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Impact of the Porosity from Incremental and Bulk Resin Composite Filling Techniques on the Biomechanical Performance of Root-Treated Molars

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Clinical Relevance

The presence of porosity confined inside a restoration had no effect on the biomechanical performance of the root-treated molars. Clinicians should select the restorative materials based on the mechanical properties and decreased polymerization shrinkage; additionally, they should consider the cusp coverage for severely weakened root-treated molars.

SUMMARY

Objectives: To analyze the effect of the porosity caused by incremental and bulk resin composite filling techniques using low- and high-viscosity composite resins on the biomechanical performance of root-treated molars.

Methods: Forty intact molars received standardized mesio-occlusal-distal (MOD) cavity preparation, were root treated, and randomly divided into four groups with different filling techniques (n=10). The first involved two incremental filling techniques using VIT/Z350XT, a nanofilled composite resin

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http://doi.org/10.2341/19-297-L

(Filtek Z350XT, 3M ESPE) associated with a resin-modified glass ionomer cement, and resin-modified glass ionomer cement (RMGIC; Vitremer, 3M ESPE) for filling the pulp chamber. The second involved TPH/VIT, a microhybrid composite resin TPH3 Spectrum associated with Vitremer. The third and fourth involved two bulk-fill composite resins: SDR/TPH, a low-viscosity resin composite (Surefill SDR flow, Dentsply) associated with TPH3 Spectrum, and POST, a high-viscosity bulk-fill resin composite (Filtek Bulk Fill Posterior, 3M ESPE). The volume of the porosity inside the restoration was calculated by micro-CT. The cusp deformation caused by polymerization shrinkage was calculated using the strain-gauge and micro-CT methods. The cusp deformation was also calculated during 100 N occlusal loading and loading to fracture. The fracture resistance and fracture mode were recorded. Data were analyzed by one-way analysis of variance and Tukey test. The fracture mode was analyzed by the χ^2 test. The volume of the porosity was correlated with the cusp deformation, fracture resistance, and fracture mode (α=0.05).

Results: Incremental filling techniques associated with RMGIC resulted in a significantly higher porosity than that of both bulk-fill techniques. However, no significant difference was found among the groups for the fracture resistance, fracture mode, and cusp deformation, regardless of the measurement time and method used. No correlation was observed between the volume of the porosity and all tested parameters.

Conclusions: The porosity of the restorations had no influence on the cuspal deformation, fracture resistance, or fracture mode. The use of the RMGIC for filling the pulp chamber associated with incremental composite resins resulted in similar biomechanical performance to that of the flowable or regular paste bulk-fill composite resin restorations of root-treated molars.

INTRODUCTION

Dental caries in first permanent molars are a chronic and multifactorial disease that can cause morbidity, such as pain and suffering.[1] Caries tend to progress quickly due to broad dentin tubules and wide pulp chambers in first molar teeth, which may facilitate the infection of the dental pulp and frequently require root canal treatment.[2-4]

Permanent molar teeth severely damaged after root canal treatment can be restored using direct composite resins to avoid tooth extraction.[4] The adhesive restorative procedure has been indicated to reinforce weakened tooth structures and is considered to be more conservative than indirect restoration.[5-8] Restorative protocols using an increment of 2 mm during oblique filling have been shown to achieve good mechanical properties while minimizing the shrinkage stress caused by several light activations.[9-11] The use of a resin-modified glass ionomer cement (RMGIC) to fill the pulp chamber followed by composite resin restoration resulted in favorable conditions by reducing the cuspal strain and increasing the fracture resistance compared with those for an incremental composite resin.[12] Regular paste or flowable bulk-fill composite resins covered with a low shrinkage resin composite can minimize the negative effects of residual shrinkage stress and are a viable restorative protocol for root-treated molars.[13]

These techniques for root canal–treated teeth with a remaining coronal structure frequently produce large and deep cavities, increasing the risk for incorporation of voids and bubbles during the restorative procedure.[14,15] The presence of porosity likely accelerates the deterioration of the material, resulting in marginal infiltration, discoloration, increased wear, and decreased flexural strength.[16] The voids between the increments can be incorporated during the insertion of the material.[17,18] The presence of voids and gaps remaining after condensation has been shown when low-viscosity composite resins are used; however, most of the results presented in the literature are related to small cavities.[19] The correlation between voids, polymerization shrinkage, and the mechanical resistance of posterior composite resins are inconclusive.[20] Therefore, the aim of this *in vitro* study was to evaluate the effect of the porosity generated during filling techniques: incremental filling techniques associated with a RMGIC, a bulk-fill flowable composite resin used to fill the pulp chamber associated with conventional composite resin, or regular paste bulk-fill composite resins to fill the entire cavity, on the biomechanical performance of root-treated molar teeth with large class II cavities. The null hypothesis was that the porosity of the restoration generated by different filling techniques would not influence the biomechanical performance of restored root-treated molar teeth.

METHODS AND MATERIALS

Study Design

Forty human molars received standardized class II mesio-occlusal-distal (MOD) cavity preparations and were root treated. The teeth were restored with four different protocols following the instructions from the manufacturer. The number of samples was based on the coefficient of variability and a sample calculation. The power of the test was 80% with a minimum detectable difference of 20; there was a residual standard deviation of 15% and a significance level of 0.05, resulting in 10 samples per group. The composition of the resin composites provided by the manufacturers is listed in Table 1. The teeth were tested for cuspal deformation using strain gauges during the restorative procedure (CSt-Re), using micro–computed tomography (CT) images, and during 100 N occlusal loading (CSt-100N), and at the fracture resistance (CSt-Fr). The fracture resistance at the axial occlusal compressive load and fracture mode were evaluated after testing.

Tooth Selection and Cavity Preparation

Forty extracted, intact, caries-free human mandibular third molars were used (Ethics Committee in Human Research approval no. 06257012.1.0000.5152). The

Table 1: *Resin Composite Information Based on the Data Reported by the Manufacturer*[a]

Material	Code	Shade	Material Type	Increment Size and Light Activation Time	Organic Matrix	Filler	Filler % w/Vol
Vitremer (3M ESPE, St Paul, MN, USA)	RMGIC	A2	Resin-modified glass ionomer cement	2.0 mm - 40 seconds	Poly (acrylic-itaconic) acid with pendent methacrylate, H_2O	Fluoroaluminosilicate glass, microencapsulated	—
Filtek Z350 (3M ESPE, St Paul, MN, USA)	Z350	A2	Nanohybrid resin composite	2.0 mm - 20 seconds	BisGMA, UDMA, TEGDMA	Silica and zirconia nanofillers, agglomerated zirconiasilica nanoclusters	78.5/59.5
TPH3 Conventional (Dentsply -Konstanz, BW, Germany)	TPH	A2	Nanohybrid resin composite	2.0 mm - 20 seconds	BisGMA, BisEMA	Barium, boron, alumino-silicate glass	75/57
Surefil Flow (Dentsply -Konstanz, BW, Germany)	SDR	A2	Low-viscosity bulk-fill resin composite	4.0 mm - 20 seconds	Modified UDMA, dimethacrylate and difunctional diluents	Barium and strontium aluminofluoro-silicate glass	68/44
Filtek Posterior Bulk fill Regular (3M ESPE, St Paul, MN, USA)	POST	A2	High-viscosity bulk-fill resin composite	5.0 mm - 20 seconds	AUDMA, UDDMA, UDMA.	Silica, zirconia, and YbF_3	76.5/59.5

BisEMA, bisphenol A polyethylene glycol diether dimethacrylate; BisGMA, bisphenol A diglycidyl methacrylate; EBPADMA, ethoxylated bisphenol A dimethacrylate; EDMAB, ethyl-4-dimethylaminobenzoate; TEGDMA, triethyleneglycol dimethacrylate; UDDDMA, dodecanediol dimethacrylate; UDMA, urethane dimethacrylate; YbF_3, ytterbium fluoride.

[a]*Compositions provided by manufacturers.*

teeth that were selected had an intercuspal width within a maximum deviation of 10% from the determined mean.[11] The intercuspal width of the selected molar teeth varied between 5.2 and 6.2 mm. To simulate the periodontal ligament, the teeth had their roots covered with a 0.3-mm layer of a polyether impression material (Impregum, 3M ESPE, St Paul, MN, USA) and were embedded in a polystyrene resin (Cristal, Piracicaba, SP, Brazil) up to 2 mm below the cementum-enamel junction to simulate the alveolar bone.[21] Then, the teeth were cleaned using a rubber cup and fine pumice water slurry. Class II MOD cavities with approximately 4/5 of the intercuspal width and 5-mm depth were prepared in all samples with a diamond bur (#3099 diamond bur, KG Sorensen, Barueri, SP, Brazil) with abundant air-water spray using a cavity preparation machine.[22] The machine consisted of a high-speed handpiece (Extra torque 605 C, Kavo do Brasil, Joinvile, SC, Brazil) coupled to a mobile base that can move vertically and horizontally with three precision micrometric heads (152-389, Mitutoyo, Suzano, SP, Brazil), attaining a 0.002-mm accuracy. The root canal access was manually performed with a diamond bur (#1016 HL KG Sorensen), and the treatment was performed by a calibrated operator using a rotary nickel-titanium (Ni-Ti) System (Dentsply Maillefer, Petrópolis, RJ, Brazil). The teeth were instrumented at the previously determined working length using rotary files (ProTaper Universal, Dentsply Maillefer) following the instructions provided by the manufacturer. Each instrument was passively introduced into the root canals at 250 rpm (X Smart, Dentsply Maillefer). The irrigation was performed using 1% NaOCl after each instrument. The roots were filled with gutta-percha (Dentsply Maillefer) and a calcium hydroxide-based root canal sealer (Sealer 26, Dentsply Maillefer).

The teeth were randomly divided into the following four groups (n=10) according to the materials and restorative techniques.

Group 1. VIT/Z350—

RMGIC (Vitremer, A2 Shade, 3M ESPE) was used to fill the pulp chamber. The RMGIC was manipulated and inserted using a commercial syringe (Centrix, Shelton, CT, USA) and was light cured for 20 seconds using a multipeak light curing unit (Bluephase G2, Ivoclar Vivadent AG, Schaan, Liechtenstein) that used 1200 mW/cm^2, which was checked by using a MARC Resin Calibrator (BlueLight, Halifax, NS, Canada). Selective etching of the enamel was performed for 10 seconds, and a two-step self-etching adhesive system (Single Bond Universal, 3M ESPE) was used for hybridization procedures in all groups. The conventional nanofilled resin composite (Filtek Z350, 3M ESPE) was incrementally inserted in eight increments of 2.0 mm starting with the proximal surfaces (two increments to reconstruct the medial proximal surface, two increments to reconstruct the distal proximal surface, and four increments to reconstruct the occlusal box).

Group 2. VIT/TPH—

RMGIC (Vitremer, 3M ESPE) was used to fill the pulp chamber followed by an incremental filling technique with a microhybrid resin composite (TPH3 Spectrum, Dentsply), following the same restorative protocol described for group 1.

Group 3. SDR/TPH—

A low-viscosity bulk-fill resin composite (Surefill SDR Flow, Dentsply, Konstanz, BW, Germany) was inserted in two increments of approximately 4.0 mm to replace the dentin and covered with two increments of 2.0 mm of conventional resin composite, TPH3 Spectrum (Dentsply) to reconstruct the enamel, following the same restorative protocol described for group 1.

Group 4. POST—

A high-viscosity bulk-fill resin composite (Filtek Bulk Posterior, 3M ESPE) was inserted in two increments of approximately 5.0 mm from the pulp chamber to replace the dentin and enamel.

After restoration, all specimens were stored in relative humidity at 37°C for 24 hours and then finished using diamond burs (#2135F and 2135FF, KG Sorensen) with an intermittent water spray.[23]

Cuspal Deformation: Strain Gauge and Micro-CT Testing

Cuspal deformation was measured with strain gauges (PA-06-060CC-350L, Excel Sensores, Embú, SP, Brazil) that had an internal electrical resistance of 350 Ω, a gauge factor of 2.0, and a grid size of 21.0 mm^2. The gauge factor was a proportional constant between the electrical resistance variation and strain. One strain gauge was placed on the external surface of the lingual cusp, and the other was placed next to the buccal cusp in the height of the pulp chamber. The region where a finite element model indicated the presence of the highest polymerization strains herein was used.[24]

In addition, two strain gauges were fixed to another intact tooth to compensate for dimensional deviations due to temperature effects. The strain gauges were bonded with a cyanoacrylate-based adhesive (Super Bonder, Loctite, Itapeví, SP, Brazil), and the wires were connected to a data acquisition device (ADS0500IP, Lynx, São Paulo, Brazil).[11,24,25.]

Cuspal Deformation and Void Volume of Restorations on Micro-CT

To evaluate the cuspal deformation and void volume produced by the resin restoration protocols, the teeth were scanned after cavity preparation and after restoration using micro-CT equipment (SkyScan 1272, Bruker, Kontich, Belgium), as previously described by Oliveira and others.[25] To standardize and allow superimposition of the images, the teeth were placed in the micro-CT in the same position with the buccal face looking toward the same direction. The image acquisition required approximately 38 minutes to scan each tooth using the following parameters: an exposure time of 1100 milliseconds, an energy of 100 KV-100 μA, a 180° rotation with 0.5° steps, a Cu filter with a thickness of 0.11 mm, and a 12-μm voxel size. The scan images acquired by micro-CT were imported to a workstation and rebuilt using Nrecom software (version 1.6.10.1, Skyscan) in approximately 1.050 slices, respecting the anatomical limits of the samples. The reconstructed images were overlaid using DataViewer software (version 1.5.1.2, SkyScan). To align the different images of the prepared and restored teeth, a reference point was selected that was distant from the area affected by any shrinkage. The volume of the root portion of the tooth below the cementoenamel junction, which included both the pulp chamber and canals, was used as a reference. The prepared tooth image and the restored tooth image (target) were superimposed, which generated a volume of difference image (Diff). This Diff image represented the volume of the cusp deformation caused by the polymerization shrinkage of the resin composite restoration. The micro-CT analyzer software (CTAn, version 1.13, SkyScan) was used to threshold the regions of interest (ROI) and calculate the difference in the overlapping of all 2D images present in the volume of interest using a 3D analysis tool. The number of layers was the same for all analyzed Diff images for a total of 800 layers, each with a resolution of 0.4 mm. The regions of interest were positioned in the same area of the cusp where the strain gauge was positioned in the sample. The cusp deformation volume values were obtained in mm^3, and the percentage of this deformation was calculated as a function of the total volume of each cusp.

The scanned images of the teeth after the restorative procedure were evaluated for void volume with CTAn analysis software (SkyScan). Initially, a new ROI was defined, this time located in the region of the restorative material. Then, the threshold was determined based on the density difference between the voids and the restorative material. Using a 3D analysis tool, it was possible to extract the data for the void volume in mm^3 and to calculate how much these void volumes represented in proportion to the total volume of the restorative material, which were expressed as percentages of the total volume of the restorative material.

Using the CT-VOL software (version 2.0, SkyScan), tridimensional images were generated from the differences in the cusp shape volumes caused by resin composite shrinkage and images of the porosity in the restorations.

Mechanical Cycling Tests

To simulate five years of aging, chewing cycles were simulated to induce mechanical fatigue (Biocycle, Biopdi, São Paulo, SP, Brazil) after the cuspal deformation measurements and micro-CT scanning. The samples were submerged in water at approximately 37°C and cycled with an axial compressive load from 0 to 50 N for 1,200,000 times with an 8.0-mm-diameter stainless steel sphere on the occlusal cusps with a 2 Hz frequency.[26,27]

Cuspal Strain During Fracture Procedure (CSt-Fr), Fracture Resistance, and Fracture Mode

Strains were recorded under 100 N loading (CSt-100N) with strain gauges. The load required (N) to cause fracture of the samples was recorded on a computer with control and data acquisition software (TESC; EMIC, São José dos Pinhais, PR, Brazil). The strains were also recorded at the failure load (CSt-Fr). Axial compressive loading was applied with a stainless steel sphere with a diameter of 8 mm at a crosshead speed of 0.5 mm/min in a universal testing machine (DL2000, EMIC) with a 500 N load cell (Figure 1).

The fracture modes of each sample were evaluated by three operators and then assigned to one of four categories proposed by Burke[28]: 1) fractures involving a small portion of the coronal tooth structure; 2) fractures involving a small portion of the coronal tooth structure and cohesive failure of the restoration; 3) fractures involving the tooth structure, cohesive and/or adhesive failure of the restoration, with root involvement that can be restored in association with periodontal surgery; and 4) severe root and crown fracture, which require extraction of the tooth.

Statistical Analysis

The cuspal deformation, fracture resistance, and void volume data were tested for a normal distribution (Shapiro Wilk test) and an equality of variances (Levene test) followed by parametric statistical tests. One-way analysis of variance (ANOVA) was performed

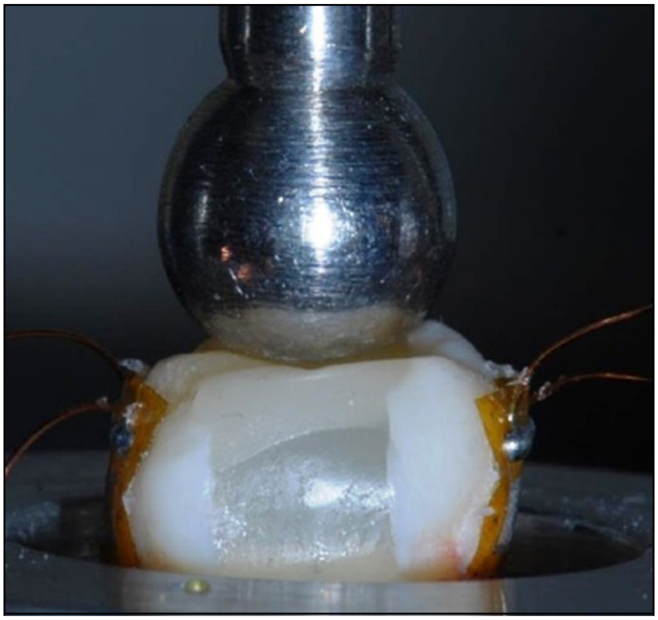

Figure 1. *Loading application for cusp deformation measurement at 100 N and at fracture failure.*

in a split-plot arrangement for cusp strain values, with the plot represented by a restorative protocol and the subplot represented by the cusp type. One-way ANOVA was performed for the fracture resistance and void volume values. Multiple comparisons were made using Tukey test. A Pearson correlation test was used to correlate the measured cusp deformation caused by the polymerization shrinkage obtained from the strain gauge and micro-CT methods. The failure mode data were subjected to the χ^2 test. All tests employed $\alpha = 0.05$ as the significance level, and all analyses were carried out with the statistical package Sigma Plot version 13.1 (Systat Software Inc, San Jose, CA, USA).

RESULTS

Porosity of the Restorations: Micro-CT

The porosity generated during the restorative procedures was evaluated by micro-CT, and the results are shown in Figure 2. The one-way ANOVA showed a significant effect of the restorative technique on the percentage of porosity (p<0.001). The POST had lower porosity than that of the VIT/TPH3 and VIT/Z350 samples. The SDR/TPH sample had a similar porosity to that of all the other groups.

Cuspal Deformation: Strain Gauge and Micro-CT

The cuspal deformation means and standard deviations caused by the polymerization shrinkage, occlusal loading, and fracture resistance measured by the strain gauges (n=10) are shown in Table 2. The one-way ANOVA showed that all restorative protocols had similar cuspal deformations as a function of the polymerization shrinkage (p=0.992), occlusal loading (p=0.342), and fracture resistance (p=0.941). However, the cusp type had a significant effect for all the measurements of the polymerization shrinkage (p<0.001), occlusal loading (p<0.001), and fracture resistance (p<0.001). The lingual cusp had a significantly higher deformation than that of the buccal cusp for all measurements. The Pearson correlation showed a low correlation for the cuspal deformation measured with strain gauge caused by polymerization shrinkage with porosity inside the restoration (p=0.576), during occlusal loading (p=0.345), and at the fracture resistance (p=0.125).

The cuspal deformation means and standard deviations measured after restorative protocols using the micro-CT method are shown in Table 3 and Figure 3. The one-way ANOVA showed that all restorative protocols showed a similar cusp deformation (p=0.325); however, the cusp type (p<0.001) had a significant effect. The micro-CT showed that the lingual cusp had a greater deformation than that of the buccal cusp. The Pearson correlation showed a low correlation for the cuspal deformation caused by the restorative procedure measured with micro-CT (p=0.352).

Fracture Resistance and Fracture Mode

The means and standard deviations of the fracture resistance for all restorative techniques are shown in Table 4. The one-way ANOVA showed no significant difference among the groups (p=0.786). The χ^2 test showed no difference in the fracture mode for all tested restorative protocols (p=0.911). The ratio between the maximum resistance and cusp deformation at the moment of fracture is shown in Table 4. No difference was found among the tested restorative protocols (p=0.741).

DISCUSSION

In the present study, the null hypothesis was accepted, and the porosity inside the different materials used to fill the pulp chamber had no influence on the cusp deformation, fracture resistance, or fracture mode of the root-treated molars.

The use of RMGIC to fill the pulp chamber demonstrated a lower cusp deformation and higher fracture resistance than those samples with the incremental filling technique. The VIT/Z350XT and VIT/TPH groups, which contained RMGIC inserted

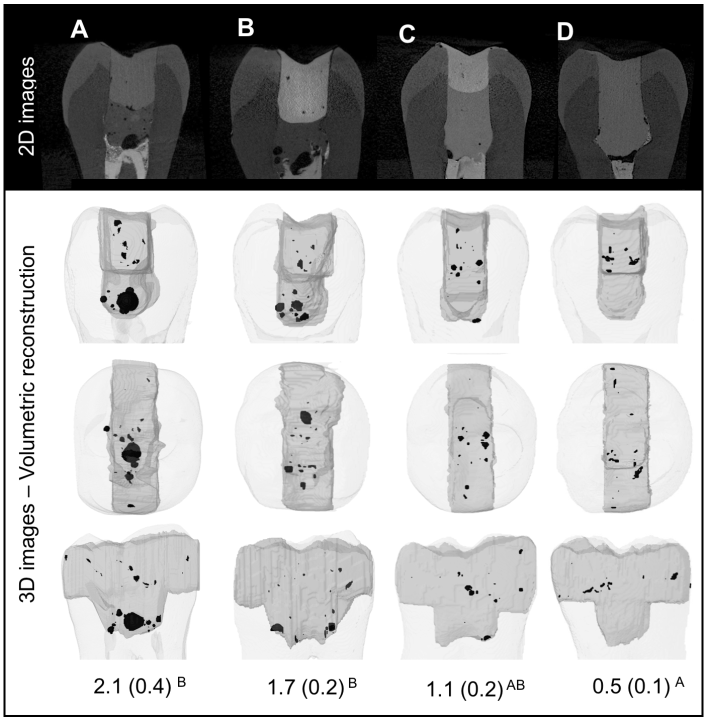

Figure 2. *Images of the 2D and 3D porosity in the restorations. (A): VIT/Z350. (B): VIT/TPH. (C): SDR/TPH. (D): POST. Means and standard deviations of the percentages of the bubble volumes in the restoration were measured by micro-CT (n=10). Different letters indicate a significant difference for a comparison of the resin composites (*p*<0.05).*

into the pulp chamber combined with the incrementally inserted conventional resin composite, resulted in an elevated number of voids, most likely because RMGIC requires mixing and insertion to incorporate voids within the material.[29,30] The elevated amount of porosity presented in these two groups was located inside the pulp chamber. The insertion of the RMGIC into the pulp chamber can also lead to air entrapment between the material and the tooth structure. Laboratory studies have shown that insertion using different methods, such as with a Centrix syringe or simple low-cost syringe, was effective in decreasing porosity

Table 2: *Means and Standard Deviations of Cusp Deformations (μS) Caused by Polymerization Shrinkage, Occlusal Loading, and Fracture Resistance Measured by Strain Gauges (n=10)*

Groups	Cusp Strain Filling Technique (μS)[a]			Cusp Strain at 100 N Loading (μS)[a]			Cusp Strain at Fracture Load (μS)[a]		
	Buccal Cusp	Lingual Cusp	Mean Cusps	Buccal Cusp	Lingual Cusp	Mean Cusps	Buccal Cusp	Lingual Cusp	Mean Cusps
SDR/THP	173.7 (45.4) a	226.5 (65.9) b	180.1 (41.3) A	21.0 (6.6) a	49.9 (8.6) b	35.5 (7.5) A	368.7 (63.9) a	640.2 (244.8) b	486.8 (81.7) A
POST	161.5 (54.8) a	338.3 (78.6) b	249.9 (44.0) A	22.3 (8.5) a	47.2 (13.1) b	35.8 (9.5) A	348.0 (75.3) a	556.8 (194.2) b	457.7 (76.9) A
RMGIC/ Z350XT	164.1 (56.6) a	341.2 (75.2) b	256.9 (46.0) A	22.5 (9.5) a	35.2 (10.3) b	28.8 (8.4) A	285.6 (62.9) a	502.8 (179.9) b	394.2 (73.4) A
RMGIC/TPH	178.9 (66.2) a	341.7 (88.0) b	260.6 (50.7) A	22.2 (6.9) a	36.0 (9.4) b	29.1 (8.6) A	287.3 (84.2) a	564.1 (190.7) b	427.5 (85.3) A

[a]*Different letters indicate a significant difference: uppercase letters were used to compare the resin composites, and lowercase letters were used to compare the cusp location (*p*<0.05).*

Table 3: *Means and Standard Deviations of Cusp Deformations Caused by Polymerization Shrinkage for Filling Techniques Measured Using Micro-CT (%)*			
Groups	**Cusp Strain Filling Technique %**		
	Buccal Cusp[a]	**Lingual Cusp[a]**	**Mean Cusps[a]**
SDR/TPH	2.0 (0.3) a	2.8 (0.4) b	2.3 (0.3) A
POST	2.2 (0.3) a	2.7 (0.2) b	2.5 (0.2) A
VIT/Z350	2.4 (0.3) a	3.2 (0.9) b	2.8 (0.4) A
VIT/TPH	2.5 (0.5) a	3.0 (0.4) b	2.7 (0.2) A

[a]*Different letters indicate a significant difference: uppercase letters were used to compare the resin composites, and lowercase letters were used to compare the cusp location (*$p<0.05$*).*

in the material.[30] It is important to evaluate whether voids were also affected by the size of the cavity while the clinicians inserted the material to the bottom of the cavity.[31] Additionally, the restoration of deep cavities using the incremental technique with increments of 2 mm may explain the entrapment spaces and resulting air voids between the increments.[17,18,32] Thus, material manipulation by the operator during its insertion is seldom recommended.[18,20]

When restoring the cavity using a bulk-fill resin composite, the risk of void generation between increments decreased significantly, as observed for the POST group, since the material can be inserted in a large increment (4-5 mm). However, if the viscosity of the material is high, it could enable void aggregation.[18] The manipulation of the material during insertion is minimal and has the possibility to be condensed during its insertion to accommodate the material, which is an influential factor on the porosity.[33] The presence of the voids in the SDR group may originate from the encapsulation process of the material and its intrinsic porosity, which cannot be controlled by the operator.[33]

Theoretically, the presence of voids may represent points of crack propagation, which may result in reduced material resistance and restoration longevity.[30,34] However, in the present study, porosity

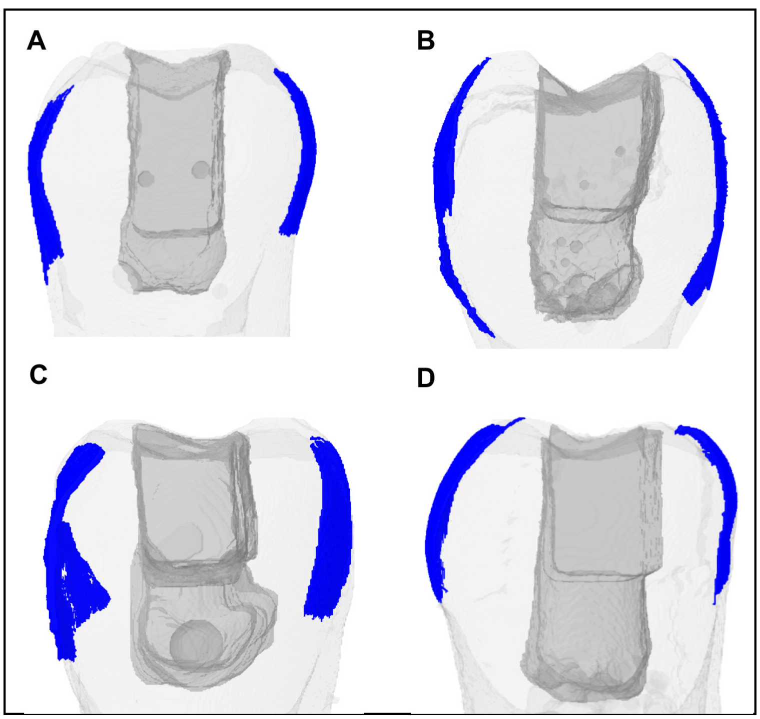

Figure 3. *Volume of the cusp deformation calculated with micro-CT. Difference in the overlap of the prepared images in proximal view. (A): SDR/TPH. (B): VIT/TPH. (C): VIT/Z350. (D): POST.*

Table 4: Means (Confidence Interval-95% Confidence Interval) of the Fracture Resistance (n), Mode of Fracture, and Ratio Between Maximum Cusp Deformation/Fracture Resistance Measured by the Axial Compression Test (n=10)

Group	Fracture Resistance (N)	Fracture Mode				Ratio Between Strain/Fracture Resistance[a]
		I	II	III	IV	
SDR/THP	1390.9 (1080.2-1701.5) A	0	1	9	0	0.36 A
POST	1375.5 (1047.0-1704.4) A	0	0	10	0	0.31 A
VIT/Z350XT	1294.7 (944.7-1644.7) A	0	2	8	0	0.32 A
VIT/TPH	1261.3 (886.5-1636.1) A	0	2	8	0	0.33 A

[a]*Uppercase letters were used to compare the restorative protocol* ($p<0.05$).

inside the restorations was not sufficient to influence the mechanical performance of the restorations, since no difference among the restorative protocols was observed for all biomechanics parameters that were evaluated. This finding can be attributed to the fact that despite the presence of porosity in the restorative materials, the total volume of voids was very small when compared to the total volume of the restoration. In addition, a large number of voids were located inside the pulp chamber of the restorations and not at critical points, such as in the interface region and close to the occlusal surface.

The cuspal deformation, fracture resistance, and failure mode of the different protocols of restored teeth result from the interaction among multiple factors, such as the restorative preparation design, magnitude and type of the load, mechanical properties of the restoration, and the use of low-modulus intermediate layers.[35] The use of RMGIC to fill the pulp chamber can reduce the resin composite volume needed to fill the cavity and the side effects of polymerization shrinkage caused by the incremental filling technique.[36] The use of RMGIC, which presents lower elastic modulus into the pulp chamber and also the empty volume created by porosity inside the RMGIC, can result in a the cushioning effect. This effect can result in stress absorption improving mechanical behavior. The use of a bulk-fill resin composite, regardless of the viscosity, reduces the polymerization shrinkage stress and improves the biomechanical performance.

In addition to discussing fracture resistance values, it may be important to analyze the fracture modes in each experimental group.[35] The fracture modes observed were predominantly type III fractures involving the tooth structure and cohesive and/or adhesive failure of the restoration with root involvement. This type of tooth fracture may be amenable to further treatment, involving a new restoration in association with periodontal surgery. However, this type of treatment is complex, expensive, and time consuming, therefore, this type of fracture should be avoided, indicating the value of cusp coverage to increase the fracture resistance and prevent further damage to a weakened endodontically treated tooth.[37,38]

The cuspal deformation during the restorative procedures, the occlusal loading of 100 N and associated deformation, and the maximum load to fracture were not influenced by the different restorative protocols. The remaining lingual surface of the tooth showed a higher deformation than that of the buccal surface during occlusal loading at 100 N and at the moment of fracture, regardless of the restorative protocol. The lower volume of dentin on the lingual surface could explain the elevated deformation.[39] The different tested protocols have a similar low elastic modulus that was used to restore the pulp chamber. The materials used—namely, VIT, SDR, and POST—have a lower elastic modulus than that of a conventional resin composite, which led to a higher capacity of elastic deformation.[12,13,23] The presence of the porosity located inside the restoration did not significantly influence the biomechanical performance of the root-treated molars that were restored with the direct resin composite restorations; however, clinicians should always avoid porosity in restorations because locations close to the surface or at the interface can cause other negative factors.

CONCLUSIONS

Within the limitations of this *in vitro* study, the porosity generated during restorative protocols had no influence on the cuspal deformation, fracture resistance, or fracture mode. The use of the RMGIC to fill the pulp chamber and the incremental filling technique resulted in similar biomechanical performance for the low- and high-viscosity bulk-fill resin composites for the restoration of root-treated molar teeth.

Acknowledgements

This study was supported by grants from CNPq, FAPEMIG, and CAPES-Finance code 001. This study was carried out at the Biomechanics, Biomaterials and Cell Biology Research Centre – CPBIO/FOUFU.

Regulatory Statement

This study was conducted in accordance with all the provisions of the human subjects oversight committee guidelines and policies of the Ethics Committee in Human Research at the Federal University of Uberlandia. The approval code issued for this study is 06257012.1.0000.5152

Conflict of Interest

The authors 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.

(Accepted 20 May 2020)

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