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Molar cusp deformation evaluated by micro-CT and enamel crack formation to compare incremental and bulk-filling techniques

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ABSTRACT

Objectives: To describe a method of measuring the molar cusp deformation using micro-computed tomography (micro-CT), the propagation of enamel cracks using transillumination, and the effects of hygroscopic expansion after incremental and bulk-filling resin composite restorations.

Methods: Twenty human molars received standardized Class II mesio-occlusal-distal cavity preparations. They were restored with either a bulk-fill resin composite, X-tra fil (XTRA), or a conventional resin composite, Filtek Z100 (Z100). The resin composites were tested for post-gel shrinkage using a strain gauge method. Cusp deformation (CD) was evaluated using the images obtained using a micro-CT protocol and using a strain-gauge method. Enamel cracks were detected using transillumination.

Results: The post-gel shrinkage of Z100 was higher than XTRA ($P < 0.001$). The amount of cusp deformation produced using Z100 was higher compared to XTRA, irrespective of the measurement method used ($P < 0.001$). The thinner lingual cusp always had a higher CD than the buccal cusp, irrespective of the measurement method ($P < 0.001$). A positive correlation ($r = 0.78$) was found between cusp deformation measured by micro-CT or by the strain-gauge method. After hygroscopic expansion of the resin composite, the cusp displacement recovered around 85% ($P < 0.001$). After restoration, Z100 produced more cracks than XTRA ($P = 0.012$).

Conclusions: Micro-CT was an effective method for evaluating the cusp deformation. Transillumination was effective for detecting enamel cracks. There were fewer negative effects of polymerization shrinkage in bulk-fill resin restorations using XTRA than for the conventional incremental filling technique using conventional composite resin Z100.

Clinical significance: Shrinkage and cusp deformation are directly related to the formation of enamel cracks. Cusp deformation and crack propagation may increase the risk of tooth fracture.

1. Introduction

Resin composites are extensively used to restore teeth [1,2]. Despite advances in techniques and materials, even bulk-fill resin composites [3,4], still exhibit polymerization shrinkage [5]. Conventional resin composites must be inserted and light cured in at most 2 mm increments to reduce shrinkage stress and to achieve acceptable resin properties [5,6]. On the other hand, light cured bulk-fill resin composites can be used in increments of up to 4–5 mm [7], and same materials may produce lower shrinkage stress than conventional resin composites depending to the composition, viscosity and elastic modulus [8].

Polymerization shrinkage can be affected by several factors, such as the composition of the material [9], cavity configuration or C-factor [10], and the restorative technique [5]. The stresses generated during the polymerization may cause cusp deformation and enamel cracks [9]. Clinically this may cause increased postoperative sensitivity, more microleakage, marginal discoloration, recurrent caries, and pulpal complications [1,4,11–13]. These have been the most common reasons to replace resin composite restorations [14]. Water absorption causes hygroscopic expansion of the resin composite and can counteract some of the negative effects of polymerization shrinkage [15,16], however this takes time to occur. Although this factor is positive for the tooth-

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restoration complex, if the hygroscopic expansion is greater than the polymerization shrinkage, the expansion will generate stresses within the tooth [17].

Several devices and methods have been described for analyzing the polymerization shrinkage [18], whether it be volumetric [19] or linear shrinkage [7,20–22]. Measuring the cusp deformation has been reported to be a good technique to analyze and predict the effects of polymerization shrinkage on the restored tooth [3,16] because it reflects the effects of the internal stresses on the tooth [23]. The cusp deformation under occlusal loading, measured either by the linear displacement or by a strain gauge method have also been used [5,24]. The use of non-destructive methodologies favors the combination of several methods to achieve different perspectives on the effects of the shrinkage [18]. Determining crack formation in the tooth and its propagation can be directly related to cusp deflection and since the same samples can be used, this facilitates the interpretation and allows direct correlation of the results [3].

The internal adaptation of the restorative material in the cavity, the restorative material itself and the dental structures can be examined using two dimensional (2D) and three dimensional (3D) micro-CT images with a high spatial resolution (maximum resolution of 1.10 μm) [25]. This method has demonstrated its efficacy to analyze the polymerization shrinkage vectors [26] and to evaluate the presence of any gaps after silver nitrate infiltration without damaging the specimens [27,28]. This method is also able to quantify the volumetric shrinkage of resin composites [25,29], and can characterize both the pattern and volume of polymerization shrinkage [30]. Despite the diverse uses of the micro-CT, to the authors knowledge, there are no studies that have analyzed the cusp deformation and the effect of hygroscopic expansion in molar class II resin composite restorations using micro-CT.

The aim of this study was to describe and validate a method of measuring cuspdeformation using micro-CT, the propagation of enamel cracks using transillumination, and the effects of hygroscopic expansion of both incrementally filled and bulk-filled resin composite restorations. The null hypotheses were:

1. There would be no correlation between the cusp deformation evaluated with micro-CT, and the strain gauge method.
2. That the bulk-fill resin composite would not exhibit different post-gel shrinkage and would not generate different amounts of cusp deflection and enamel cracking compared to the incrementally placed conventional resin composite.
3. The bulk-fill resin composite and the conventional resin composite would not exhibit different amounts of hygroscopic expansion after 7 days in water.

2. Materials and methods

2.1. Study design

Twenty human molars received standardized Class II mesio-occlusal-distal (MOD) cavity preparations. Restorations were made with two restorative protocols according to manufacturer's instructions: using a bulk-fill resin, XTRA (X-tra fil, VOCO, Cuxhaven, Germany) or an incrementally placed conventional composite resin, Z100 (Z100 Restorative, 3 M ESPE, St. Paul, MN, USA). The number of samples for each methodology was based on the coefficient of variability and the sample calculation. The power of the test was 80% with a minimum detectable difference of 20%, a residual standard deviation of 15% and a significance level of 0.05, which resulted in a number of samples of n = 10 per group. Considering the data variation of micro-CT methodology and the cost of each scan, the number of sample was reduced (n = 5).

The composition of the resin composites as provided by the manufacturers are listed in Table 1. The two resin composites were tested for post-gel shrinkage (Shr) using the strain gauge method. Teeth were tested for cuspal deformation using strain gauges as they were restored with the resin composite. Enamel cracking was detected and classified using a standardized transillumination technique. Cusp deformation (CD) was evaluated using micro-CT and the novel protocol developed in this study.

2.2. Post-gel shrinkage (Shr)

The post-gel linear shrinkage was determined using a previously described strain gauge method [22]. This method allows real time measurement of shrinkage strain. When the composite sample is exposed to the light curing, the strain is recorded and the measurement is continued for ten minutes [22]. Ten specimens were tested for each restorative material (n = 10). The materials were shaped into a hemisphere on top of a biaxial strain gauge (CEA-06-032WT-120f) that measured the shrinkage strains in two perpendicular directions. A strain conditioner (ADS0500IPg) converted electrical resistance changes in the strain gauge to voltage changes through a quarter-bridge circuit with an internal reference resistance of 120 Ω. The strain values measured along the two axes were averaged because the material properties were considered to be homogeneous and isotropic on a macro scale. Both resin composites were inserted in increments that were 1 mm thick, and 2 mm × 2 mm, by the same operator, and light activated using the same Bluephase G2 (Ivoclar Vivadent, AG, Schaan, Liechtenstein) light-curing unit according to manufacturer's instructions: for 20 s for XTRA and 40 s for Z100, with the light tip held at 1 mm distance from the surface of the resin composite. The strain values were collected for 10 min after light activation to monitor the post-gel shrinkage of the resin composites. Strain recorded from the two axes of the strain gauge were averaged and plotted as a function of time for each sample. Then the strain values obtained from the ten samples was used for created a mean curve of the strain at each material [22]. The final values, which represented the linear shrinkage, was converted to percentage and then multiplied by three to obtain the volumetric shrinkage [5].

2.3. Tooth selection and cavity preparation

Twenty extracted intact caries-free mandibular third human molars were used (Ethics Committee in Human Research approval #1.372.102). The teeth were stored in distilled water in the refrigerator before use. To standardize the samples, the tooth dimensions were measured with digital micrometer (Absolute AOS, Mitutoyo Sul Americana Ltda., Suzano, SP, Brasil). Any deviations in the intercuspal width size were kept to a maximum deviation of 10% from the mean value. Five measurements of the crown were made to calculate the volume: buccal and lingual cusp height, intercuspal distance, buccal/lingual, and mesio/distal width. The teeth were randomly allocated to the two groups (n = 10) and the mean crown volume before preparation (mm^3) for XTRA was 762.9 ± 183.4 and for Z100 it was 748.0 ± 107.2. These volumes were statistically similar (P = .827).

To allow some freedom of movement, the roots were covered with a 0.3 mm layer of a polyether impression material (Impregum F; 3 M, St Paul, MN, USA), and then embedded in a polystyrene resin (Cristal, Piracicaba, SP, Brazil) to 2 mm below the cemento–enamel junction. This simulated the periodontal ligament and the alveolar bone [31]. Large Class II MOD cavities were prepared in all specimens that were 4/5 of the intercuspal width and 4 mm deep in occlusal box with a cylindrical with a rounded ended diamond bur (#3099 diamond bur, KG Sorensen, Cotia, SP, Brazil) using copious air–water spray and a mechanical cavity preparation device [32]. In an attempt to standardize the preparations, the thickness of hard tissue of each cusp was measured during the preparation and the location of the pulp horns were evaluated using a radiograph. The cusp deformation was measured with strain gauges and then transillumination was used to determine the presence of enamel cracks in the teeth.