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Incremental Filling Technique and Composite Material—Part I: Cuspal Deformation, Bond Strength, and Physical Properties

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Clinical Relevance

The use of a large number of increments caused an increase in cuspal deflection during composite polymerization in large posterior restorations. A balance between adequate bonding with good mechanical properties of the composite and lower cuspal deformation was obtained with 2.0-mm increments.

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SUMMARY

Objectives: To evaluate the effect of composite resins (one conventional and two low-shrink composites) and filling techniques on cuspal strains (CS), microtensile bond strength (μTBS), composite ultimate tensile strength (UTS), and mechanical properties of the composites at various depths in molars with large Class II restorations.

Materials and Methods: One hundred seventeen human molars received standardized Class II mesio-oclusal-distal cavity preparations and restorations with three composites (Filtek LS [3M-ESPE]; Aelite LS [BISCO]; and Filtek Supreme [3M-ESPE]) using three filling techniques (bulk, eight increments, and 16 increments). CS was measured using strain gauges, after which the same restored teeth were used to assess μTBS and UTS. The elastic modulus (E) and Vickers hardness (VH) at different depths were determined from microhardness indentations. The CS, μTBS, UTS, E,

and VH data were statistically analyzed using split-plot analysis of variance and Tukey test (*p*=0.05).

Results: The CS was higher when using 16 increments. The 'low-shrink' composites caused lower CS. The μTBS and UTS were similar for eight- and 16-increment techniques and higher when compared to the bulk filling in all composites. E and VH were constant through the depth when applied in eight or 16 increments.

Conclusions: Type of composite and filling technique affected the CS, μTBS, UTS, and mechanical properties of large Class II restorations. The eight-increments filling technique resulted in generally less CS with the same μTBS and UTS than was obtained with 16 increments, without affecting E and VH through the depth of the composites.

INTRODUCTION

Volumetric shrinkage is a consequence of the polymerization process, whereby the conversion of monomer molecules results in a cross-linked polymer network.[1] During this polymerization reaction, the composite changes from a predominantly viscous to a predominantly solid substance, which can be characterized by the development of the elastic modulus (E).[2] Residual shrinkage stresses can evolve when volumetric polymerization contraction is accompanied by this E development and the surrounding tooth structure restricts the volumetric changes.[3,4] It is generally believed that these prestressed restorations will have adverse clinical consequences.[5] Polymerization shrinkage of composite resins has been a clinical concern, and the associated stresses are thought to play a role in marginal failures, microleakage, and recurrent caries.[4-8] On the other hand, other studies[9,10] found a low degree of correlation between clinical failures and composite shrinkage. Marginal gaps created by polymerization shrinkage did not appear to increase the risk for secondary caries but can lead to marginal staining, which may be diagnosed as secondary caries.[9]

Shrinkage stresses manifest themselves most directly in cuspal deflection of restored teeth.[1,11] Cuspal deflection usually increases with increasing cavity dimensions and signifies an increased risk of tooth fracture.[12-14] How much stress is generated by polymerization shrinkage depends on multiple factors, such as curing light intensity, photoactivation time, mechanical properties of materials and tooth structure, and restorative placement technique, as well as the geometry and extent of the cavity.[2,15]

New low-shrink composite resins and restorative protocols have been developed to minimize polymerization shrinkage and stress. Incremental filling techniques have often been indicated to decrease the effects of shrinkage and stress generated at the adhesive interface.[16] However, a study[2] using finite element analysis showed that incrementally filling could produce higher shrinkage stresses at the adhesive interface. On the other hand, light-curing large restorations in bulk raises concerns with regard to whether the composite can be adequately cured throughout the whole restoration depth because increasing the depth of an increment or restoration decreases the light intensity that reaches the bottom of such layers and consequently may not reach an adequate degree of conversion.[17] An inadequate cure compromises the mechanical properties of a composite restoration and its adhesion and, consequently, its long-term clinical success.[18]

Questions also remain about how shrinkage stresses may compromise the interface and/or the mechanical properties of a restoration. Both the adhesion to tooth substrate and the mechanical properties of a restoration might reflect the contraction stress behavior of a composite resin during polymerization.[19,20]

Assessment of the effect of composite resins and bulk/incremental filling techniques on the mechanical performance of restored teeth therefore requires a systematic and comprehensive study of the tooth deformation, bond strength, and mechanical properties. The purpose of this study was to investigate those factors in molars with an extensive Class II restoration. The null hypothesis was that the restorative materials and filling techniques would not affect cuspal deformation, bond strength, and mechanical properties in restored molars.

MATERIALS AND METHODS

Teeth Selection and Cavity Preparation

One hundred seventeen extracted intact, caries-free human third molars were used with approval from the University Ethics Committee in Human Research. The teeth were selected to have an intercuspal width that fell within a maximum deviation of not more than 10% of the determined mean. The measured intercuspal width varied between 5.17 mm and 6.13 mm. The teeth were embedded in a polystyrene resin (Cristal, Piracicaba, SP, Brazil) up to 2.0 mm below the cervical line to simulate alveolar

Table 1: *Dental Composites Tested in the Study (Information Provided by the Respective Manufacturers)*

Composite Resins	Wt%	Vol%	Filler Type	Matrix	Manufacturer
Filtek LS (LS)	76	55	Quartz and yttrium fluoride (0.1-2.0 μm)	TEGDMA, ECHCPMS	3M ESPE, St Paul, MN, USA
Aelite LS Posterior (AE)	84	74	1.1 μm	Bis-GMA, UDMA	BISCO, Schaumburg, IL, USA
Filtek Supreme (SU)	82	60	Silica nanofillers (75 nm) zirconia nanofillers (5-10 nm) and agglomerated zirconia/silica nanoclusters (600-1400 nm)	Bis-GMA, Bis-EMA, UDMA, TEGDMA	3M ESPE, St Paul, MN, USA

Abbreviations: Bis-EMA, bisphenol-A hexaethoxylated dimethacrylate; Bis-GMA, bisphenol-A glycol dimethacrylate; ECHCPMS, 3,4-epoxycyclohexylcyclopolymethylsiloxane; TEGDMA, triethylene glycol dimethacrylate; UDMA, urethane dimethacrylate.

bone.[21] The teeth were cleaned using a rubber cup and fine pumice water slurry and distributed into nine groups of 13 teeth apiece. Ten teeth per group were restored and used for cuspal deflection measurement using strain gauges and afterwards for the bond strength and ultimate tensile strength of the composite restoration using a microtensile test. The other three teeth per group were restored and used for the measurement of Vickers hardness (VH) and E using the continuing indentation method. All restored teeth had Class II cavities with 4.5-mm intercuspal width and 5-mm depth, prepared with a diamond bur (#3099 diamond bur, KG Sorensen, Barueri, SP, Brazil) in a high-speed handpiece with copious air-water spray using a cavity preparation machine.[22] This machine consisted of a high-speed handpiece (EXTRA torque 605 C; KaVo do Brasil, Joinvile, SC, Brazil) coupled to a mobile base. The mobile base moves vertically and horizontally with three precision micrometric heads (152-389; Mitutoyo Sul Americana Ltda, Suzano, Brazil), attaining a 0.002-mm level of accuracy.

Cuspal Strain (CS)

Cuspal deformation was measured with strain gauges (PA-06-060CC-350L, Excel Sensores, SP, Brazil), which had an internal electrical resistance of 350 Ω, a gauge factor of 2.07, and a grid size of 21.02 mm^2. The gauge factor is a proportional constant between electrical resistance variation and strain. The strain gauges were bonded to the cervical area of the buccal and lingual surfaces ($n=10$) with cyanoacrylate adhesive (Super Bonder; Loctite, São Paulo, Brazil), and the wires were connected to a data acquisition device (ADS0500IP; Lynx Tecnologia Eletrônica, São Paulo, SP, Brazil). The strain gauges were placed in the region where a finite element model had indicated the presence of the highest polymerization stresses.[23] In addition, two strain gauges were fixed to another intact tooth to compensate for dimensional deviations due to temperature effects.

The materials used in this study were two low-shrink composite resins, Filtek LS (LS) and Aelite LS (AE), and one conventional composite resin, Filtek Supreme (SU). Their composition and manufacturer information are listed in Table 1. Adhesive systems specific to each composite (LS: S System Adhesive Self-Etch Primer and Bond [3M ESPE, St Paul, MN, USA]; AE: All-Bond SE [Bisco, Schaumburg, IL, USA]; and SU: Adper Easy one [3M ESPE]) were used according to the manufacturers' instructions. The cavities were restored using three filling techniques: bulk, eight increments, and 16 increments. Average volumes of composite per increment for each technique were 221.3 mm^3, 27.66 mm^3, and 13.83 mm^3, respectively. A Teflon matrix with the cavities was made to standardize each composite resin increment before the insertion into the cavity (Figure 1). Each increment was light-cured for 40 seconds using a light source with 550 W/cm^2 output (Demetron Kerr; Orange, CA, USA) by placing from the occlusal direction closest to the cavity. The total energy for each filling technique was 22 J/cm^2 for the bulk technique; 176 J/cm^2 for the eight-increment technique, and 352 J/cm^2 for the 16-increment technique. The cuspal deformation data were obtained from the strain gauges through data analysis software (AqDados 7.02 and AqAnalisys; Lynx). The strain values were recorded at 4 Hz during the restorative procedure and continued for 10 minutes after curing the last increment.

Bond Strength (μTBS) and Ultimate Tensile Strength (UTS)

The restored teeth were stored for 24 hours in distilled water at 37°C, after which the occlusal surface was removed and discarded. The specimens were sectioned bucco-lingually into six slabs of 1 mm in thickness using a low-speed diamond saw (Isomet,

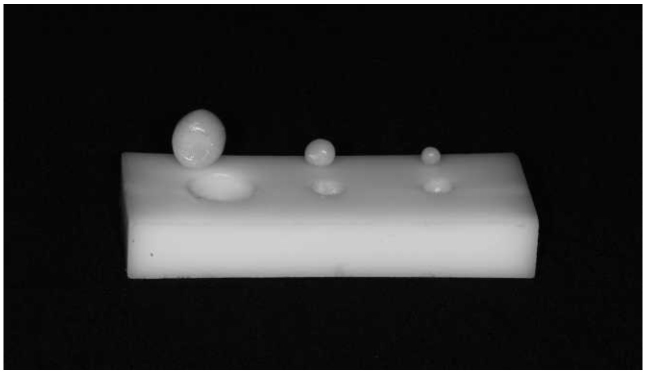

Figure 1. *A Teflon matrix made to standardize each composite resin increment before the insertion into the cavity.*

Buehler, Lake Bluff, IL, USA) under water cooling. Each slab was serially sectioned horizontally to harvest two sticks with 1.0 mm × 1.0 mm cross sections at two cavity depths (six sticks for each depth). A top stick represented the upper 2 mm occlusal region of the dentin/composite interface, and a bottom stick represented the bottom 2 mm in the cervical region of the dentin/composite interface. In each experimental group, half of the sticks from each depth were subjected to the μTBS test (n=30; 10 teeth per group, three sticks per region). The other half of the sticks were trimmed to an hourglass shape at the center of the restorative material and used for the measurement of the UTS of the composite resin (Figure 2).

For the μTBS and UTS tests, the ends of the specimen were glued to a microtensile device in the testing machine (EMIC DL 2000, São José dos Pinhais, Paraná, Brazil) using cyanoacrylate glue (Super Bonder Flex Gel, Henkel Loctite Adesivos Ltda, Itapevi, SP, Brazil) to cover all the faces of the specimens[24,25] and were then subjected to a tensile load at a crosshead speed of 1 mm/min. The cross-sectional area of each stick was measured using a digital caliper (Mitutoyo CD15, Mitutoyo Co, Kawasaki, Japan). The μTBS and UTS were calculated by dividing the fracture load by the surface area, measured to the nearest 0.01 mm with the digital caliper.

After the μTBS test, the specimens were examined with a stereomicroscope (Leika Ecafix, Tokyo, Japan) at 40× magnification. The fractured surfaces were classified as cohesive failure in composite, adhesive failure, or mixed failure.

E and VH

The other three restored teeth from each group were used for the analysis of mechanical properties (E and VH) of the composites at five depths. Each restored tooth was sectioned in the buccal-lingual direction into two halves using a precision saw (Isomet, Buehler). One section per tooth was randomly selected for assessment of the mechanical properties. The specimens were embedded with methacrylate resin (Instrumental Instrumentos de Medição Ltda, São Paulo, SP, Brazil). Prior to testing, the surfaces were finished with silicon-carbide paper (#600, 800, 1200, and 2000 grit sizes; Norton, Campinas, SP, Brazil) and polished with metallographic diamond pastes (6-, 3-, 1-, and 1/4-μm sizes; Arotec, São Paulo, SP, Brazil). Using a Vickers indenter (CSM Micro-Hardness Tester; CSM Instruments, Peseux, Switzerland), indentations were made every 1.0 mm from 0.5 mm to 4.5 mm, measured from the pulpal wall of the restorations. The indentation was carried out with controlled force, whereby the test load was increased or decreased at a constant speed ranging between 0 and 500 mN in 20-second intervals. The maximum force of 500 mN was held for five seconds. The load and the penetration depth of the indenter were continuously measured during the load-unload-hysteresis.

The universal hardness is defined as the applied force divided by the apparent area of the indentation at the maximum force. The measurements were expressed in VH units by applying the conversion factor supplied by the manufacturer. The indentation modulus was calculated from the slope of the

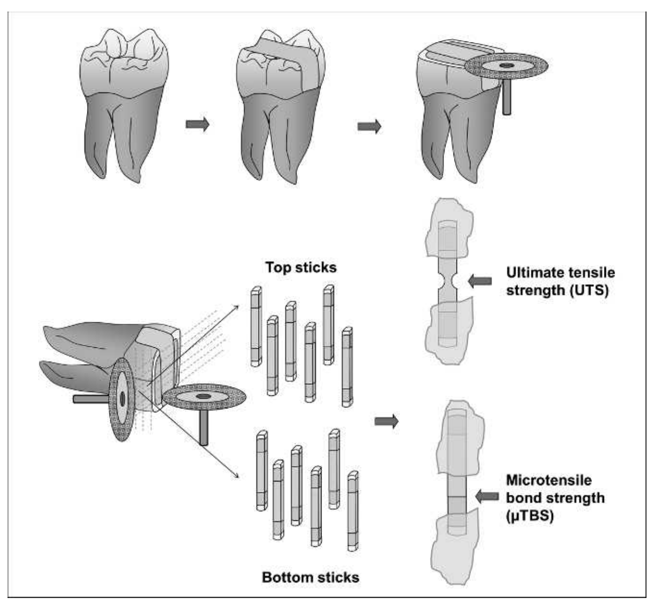

Figure 2. *Schematic illustration describing the sample preparation for the microtensile tests used to measure the microtensile bond strength and ultimate tensile strength at the top and the bottom of the cavities.*

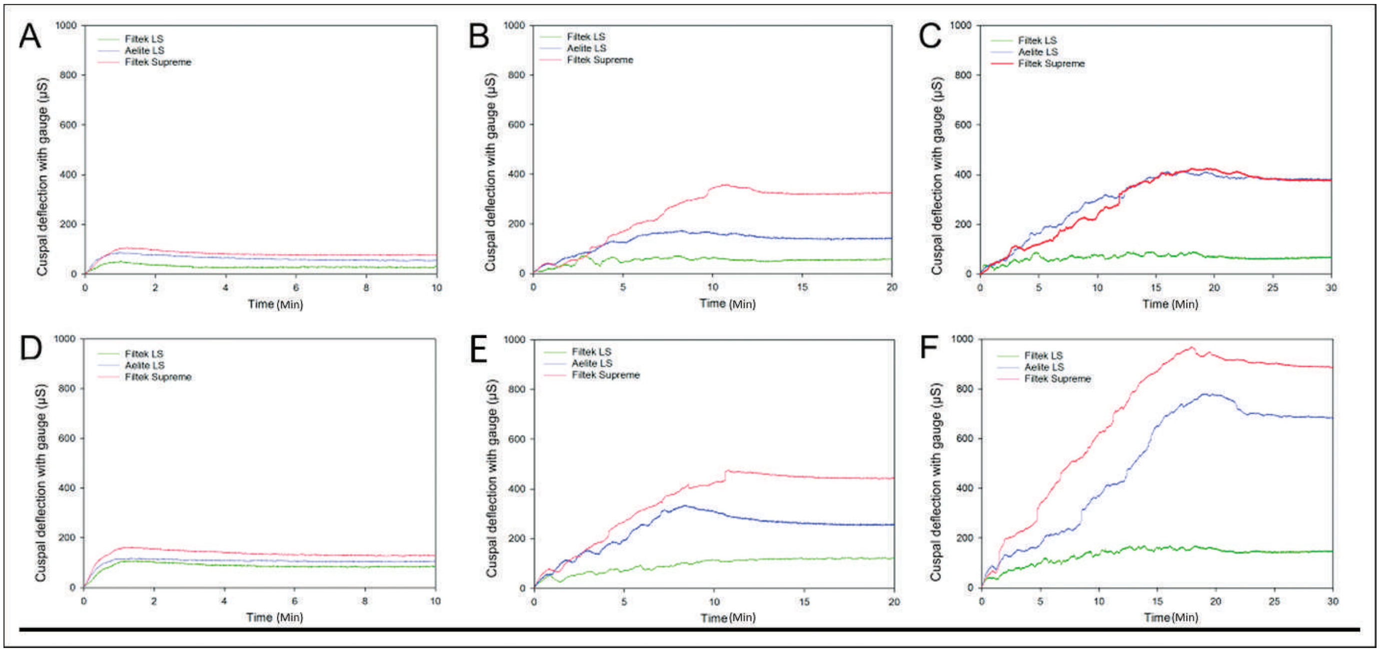

Figure 3. *Cuspal deformation in microstrains (μS) measured with strain gauges placed on the buccal or lingual cuspal surfaces. (A) Buccal cusp of the tooth filled in bulk; (B) buccal cusp of the tooth filled in eight increments; (C) buccal cusp of the tooth filled in 16 increments; (D) lingual cusp of the tooth filled in bulk; (E) lingual cusp of the tooth filled in eight increments; and (F) lingual cusp of the tooth filled in 16 increments.*

tangent of the indentation depth curve at the maximum force and is comparable to the E of the material.[26]

Statistical Analysis

The cuspal deflection, μTBS, UTS, E, and VH data were tested for normal distribution (Shapiro-Wilk, $p>0.05$) and equality of variances (Levene test, $p>0.05$), followed by parametric statistical tests. Analysis of variance (ANOVA) was performed in a split-plot arrangement, with the plot represented by the composite resin, restorative technique, and their interaction and the subplot represented by depth of the cavity. Multiple comparisons were made using the Tukey test. The data of fracture mode were subjected to the chi-square test ($p<0.05$). All tests employed a 0.05 level of statistical significance, and all statistical analyses were carried out with the statistical package SAS® System version 9.1 (SAS Institute Inc, Cary, NC, USA).

RESULTS

CS

The behavior and values of the cuspal deformation (strain) for the three composites (LS, AE, and SU) and the three filling techniques (bulk and 8- and 16-increment) are shown in Figure 3 and Table 2. LS had the lowest values of cuspal deformation, followed by AE and SU in eight- and 16-increment filling techniques. This behavior was consistent for both buccal and lingual cusps, with the higher strain values for the lingual cusp for AE and SU. Cuspal deformation for the LS restored teeth was not significantly different among the three filling techniques. AE and SU had lower lingual cuspal

Table 2: *Cuspal Deformation (μS) Measured by Strain Gauges (n=10 Teeth)*[a]

Composite Resins	Mean (Standard Deviation)					
	Buccal			Lingual		
	Bulk	Eight Increments	16 Increments	Bulk	Eight Increments	16 Increments
Filtek LS	69.2 (34.4) Aa	86.3 (43.7) Aa	79.1 (49.9) Aa	124.8 (51.9) Aa	134.5 (41.7) Aa	167.5 (67.9) Aa
Aelite LS	106.3 (32.7) Aa	187.7 (73.4) Ab	406.4 (315.8) Bb*	140.5 (32.3) Aa	328.0 (169.4) Bb	652.2 (398.1) Cb*
Filtek Supreme	119.3 (49.8) Aa	373.5 (166.6) Bb	424.6 (246.5) Bb*	175.5 (60.9) Aa	509.6 (226.1) Bb	940.9 (761.2) Cc*

[a] *Different uppercase letters in rows are designed to compare restorative technique for each cusp; lowercase letters in columns are designed to compare composite resin for each cusp; * Significant difference for pairwise comparison between buccal and lingual cusps (p<0.05).*

Table 3: *Microtensile Bond Strength Mean Values (MPa) for Each Group (n=10 Teeth)*[a]

Composite Resins	Mean (Standard Deviation) Microtensile Bond Strength, MPa					
	Top of Restoration			Bottom of Restoration		
	Bulk	Eight Increments	16 Increments	Bulk	Eight Increments	16 Increments
Filtek LS	7.9 (3.1) Ca	17.3 (5.5) Bb	28.2 (6.8) Aa	5.6 (1.7) Cb	20.3 (6.1) Ba	27.8 (7.8) Aa
Aelite LS	8.7 (2.4) Ba	16.1 (5.0) Ab*	18.7 (7.0) Ab	6.7 (2.6) Bb	22.3 (6.6) Aa*	19.3 (8.3) Ab
Filtek Supreme	11.0 (5.7) Ba	29.2 (6.4) Aa*	24.4 (6.9) Aab	14.5 (5.2) Ba	22.3 (10.5) Aa*	25.9 (8.6) Aa

[a] *Different uppercase letters in rows are designed to compare restorative technique for each region, lowercase letters in columns are designed to compare composite resin for each region indicate significant differences; * Significant difference for pairwise comparison between top and bottom for each group* ($p<0.05$).

deformation when the bulk filling technique was used, followed by the eight- and 16-increment filling techniques.

μTBS

The μTBS values in MPa (mean and standard deviation) for the three composite resins, the filling techniques, and the regions of the cavity for the experimental groups are presented in Table 3. ANOVA revealed a statistically significant difference among the composite resins ($p<0.0001$), the filling techniques ($p<0.0001$), the interactions between composite resins and filling technique ($p=0.0064$), and the interactions between composite resin, filling technique, and region of cavity ($p=0.0094$).

LS had significantly higher μTBS with the 16-increment technique than with the other two techniques, and it had significantly lower μTBS with the bulk technique, regardless of top or bottom region. For AE and SU there was no significant difference between the eight- and 16-increment techniques, whereas the bulk technique had the lowest μTBS values, regardless of the cavity region.

No significant difference in μTBS among the three composite resins filled in bulk was found for the top of the restoration. However, SU had significant higher μTBS values than did the other composite resins at the bottom of the restorations. For the eight-increment technique, SU had significantly higher μTBS than for both low-shrink composite resins LS and AE at the top of the restoration; however, none of these values was significantly different at the bottom. For the 16-increment technique, LS had significantly higher μTBS than AE at the top of the restoration, and AE had significantly lower μTBS than both SU and LS at the bottom.

Fracture mode distributions and statistical differences are shown in Figure 4. All composites filled

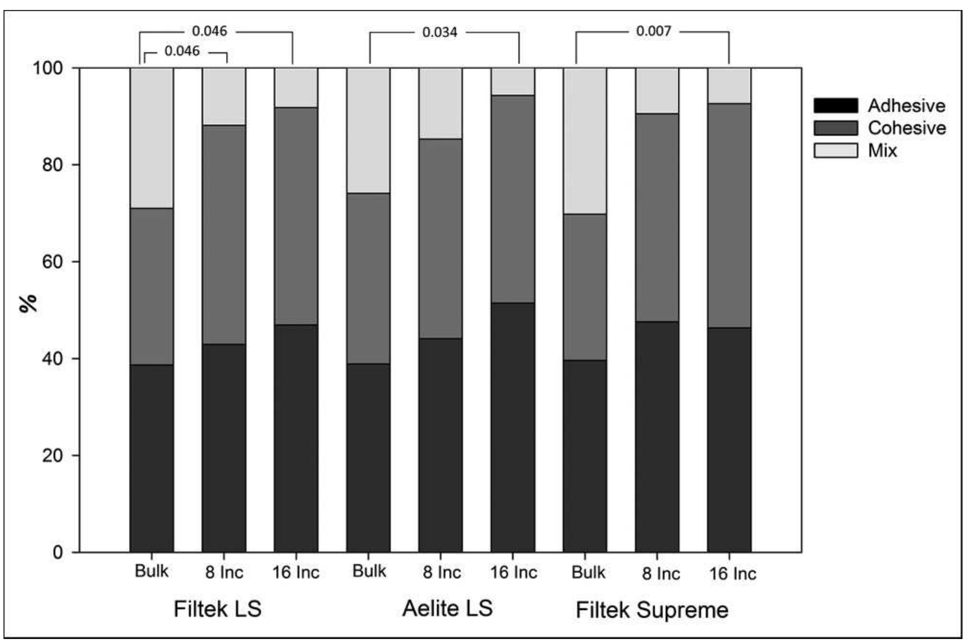

Figure 4. *Fracture mode distribution. T indicates the top region of the restoration; B is the bottom region of the restoration.* p *Values for significant differences found by chi-square test* ($p<0.05$).

Table 4: *Ultimate Tensile Strength (MPa) of the Composite Restoration (n=10)*[a]

Composite Resins	Mean (Standard Deviation) Ultimate Tensile Strength, MPa						Pooled Average
	Bulk		Eight Increments		16 Increments		
	Top	Bottom	Top	Bottom	Top	Bottom	
Filtek LS	17.4 (4.7)	13.8 (5.2)	42.1 (12.9)	41.9 (12.2)	40.1 (8.6)	36.7 (11.2)	33.3 (14.9) A
Aelite LS	16.9 (6.4)	17.8 (6.3)	38.4 (9.8)	39.6 (9.7)	40.7 (13.9)	42.6 (11.5)	32.0 (13.9) A
Filtek Supreme	13.1 (4.7)	12.1 (5.4)	43.6 (12.4)	37.5 (7.5)	45.5 (12.9)	44.3 (11.3)	32.4 (17.4) A
Pooled average	15.2 (5.7) B		40.5 (10.6) A		41.2 (11.2) A		

[a] *For the pooled averages, means followed by distinct letters are significantly different (Tukey test, 95% confidence level). None of the pairwise comparisons between the top and bottom values were significantly different.*

showed similar failure patterns, regardless of the filling technique used. The incidence of mixed failures was higher with the bulk technique compared to the 16-increment filling technique for all composites and compared to the eight-increment filling technique for FS.

UTS

The UTS values in MPa (mean and standard deviation) for the three composite resins, the filling techniques, and the regions of the cavity are shown in Table 4. ANOVA revealed a statistically significant difference only for the filling technique ($p<0.05$). The UTS was significantly lower with the bulk filling technique than with the eight- and 16-increment techniques, regardless of the composite resin and region of the cavity.

E

The E values in GPa for the three composites and the filling technique at various depths of the restorations are shown in Figure 5. The E of AE decreased in the bulk filling technique when the depth of the restoration increased, while the E of LS and SU was constant between the depths of 0.5 and 2.5 mm and was significantly decreased beyond 2.5 mm. For the eight-increment technique, LS and SU maintained a constant E throughout the depth of the restoration, while AE maintained the constant E up to 3.5 mm deep and decreased significantly for the 4.5-mm depth. For the 16-increment technique, the E was constant for all of the depths in all composites.

AE had significantly higher E values than did SU and LS up to 1.5 mm in depth for the bulk filling technique and had significantly higher E values at all depths with the eight- and 16-increment techniques. SU and LS showed similar E values for the bulk filling technique, regardless of the restoration depth. However, for the eight- and 16-increment techniques the LS had significantly lower E than did SU, regardless of the depth.

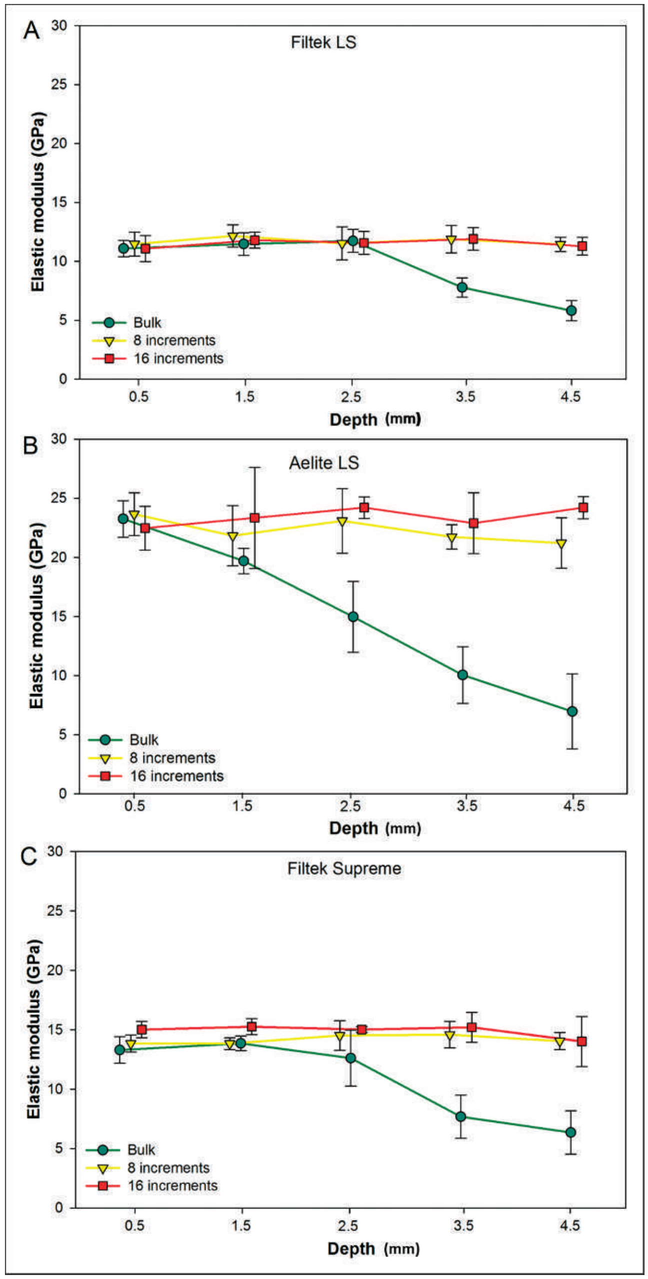

Figure 5. *Elastic modulus at various restoration depths for (A) Filtek LS; (B) Aelite LS; and (C) Filtek Supreme.*

VH

The VH values of the three composite resins for each filling technique at various restoration depths are presented in Figure 6. For the bulk filling technique, the VH of AE and SU decreased when the restoration depth increased, while LS had constant VH up to 2.5 mm and significantly decreased VH afterwards. For the eight-increment technique, LS had constant VH regardless of cavity depth. The VH of AE dropped at 1.5 mm in depth, remained constant from 2.5 to 3.5 mm in depth, and decreased again at 4.5 mm in depth. SU showed a significant reduction in VH at 1.5 and 2.5 mm and remained constant afterwards. For the 16-increment technique, VH remained constant with the increasing restoration depth.

AE and SU had significantly higher VH values than did LS up to 1.5 mm of the restorations for the bulk technique and had significantly higher VH in all depths for the eight- and 16-increment techniques. AE and SU had similar VH values for the bulk and eight-increment filling techniques regardless of the restoration depth. However, AE had significantly higher VH values than did SU up to 3.5 mm in depth for the 16-increment technique.

DISCUSSION

The null hypothesis was rejected: the filling technique and composites significantly affected all properties tested (CS, μTBS, UTS, E, and VH).

Cuspal Deformation

Cuspal deformation in composite restored teeth is affected by many factors, including the size of the cavity, the properties of the restorative material, and the filling technique.[27,28] In this study the size of the cavity was standardized for all samples. Assuming similar tooth properties, shapes, and sizes, the main variables causing differences in cuspal deformation were therefore the properties of the composites and the filling techniques. LS-restored teeth had lower cuspal deformation (statistically significantly so for the incremental fillings), followed by AE and SU, regardless of the filling technique. From a mechanical perspective, the main differences between the three composite resins were the E and polymerization shrinkage. Under certain conditions, cuspal deflection can be expected to increase with increasing E.[29] However, for SU we found higher CS values than for AE, despite its lower E. This result can be explained by the postgel shrinkage, which was lower for Filtek LS compared with Filtek Supreme and Aelite LS. Higher postgel shrinkage values have

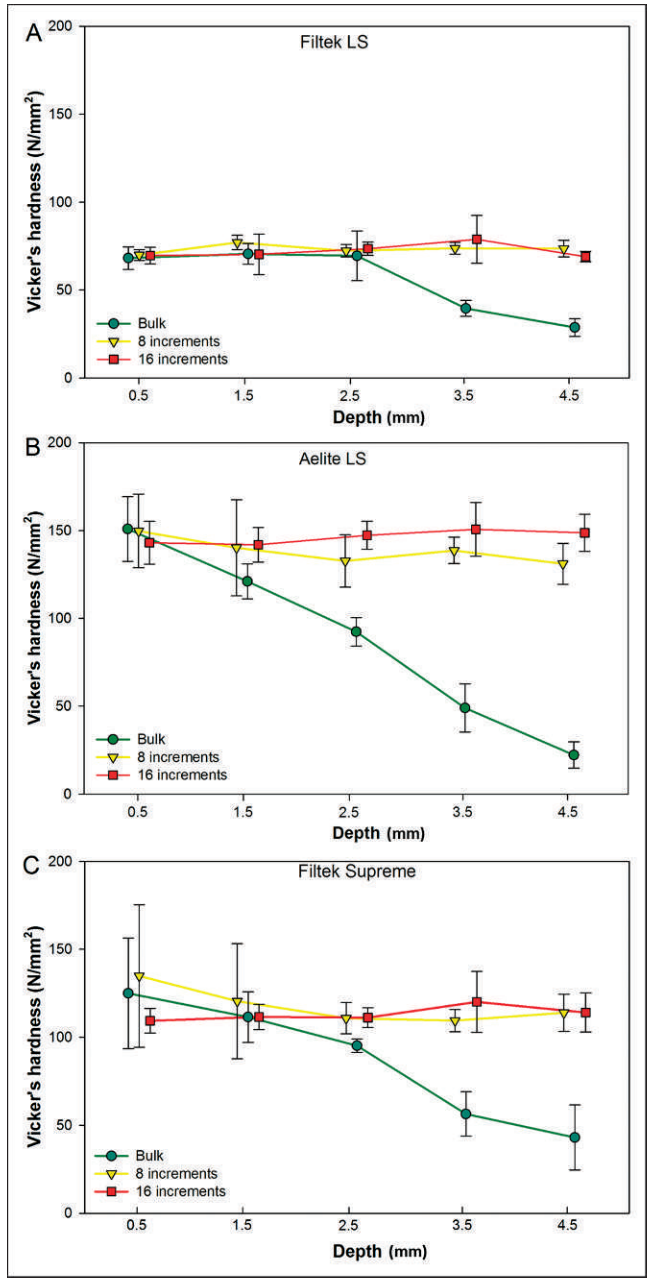

Figure 6. *Vickers Hardness at various restoration depths for (A) Filtek LS; (B) Aelite LS; and (C) Filtek Supreme.*

been shown[30] to increase residual shrinkage stresses and can therefore also increase cuspal deformation of restored teeth.

No significant differences in cuspal deflection between bulk and incremental filling techniques were found when only two or three increments were used in the restorative procedure.[31] In this study, however, we found generally higher cuspal deformation values for AE and SU when the number of increments was eight or 16, compared to the values found with the bulk filling technique. These successive polymerization steps generated cumulative deformation of the tooth, resulting in a final deformation that exceeded that of the bulk filling technique. We also found that lingual cusps had higher cuspal deformation than buccal cusps, which was statistically significant for Aelite LS and Filtek Supreme when restored with the 16-increment filling technique. This result can be explained by the amount of remaining tooth structure. Third molars had narrower cervical areas lingually than they did buccally, and, thus, the lingual cusps can be expected to be less stiff than the buccal cusps.

μTBS

Although it is important for clinicians to choose restorative materials and filling techniques that cause minimal cuspal deformation, such choices should not come at the expense of the μTBS and the physical properties of the material. Excellent bonding and properties are critical for optimal clinical performance of a restoration. In the present study the μTBS obtained with the incremental techniques was higher than that obtained with the bulk technique in all materials tested. This result is consistent with those of other studies[12,19] and can be attributed to the composite receiving sufficient light energy to properly cure in an incremental technique, whereas the composite in a bulk filling is usually too thick to reach the same degree of cure throughout the entire depth of the restoration.[17] For the AE and SU, both the eight- and 16-increment techniques showed similar μTBS values, which means that the eight-increment technique had the benefit of less cuspal deformation than the 16-increment technique without compromising the μTBS.

μTBS has also been related to polymerization shrinkage stresses, whereby a higher stress condition has been related to lower μTBS values.[32] This study, however, found lower μTBS values for teeth that had less deformation. The lower μTBS might have been caused by differences in composite cure. A lesser cure in the bulk filled restoration would reduce the tensile strength of the composite, as shown in Table 4. Observation of the failure modes also seems to support this explanation, because the bulk filled restorations tended to have significantly higher incidence of mixed failures than did the incrementally cured restorations. Additionally, note that the light emitted by the light-curing unit, which had the tip touching the cusps, for bulk restoration was only 22 J/cm^2, compared to 176 and 352 J/cm^2 with the incremental techniques, which reduced its cure.

Mechanical Properties

The results of this study showed that all composites had similar UTS values for bulk filling regardless of region of the restoration, but the UTS values were significantly lower than the values obtained when the restoration was placed in increments. UTS has been directly correlated with the quality of polymerization.[12] Therefore, considering their equivalent UTS values, both the eight- and 16-increment techniques provided more light energy for better polymerization. It has also been reported[19,33] that UTS of composite decreased when it was cured under constrained conditions. In the current study the UTS values were the lowest in the bulk placed restorations, while the incrementally cured restorations had significantly higher UTS values. Since it can be argued, based on the tooth deformation results, that the incremental restorations were more highly stressed, this study found that UTS increased with increasing shrinkage stress. Differences in UTS values between bulk and incremental techniques may be partly ascribed to differences in the degree of cure, which are reflected in the VH values: at the bottom of the restoration the VH values were lower when using the bulk technique, and, thus, the mechanical properties may not have been fully developed. However, VH values could also not explain why the UTS values of the bulk fillings were similar in the top and bottom regions because significantly lower VH values were found in the bottom region. The VH results could also not explain why the UTS at the top region was lower for bulk than for incrementally placed restorations, because they had similar VH values regardless of filling technique.

All composites showed constant values of VH in all depths of the restorations when 16 increments were used, suggesting adequate polymerization and degree of conversion of the monomers.[33] For the eight-increment technique, AE and SU had decreased VH near the restoration surface, which remained constant and dropped again in the bottom region of the restoration, while the VH of LS remained constant at all depths. For bulk fillings, the VH values of AE and SU gradually decreased with depth, while the VH of LS remained constant to a depth of 2.5 mm before decreasing. The VH values confirmed that a bulk filling technique may not allow adequate polymerization of the monomers deeper in the restoration. We also showed that the E decreased with increasing restoration depth for all composites that were cured in bulk. SU and LS had constant E values through the depth when filled in eight increments, whereas all materials had constant E when filled in 16 increments. Similar results have been reported[34] in an investigation of the relationship between E and depth of the cavity. It can be expected that the quality of the polymerization throughout a restoration is essential for adequate mechanical properties of a composite material and therefore justifies the need for incremental placement.[35]Monomers such as bisphenol-A glycol dimethacrylate and triethylene glycol dimethacrylate exhibit 5.2% and 12.5% volumetric shrinkage, respectively, but this has been reduced to 2% to 6% in composites as a result of the presence of fillers.[36] An increase in filler volume content leads to reduction in volumetric shrinkage as the resin content is smaller, yet high filler volume results in stiff materials with a high E, which generates higher stresses for the same shrinkage values.[23] This aspect may explain the similar performance of Filtek Supreme and the Aelite LS. Although Aelite LS is marketed as a low-shrink composite, it has higher filler content than does Filtek Supreme.

Filtek LS is a novel low-shrink resin utilizing silorane monomers. The polymerization reaction of this composite is based on a cationic ring-opening polymerization, which results in shrinkage values below 1%.[37] A significant decrease of shrinkage stress has been reported[23] compared to that associated with methacrylate-based composites. This may explain the performance of the Filtek LS restorations compared with other composite resin tested in this study.

The problems frequently observed with posterior composite restorations, usually in the gingival area, could be related to the inferior mechanical properties and insufficient bonding to tooth structures. The finding of this study could be important for clinicians during restorative procedures of large cavities. Increasing the number of increments resulted in higher cuspal deformation, which could potentially lead to fracture of the enamel and postoperative sensitivity. Although it lowered the cuspal deformation, the bulk filling technique did not allow thorough curing throughout the restoration depth and thus compromised the bonding and mechanical properties of the restorative composite. To manage large cavity restorations the use of oblique increments has been reported[23] to result in lower residual stresses than are associated with horizontal increments. Therefore, clinicians must balance the bonding and good material properties with low cuspal deformation using the incremental technique with 2.0-mm increments for the longevity of both dental structures and the large posterior restoration.

CONCLUSIONS

Cuspal deformation in molars restored with composite was higher when 16 increments were used than when an eight-increment technique was used. One of the low-shrink composite resins (Filtek LS) also caused lower cuspal deformation. The μTBS and the composite tensile strength were similar for the eight- and 16-increment techniques and higher than those associated with the bulk filling technique. The physical properties (tensile strength, E, and VH) were approximately constant throughout the restoration depth when filled in eight or 16 increments. Incremental filling was found to be crucial for thorough curing of large restorations, although too many increments are not necessary and might lead to an increase in undesirable tooth deformation.

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Conflict of Interest

The authors of this manuscript certify that they have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in this article.

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