surface of the composite and propagated toward the gingival and then deflected, developing a compres-

Table 5: *Results of One-Way Analysis of Variance and Tukey Honest Significant Difference Multiple Comparisons of the Mean Fracture Load of Groups Prepared Following the Manufacturers' Instructions*

	Sum of Squares	Degrees of Freedom	*F*-Value	Significance (*p*)
(Intercept)	36,505	1	432.9259	0.000 (< 2.2e-16)
Materials	1566	3	6.1895	0.0023
Residuals	2361	28		
Materials	**Difference**	**Lower Bound**	**Upper Bound**	**Significance (*p*)**
Filtek Bulk Fill, Z350 XT	3.057625	−9.47811	15.593360	0.909
SDR capped, Z350 XT	1.397375	−11.13836	13.933110	0.990
Tetric N-Ceram, Z350 XT	−14.474500	−27.01024	−1.938765	0.019
SDR capped, Filtek Bulk Fill	−1.660250	−14.19599	10.875485	0.983
Tetric N-Ceram, Filtek Bulk Fill	−17.532125	−30.06786	−4.996390	0.004
TetricN-SDR capped	−15.871875	−28.40761	−3.336140	0.009



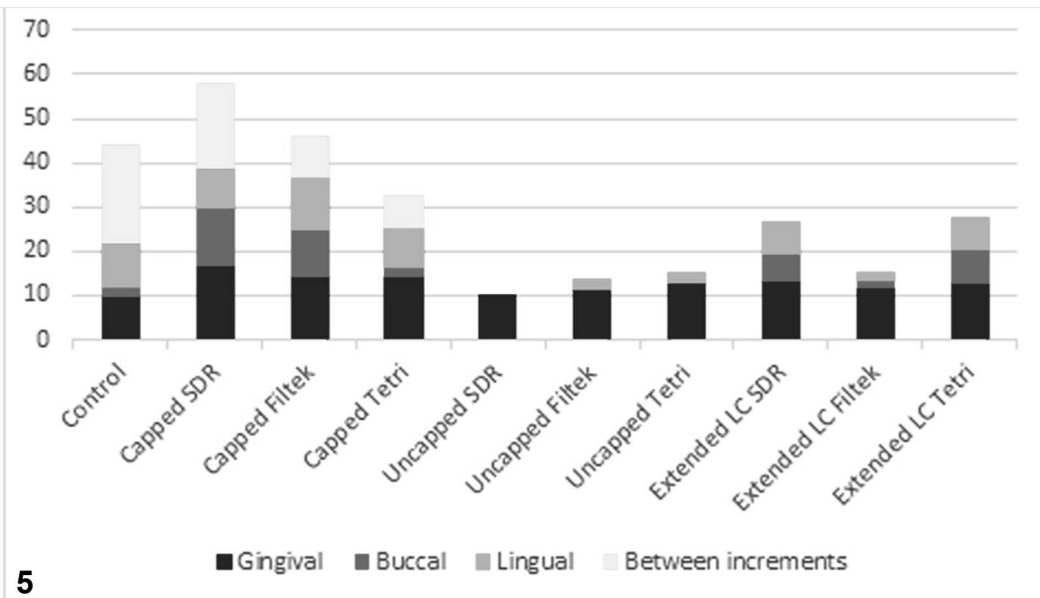


Figure 4. *Chart presenting the fracture mode of tested groups.*

Figure 5. *Mean marginal gap values of tested materials.*

sion curl that was observed in many specimens close to the gingival floor (Figure 8). In some specimens, chipping and steplike cracking patterns were seen (Figure 7d). A mirror at a crack origin was not evident on any of the specimens except one. This sample showed two sites of failures: one in the marginal ridge where the force was applied and another in the buccal wall, showing a clear mirror region where some marginal enamel had fractured (Figure 8).

DISCUSSION

Sarrett[20] has reported that the two main concerns with dental RBCs are bulk fracture and secondary caries. The propensity of a particular restoration to fracture in the oral cavity is very difficult to measure since it is affected by many factors. These factors include the material composition and properties, cavity size, integrity of the tooth structure, and the effectiveness of bonding. The restorative procedures allow transfer of the compressive masticatory stress-

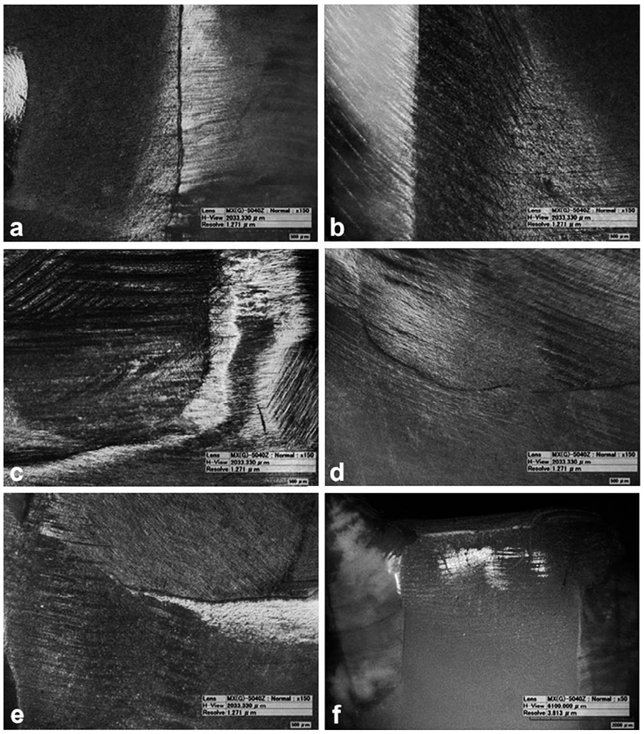


Figure 6. *Digital microscope images of marginal gaps. (a): Marginal gaps in lingual wall, capped SDR. (b): Continuous margin in buccal wall, SDR extended LC. (c): Gingival margin gaps, incremental Filtek Z350 XT. (d): Gingival margin gaps, capped Filtek Bulk-Fill. (e): Marginal gaps between increments, capped SDR. (f): Continuous margin between increments, SDR extended LC.*

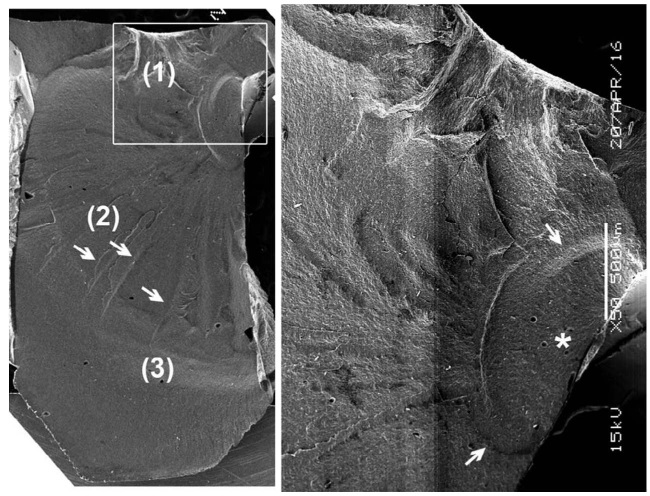


Figure 8. *Photomicrograph of a fractured sample showing two areas of fracture: one in the marginal ridge, where the force was applied, and another in the buccal wall, where some marginal enamel fractured. Left: (1): Fracture origin. (2): Mist and hackle region; radial marks can be seen (white arrows). (3): Compression curl. Right: A mirror region can be seen, indicated by the asterisk (*), and rip marks (semielliptical curved lines) are indicated by double arrows.*

es to the tooth structure and alter the original stress distributions. In addition, residual post–gel polymerization shrinkage stresses are affected by the modulus of elasticity of the composite and tooth structures, polymerization conversion rate, bonding conditions, and geometrical features.[21,22] Therefore,

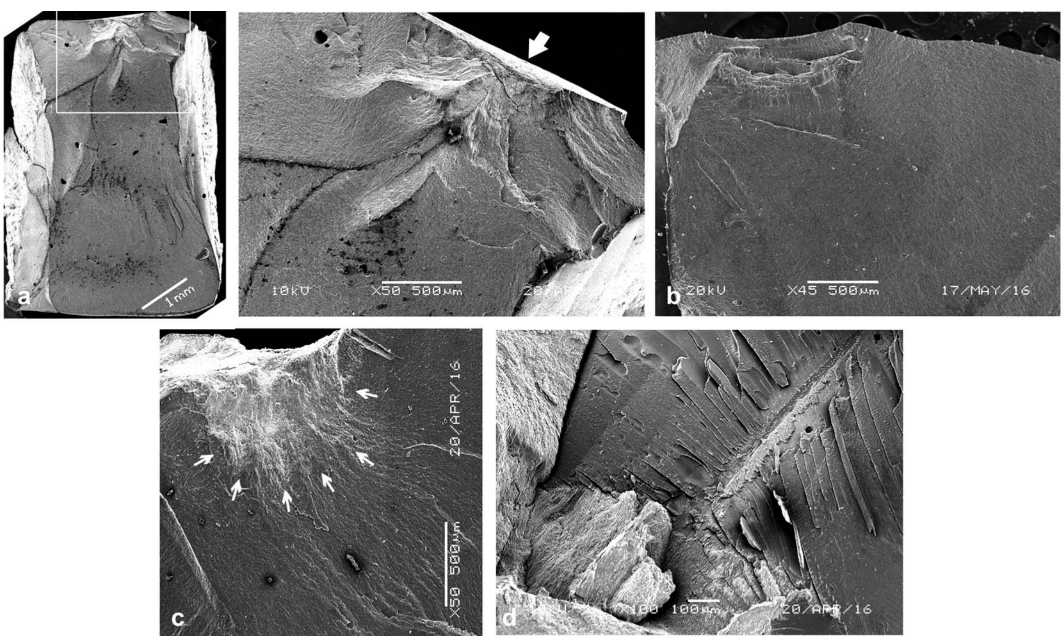


Figure 7. *(a) Fractured restoration (left) and crack initiation site represented by the arrow (right); chevron points/pattern (V-shaped radial marks) pointing toward the crack origin site, demonstrating crack branching or crack bifurcation. (b): A sample showing multiple crack planes and hackles radiating from the site of fracture origin. (c): Localized crushing and radiating hackles at the site of fracture origin; a semiellipse is also seen represented by arrows. (d): Steplike cracking patterns.*

in studying the fracture resistance (or loads at fracture) of restorations in clinical simulation conditions, the confounding factors are unavoidable, and the results should be carefully interpreted, as it is the outcome of the effects of composite resin mechanical properties, tooth factors, bond strength, and filling techniques.

Bulk-fill RBCs were developed to provide a faster restoration procedure and to minimize the possibility of void entrapment or contamination between the layers. Some studies have also reported reduced cusp deformation and higher fracture resistance with bulk-fill composites.[23,24] The addition of a 2-mm capping layer was recommended by some manufacturers.[13,14] However, the newer generation of bulk-fill RBCs are promoted to be used without a capping layer. In this study, the effect of adding a capping layer and extended light curing on fracture resistance of bulk-fill composite restorations were tested.

The capped bulk-fill composites showed fracture resistance values comparable to that of conventional nanohybrid RBC Filtek Z350 XT. Capping increased the fracture resistance values for SDR and Tetric N-Ceram Bulk-Fill composites. On the other hand, the performance of the Filtek Bulk-Fill composite was not significantly improved by the addition of a capping layer; it achieved consistently high fracture resistance values regardless of capping or light curing. Therefore, the first and third null hypotheses are partially rejected.

The Filtek Bulk-Fill composite's fracture resistance was higher than that of both SDR and Tetric N-Ceram Bulk-Fill; thus, the second null hypothesis is rejected. The performance of Tetric N-Ceram Bulk-Fill improved with the addition of a capping layer, and it was able to achieve fracture resistance values comparable to that of the Filtek Bulk-Fill composite. Higher filler loading has been associated with higher mechanical properties.[25-27] Although the filler content of Filtek Bulk-Fill (58.4% by volume) and Tetric N-Ceram Bulk-Fill (53% to 55% by volume) are comparable and both are promoted to be used without the need of a capping layer, Filtek Bulk-Fill showed a significantly higher fracture resistance. Tetric N-Ceram Bulk-Fill, with its higher filler content, was also expected to achieve higher results than SDR. However, the two materials showed similar performances. This could be related to the filler content of Tetric N-Ceram Bulk-Fill, which included prepolymerized filler particles.

Prepolymerized fillers consist of organic resin and inorganic fillers that are cured and then milled or ground down, producing resin filler particles that are added to the nonpolymerized resin and inorganic fillers. They are usually added to increase filler loading.[8,28,29] However, the inclusion of prepolymerized fillers in the filler count is believed to overestimate the actual inorganic filler content.[13,28] It has even been questioned whether prepolymerized filler particles should be considered fillers.[26] Lower mechanical properties have been reported with composites containing prepolymerized fillers.[26,30] One of the major limitations of these fillers is the weak bond between the prepolymerized particles and the clinically cured resin matrix that decreases the tensile strength of the composite.[28] The poor integration between prepolymerized fillers and the resin matrix is related to the difficulty of silanization. This is due to a lack of active binding sites since they have already been cured.[26] Another probable cause for the lower fracture resistance values of Tetric N-Ceram Bulk-Fill is the monomer component bisphenol A-glycidyl methacrylate (Bis-EMA). Tetric N-Ceram Bulk-Fill contains Bis-EMA as a comonomer, and lower flexural strength was documented for composites containing this comonomer.[31]

The higher fracture resistance of Filtek Bulk-Fill composites compared to other bulk-fill composites could be related to the incorporation of the aggregated zirconia/silica cluster filler within the filler system. In a study by Curtis and others[32] that investigated the mechanical properties of discrete filler particles by subjecting them to compression forces, the nanocluster showed the capability to withstand higher fracture forces than conventional fillers. They also showed an ability to modify the crack propagation and failure mechanisms, thus contributing to the resin matrix reinforcement. In another study, the nanocluster showed a unique response to cyclic fatigue preloading regimes, increasing the composite's resistance to fracture and strength degradation.[33]

SDR has the lowest filler content (47% by volume) of the bulk-fill materials tested in this study, which may explain the lower fracture resistance values it attained. In this study, the SDR performance was improved when it was capped, reaching values comparable to that of Filtek Bulk-Fill and capped and extended curing Tetric N-Ceram Bulk-Fill. The performances of SDR and Tetric N-Ceram Bulk-Fill were similar. Extending the light curing time did not increase the fracture strength of SDR and Tetric N-Ceram Bulk-Fill composites significantly. However, the additional time allowed uncapped Tetric N-Ceram Bulk-Fill to achieve significantly higher fracture resistance values than uncapped SDR. According to the manufacturers, Filtek Bulk-Fill and SDR are available in semitranslucent shades that help provide the desired depth of cure,[34,35] while Tetric N-Ceram Bulk-Fill has a more enamel-like translucency. An excellent depth of cure has been previously reported for SDR.[10,36] Son and others[37] reported a lower translucency parameter for Tetric N-Ceram Bulk-Fill compared to SDR and flowable Filtek Bulk-Fill. In addition, lower light attenuation—and thus a higher light transmission—was documented for SDR compared to Tetric N-Ceram Bulk-Fill.[11,37,38]

Li and others[11] suggested that translucency could be the main variable that controls curing efficiency at depth. Translucent materials reportedly allow lower light scattering[39] and have been associated with a higher depth of cure.[40,41] Tetric N-Ceram Bulk-Fill might allow less light penetration during the early polymerization period due to its higher opacity and higher viscosity; however, an increase in light transmittance was observed with the polymerized compared to the unpolymerized composite resin. Additionally, the more organized polymer network permits easier passage of light through the composite bulk.[41,42] The limited depth of cure of Tetric N-Ceram Bulk-Fill and the increase in depth of cure with extended light curing have been observed in several studies.[10,36,41,43,44]

SDR and flowable Filtek Bulk-Fill show consistent polymerization properties at different increment thicknesses, demonstrating their ability to cure sufficiently without the need to extend the light curing process. Garoushi and others[38] measured the degree of conversion of bulk-fill RBC through different increment thicknesses. Both SDR and flowable Filtek Bulk-Fill showed no correlation between thickness and degree of conversion, unlike Tetric N-Ceram Bulk-Fill, which showed a significant correlation as the degree of conversion decreased with the increase in increment thickness. Likewise, Flury and others[45] reported a decrease in Tetric N-Ceram Bulk-Fill Vickers microhardness with the increase in increment thickness, while SDR and flowable Filtek Bulk-Fill showed no significant difference in Vickers microhardness.

When reviewing the literature that compared the mechanical properties of Tetric N-Ceram Bulk-Fill and SDR, Tetric N-Ceram Bulk-Fill was reported to have a higher flexural modulus,[44] Vickers microhardness,[13,14,23] indentation modulus,[13] and modulus of elasticity.[14] SDR seems to have higher flexural strength and fracture toughness.[44] On the other hand, some studies documented comparable flexural modulus,[13] flexural strength,[14] compressive strength values, and fracture resistance for SDR and Tetric N-Ceram Bulk-Fill.[23] Tetric N-Ceram Bulk-Fill and SDR seem to have comparable mechanical properties. However, when both were compared to conventional RBCs, higher flexural strength, flexural modulus,[46] modulus of elasticity, and Vickers microhardness values[14] were reported for conventional RBCs. Nonetheless, Rosatto and others[23] recorded comparable compressive strength of Tetric N-Ceram Bulk-Fill and conventional RBCs. Another study reported no differences in fracture strength of SDR and a conventional submicron hybrid composite RBC.[47] In this study, only capped Tetric N-Ceram Bulk-Fill and SDR were able to achieve fracture resistance values comparable to that of Filtek Z350 XT.

No differences in marginal integrity between the different bulk-fill materials or between conventional nanohybrid RBC and bulk-fill materials (SonicFill, Tetric EvoCeram Bulk-Fill, and SDR) were detected in previous studies,[48,49] which is in agreement with the findings of this study. Additionally, higher marginal integrities in enamel than in dentin were reported in several studies,[48-50] consistent with the current study.

In bulk-fill materials, better adaptation without gaps between the first and second increments was observed when the same material was used, whereas when a capping layer of a different material was used, gaps were seen between the increments. Furthermore, the gap values of buccal and lingual walls increased when a capping layer was used and when the light cure exposure was extended. Gap development has been associated with polymerization contraction,[49] and extended light curing was correlated with an increase in contraction stress,[10,50] which explains the increase in gap size with extended exposure time. A higher polymerization contraction was reported for SDR than Tetric N-Ceram Bulk-Fill and conventional RBC;[49] nonetheless, the gap values of SDR in this study were comparable to that of other materials. This could be attributed to the advanced stress-decreasing resin technology incorporated within it in the form of a polymerization modulator embedded in the center of the resin monomer backbone.[51] In addition, the flowable nature of the SDR material might have allowed some stress relief during the polymerization contraction. Calheiros and others[52] and Kleverlaan and Feilzer[53] have identified the material's viscoelastic properties as the most influential factor in polymerization contraction stress development. RBC materials with higher viscosity showed higher contraction stress. The gaps at the gingival margins were wider than at the proximal margins, which is in accordance with the results reported by a previous study.[49]

Polymers can show brittle behavior, which is not significantly influenced by the strain rate. The polymer's susceptibility to cracking and brittle fracture was also found during compression testing. This susceptibility was due to any local inhomogeneity in the specimen that could lead to local tensile stress, which initialized the brittle failure. As the crack propagates, it reaches the maximum speed, which has enough energy to initiate secondary cracks, known as hackle lines. This feature was frequently seen in the scanning electron microscopic images. During the brittle fracture, the cleavage stops, and the fracture planes recombine in the course of further propagation. Chips are formed in front of the crack propagation line, and they explain the occurrence of steplike cracking patterns in some specimens.[54,55]

Fractographic features common to plastics are radial marks and rip marks. Radial marks are lines on a fracture surface that radiate outward from the origin and are formed by the intersection of brittle fractures propagating at different levels. Rip marks are shown around the mirror area as semiellipses curving around the site of impact, suggestive of subcritical crack growth.[54,55]

CONCLUSIONS

Within the limitations of this study, the following conclusions can be made:

- Filtek Bulk-Fill Posterior restorations showed consistently high fracture resistance under all conditions.
- Filtek Bulk-Fill Posterior and Filtek Z350 XT conventional composite restorations have comparable fracture resistance values.
- With restorations of SDR bulk-fill and Tetric N-Ceram Bulk-Fill, the addition of a capping layer is necessary for adequate fracture resistance.
- Tetric N-Ceram Bulk-Fill restorations can benefit from extending the curing time from 20 to 40 seconds.
- Gap formation does not differ from the bulk-fill composite and the conventional composite.
- Better adaptation between increments/layers is achieved when using the same material.

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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 College of Dentistry Research Center at King Saud University. The approval code for this study is: registration #PR 0037.

Conflict of Interest

The authors of this article 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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REFERENCES

1. Sakaguchi RL & Powers JM (2012) *Craig's Restorative Dental Materials* **13th Edition** Mosby, St Louis MO.
2. Ferracane JL (2005) Developing a more complete understanding of stresses produced in dental composites during polymerization *Dental Materials* **21(1)** 36-42. 10.1016/j.dental.2004.10.004
3. Hilton TJ (2002) Can modern restorative procedures and materials reliably seal cavities? In vitro investigations. Part 1 *American Journal of Dentistry* **15(3)** 198-210
4. 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.
5. Taubock TT, Feilzer AJ, Buchalla W, Kleverlaan CJ, Krejci I, & Attin T (2014) Effect of modulated photo-activation on polymerization shrinkage behavior of dental restorative resin composites *European Journal of Oral Sciences* **122(4)** 293-302. 10.1111/eos.12139
6. Cara RR, Fleming GJ, Palin WM, Walmsley AD, & Burke FJ (2007) Cuspal deflection and microleakage in premolar teeth restored with resin-based composites with and without an intermediary flowable layer *Journal of Dentistry* **35(6)** 482-489. 10.1016/j.jdent.2007.01.005
7. Cramer NB, Stansbury JW, & Bowman CN (2011) Recent advances and developments in composite dental restorative materials *Journal of Dental Research* **90(4)** 402-416. 10.1177/0022034510381263
8. Ferracane JL (2011) Resin composite—State of the art *Dental Materials* **27(1)** 29-38. 10.1016/j.dental.2010.10.020
9. Campodonico CE, Tantbirojn D, Olin PS, & Versluis A (2011) Cuspal deflection and depth of cure in resin-based composite restorations filled by using bulk, incremental

and transtooth-illumination techniques *Journal of the American Dental Association* **142(10)** 1176-1182.

10. Zorzin J, Maier E, Harre S, Fey T, Belli R, Lohbauer U, Petschelt A, & Taschner M (2015) Bulk-fill resin composites: Polymerization properties and extended light curing *Dental Materials* **31(3)** 293-301. 10.1016/j.dental.2014.12.010

11. Li X, Pongprueksa P, Van Meerbeek B, & De Munck J (2015) Curing profile of bulk-fill resin-based composites *Journal of Dentistry* **43(6)** 664-672. 10.1016/j.jdent.2015.01.002

12. Czasch P & Ilie N (2013) In vitro comparison of mechanical properties and degree of cure of bulk fill composites *Clinical Oral Investigations* **17(1)** 227-235. 10.1007/s00784-012-0702-8

13. Ilie N, Bucuta S, & Draenert M (2013) Bulk-fill resin-based composites: An in vitro assessment of their mechanical performance *Operative Dentistry* **38(6)** 618-625. 10.2341/12-395-l

14. Leprince JG, Palin WM, Vanacker J, Sabbagh J, Devaux J, & Leloup G (2014) Physico-mechanical characteristics of commercially available bulk-fill composites *Journal of Dentistry* **42(8)** 993-1000. 10.1016/j.jdent.2014.05.009

15. Eliades GC & Caputo AA (1989) The strength of layering technique in visible light-cured composites *Journal of Prosthetic Dentistry* **61(1)** 31-38.

16. Truffier-Boutry D, Place E, Devaux J, & Leloup G (2003) Interfacial layer characterization in dental composite *Journal of Oral Rehabilitation* **30(1)** 74-77.

17. Shawkat ES, Shortall AC, Addison O, & Palin WM (2009) Oxygen inhibition and incremental layer bond strengths of resin composites *Dental Materials* **25(11)** 1338-1346. 10.1016/j.dental.2009.06.003

18. Ribeiro JC, Gomes PN, Moyses MR, Dias SC, Pereira LJ, & Ribeiro JG (2008) Shear strength evaluation of composite-composite resin associations *Journal of Dentistry* **36(5)** 326-330, 10.1016/j.jdent.2008.01.015.

19. Ornaghi BP, Meier MM, Lohbauer U, & Braga RR (2014) Fracture toughness and cyclic fatigue resistance of resin composites with different filler size distributions *Dental Materials* **30(7)** 742-751. 10.1016/j.dental.2014.04.004

20. Sarrett DC (2005) Clinical challenges and the relevance of materials testing for posterior composite restorations *Dental Materials* **21(1)** 9-20. 10.1016/j.dental.2004.10.001

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

22. 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 10.3290/j.jad.a29012

23. 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. 10.1016/j.jdent.2015.09.007

24. Moorthy A, Hogg CH, Dowling AH, Grufferty BF, Benetti AR, & Fleming GJ (2012) Cuspal deflection and microleakage in premolar teeth restored with bulk-fill flowable resin-based composite base materials *Journal of Dentistry* **40(6)** 500-505. 10.1016/j.jdent.2012.02.015

25. Beun S, Glorieux T, Devaux J, Vreven J, & Leloup G (2007) Characterization of nanofilled compared to universal and microfilled composites *Dental Materials* **23(1)** 51-59. 10.1016/j.dental.2005.12.003

26. Randolph LD, Palin WM, Leloup G, & Leprince JG (2016) Filler characteristics of modern dental resin composites and their influence on physico-mechanical properties *Dental Materials* **32(12)** 1586-1599. 10.1016/j.dental.2016.09.034

27. Ilie N & Hickel R (2009) Investigations on mechanical behaviour of dental composites *Clinical Oral Investigations* **13(4)** 427-438. 10.1007/s00784-009-0258-4

28. Anusavice KJ, Phillips RW, Shen C, & Rawls HR (2013) *Phillips' Science of Dental Materials* **12th edition** Elsevier/Saunders, St Louis MO

29. Salazar DC, Dennison J, & Yaman P (2013) Inorganic and prepolymerized filler analysis of four resin composites *Operative Dentistry* **38(6)** E201-E209. 10.2341/12-474-l

30. Blackham JT, Vandewalle KS, & Lien W (2009) Properties of hybrid resin composite systems containing prepolymerized filler particles *Operative Dentistry* **34(6)** 697-702. 10.2341/08-118-L

31. Goncalves F, Kawano Y, Pfeifer C, Stansbury JW, & Braga RR (2009) Influence of BisGMA, TEGDMA, and BisEMA contents on viscosity, conversion, and flexural strength of experimental resins and composites *European Journal of Oral Sciences* **117(4)** 442-446. 10.1111/j.1600-0722.2009.00636.x

32. Curtis AR, Palin WM, Fleming GJ, Shortall AC, & Marquis PM (2009) The mechanical properties of nanofilled resin-based composites: Characterizing discrete filler particles and agglomerates using a micromanipulation technique *Dental Materials* **25(2)** 180-187. 10.1016/j.dental.2008.05.013

33. Curtis AR, Palin WM, Fleming GJ, Shortall AC, & Marquis PM (2009) The mechanical properties of nanofilled resin-based composites: The impact of dry and wet cyclic pre-loading on bi-axial flexure strength *Dental Materials* **25(2)** 188-197. 10.1016/j.dental.2008.06.003

34. 3M ESPE (2015) Filtek Bulk Fill Posterior Restorative Technical Product Profile. *St Paul, MN: 3M ESPE*.

35. Dentsply (2015) SureFil SDR Flow DFU. *York, PA: Dentsply*.

36. Jang JH, Park, SH & Hwang IN (2015) Polymerization shrinkage and depth of cure of bulk-fill resin composites and highly filled flowable resin *Operative Dentistry* **40(2)** 172-180. 10.2341/13-307-L

37. Son SA, Park JK, Seo DG, Ko CC, & Kwon YH (2017) How light attenuation and filler content affect the microhardness and polymerization shrinkage and translucency of

bulk-fill composites? *Clinical Oral Investigations*. **21(2)** 559-565, 10.1007/s00784-016-1920-2

38. Garoushi S, Vallittu P, Shinya A, & Lassila L (2016) Influence of increment thickness on light transmission, degree of conversion and micro hardness of bulk fill composites *Odontology* **104(3)** 291-297. 10.1007/s10266-015-0227-0

39. Leloup G, Holvoet PE, Bebelman S, & Devaux J (2002) Raman scattering determination of the depth of cure of light-activated composites: Influence of different clinically relevant parameters *Journal of Oral Rehabilitation* **29(6)** 510-515.

40. Ferracane JL, Aday P, Matsumoto H, & Marker VA (1986) Relationship between shade and depth of cure for light-activated dental composite resins *Dental Materials* **2(2)** 80-84.

41. Ilie N & Stark K (2014) Curing behaviour of high-viscosity bulk-fill composites *Journal of Dentistry* **42(8)** 977-985. 10.1016/j.jdent.2014.05.012

42. dos Santos GB, Alto RV, Filho HR, da Silva EM, & Fellows CE (2008) Light transmission on dental resin composites *Dental Materials* **24(5)** 571-576. 10.1016/j.dental.2007.06.015

43. Flury S, Hayoz S, Peutzfeldt A, Husler, J & Lussi A (2012) Depth of cure of resin composites: Is the ISO 4049 method suitable for bulk fill materials? *Dental Materials* **28(5)** 521-528, 10.1016/j.dental.2012.02.002

44. Garoushi S, Sailynoja E, Vallittu PK, & Lassila L (2013) Physical properties and depth of cure of a new short fiber reinforced composite *Dental Materials* **29(8)** 835-841. 10.1016/j.dental.2013.04.016

45. Flury S, Peutzfeldt A, & Lussi A (2014) Influence of increment thickness on microhardness and dentin bond strength of bulk fill resin composites *Dental Materials* **30(10)** 1104-1112. 10.1016/j.dental.2014.07.001

46. El-Damanhoury H & Platt J (2014) Polymerization shrinkage stress kinetics and related properties of bulk-fill resin composites *Operative Dentistry* **39(4)** 374-382. 10.2341/13-017-L

47. de Assis FS, Lima SN, Tonetto MR, Bhandi SH, Pinto SC, Malaquias P, Loguercio AD, & Bandeca MC (2016) Evaluation of bond strength, marginal integrity, and fracture strength of bulk- vs incrementally-filled restorations *Journal of Adhesive Dentistry* **18(4)** 317-323. 10.3290/j.jad.a36516

48. Al-Harbi F, Kaisarly D, Bader D, & El Gezawi M (2016) Marginal integrity of bulk versus incremental fill class II composite restorations *Operative Dentistry* **41(2)** 146-156. 10.2341/14-306-L

49. Benetti AR, Havndrup-Pedersen C, Honore D, Pedersen MK, & Pallesen U (2015) Bulk-fill resin composites: Polymerization contraction, depth of cure, and gap formation *Operative Dentistry* **40(2)** 190-200. 10.2341/13-324-L

50. Calheiros FC, Kawano Y, Stansbury JW, & Braga RR (2006) Influence of radiant exposure on contraction stress, degree of conversion and mechanical properties of resin composites *Dental Materials* **22(9)** 799-803. 10.1016/j.dental.2005.11.008

51. Dentsply (2011) SureFil SDR Flow Scientific Compendium. *York, PA: Dentsply*.

52. Calheiros FC, Sadek FT, Braga RR, & Cardoso PE (2004) Polymerization contraction stress of low-shrinkage composites and its correlation with microleakage in class V restorations *Journal of Dentistry* **32(5)** 407-412. 10.1016/j.jdent.2004.01.014

53. Kleverlaan CJ & Feilzer AJ (2005) Polymerization shrinkage and contraction stress of dental resin composites *Dental Materials* **21(12)** 1150-1157. 10.1016/j.dental.2005.02.004

54. Becker W & Lampman S (2002) Fracture Appearance and Mechanisms of Deformation and Fracture *Materials Park, OH: ASM International* 559-586

55. Callister WD & Rethwisch DG (2011) Materials Science and Engineering *New York, NY: John Wiley & Sons*.