Journal of Dentistry xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Journal of Dentistry

journal homepage: www.elsevier.com/locate/jdent

Polymerization shrinkage stresses in different restorative techniques for non-carious cervical lesions

Ayla Macyelle de Oliveira Correia[a], João Paulo Mendes Tribst[b], Felipe de Souza Matos[a], Jeffrey A. Platt[c], Taciana Marco Ferraz Caneppele[a], Alexandre Luiz Souto Borges[b,*]

[a] Department of Restorative Dentistry, São Paulo State University – UNESP, Institute of Science and Technology, São José dos Campos, São Paulo, Brazil
[b] Department of Dental Materials and Prosthodontics, São Paulo State University – UNESP, Institute of Science and Technology, São José dos Campos, São Paulo, Brazil
[c] Department of Biomedical and Applied Sciences, Division of Dental Biomaterials, Indiana University School of Dentistry (IUSD), Indianapolis, IN, USA

ARTICLE INFO

Keywords:
Finite element analysis
Composite resins
Incremental technique
Polymerization
Dental stress analysis
Non carious cervical lesions

ABSTRACT

Objective: This study evaluated the effect of different restorative techniques for non-carious cervical lesions (NCCL) on polymerization shrinkage stress of resins using three-dimensional (3D) finite element analysis (FEA).
Methods: 3D-models of a maxillary premolar with a NCCL restored with different filling techniques (bulk filling and incremental) were generated to be compared by nonlinear FEA. The bulk filling technique was used for groups B (NCCL restored with Filtek™ Bulk Fill) and C (Filtek™ Z350 XT). The incremental technique was subdivided according to mode of application: P (2 parallel increments of the Filtek™ Z350 XT), OI (2 oblique increments of the Filtek™ Z350 XT, with incisal first), OIV (2 oblique increments of the Filtek™ Z350 XT, with incisal first and increments with the same volume), OG (2 oblique increments of the Filtek™ Z350 XT, with gingival first) and OGV (2 oblique increments of the Filtek™ Z350 XT, with gingival first and increments with the same volume), resulting in 7 models. All materials were considered isotropic, elastic and linear. The results were expressed in maximum principal stress (MPS).
Results: The tension stress distribution was influenced by the restorative technique. The lowest stress concentration occurred in group B followed by OG, OGV, OI, OIV, P and C; the incisal interface was more affected than the gingival.
Conclusion: The restoration of NCCLs with bulk fill composite resulted in lower shrinkage stress in the gingival and incisal areas, followed by incremental techniques with the initial increment placed on the gingival wall.
Clinical significance: The non-carious cervical lesions (NCCLs) restored with bulk fill composite have a more favorable biomechanical behavior.

1. Introduction

The marginal adaptation of composite resin restorations can be influenced by the type of adhesive system and factors related to the development of stress during the polymerization process of the restorative material [1–4]. The stress is influenced by factors such as elastic modulus [5], quantity of restorative material, cavity geometry [6], restorative technique, and light-curing protocol [7,8]. In addition, the composite resin polymerization shrinkage is an important source of interfacial stress [5].

Polymerization shrinkage produces stress at the tooth/restoration interface, which may result in the formation of marginal gaps, microleakage and micro-cracking that promote degradation and marginal staining [7,9,10]. This, in turn, may contribute to the development of postoperative sensitivity, secondary caries [11,12] and pulpal inflammation resulting from the penetration of saliva, bacteria, and other irritating substances through the debonded interface [12]. The survival rate of these restorations can also be influenced by chemical degradation and attrition [13], stress concentration during mastication [14] and reduced adhesion to sclerotic dentin when present in NCCLs [15].

The development and improvement of restorative materials and filling techniques have been the primary approaches for reducing the stress caused by the resin composite polymerization shrinkage [16–20]. The incremental filling technique in oblique layers, with increments of less than 2 mm, reduces polymerization stress through reduced cavity configuration factor (C-factor) and thickness of the resin composite [19].

The C-factor is defined as the ratio of bonded area to un-bonded

* Corresponding author at: Department of Dental Materials and Prosthodontics, São Paulo State University – UNESP, Institute of Science and Technology, Av. Eng. Francisco José Longo, 777 - Jardim São Dimas, São José dos Campos, SP, Brazil.
E-mail address: alexandre.borges@unesp.br (A.L.S. Borges).

https://doi.org/10.1016/j.jdent.2018.06.010
Received 24 March 2018; Received in revised form 14 June 2018; Accepted 19 June 2018

area of the dental cavity [21,22]. Its value is directly related to the stress developed at the interfacial bonding area. However, stresses generated by the material within a cavity depend not only on the C-factor but also on the remaining dental structure and mass or volume of restorative material [23].

Non-carious cervical lesions (NCCLs), usually due to erosion, abrasion and/or abfraction of dental tissues [19], have a reduced C-factor. However, shrinkage stresses and microleakage are higher in restorations with larger diameters and depths and seem to be related to the volume of the restoration, but not to its C-factor [21]. Therefore, the geometry and cavity shape are the most critical factors to be considered [6,24].

Techniques and materials have been developed to improve the long-term retention of cervical restorations. For large and/or deep restorations, incremental placement with oblique layers is recommended to decrease the effects of polymerization shrinkage and the thickness of a resin composite compared to other techniques [19]. However, this technique increases the possibility of incorporating voids between resin layers, as well as the time associated with placing and curing each layer of the material [6,25].

Bulk-fill resin composites were introduced to replace the need for incremental layers [25,26]. These resins exhibit reduced volumetric contraction, lower shrinkage stress, and increased cure depth. This is possible due to the increased translucency and variations in the filler of these composites [26,27], which allows the placement of thicker increments. This prevents the formation of gaps and contamination between the layers of the material, providing more compact restorations [28,29]. These materials have the advantage of simplifying the restorative procedure and reducing the curing time compared to a conventional resin composite [25,26].

The purpose of this study was to evaluate the influence of the restorative technique, using conventional or bulk-fill resin, on shrinkage stress in class V cavities of maxillary premolars using three-dimensional (3D) finite element analysis (FEA).

2. Materials and methods

2.1. Elastic modulus

The materials used in this study were two resin composites, Filtek™ Z350 XT and Filtek™ Bulk Fill. Their composition and manufacturer information are listed in Table 1.

Three bar-shaped specimens of each resin composite (30 × 3.5 x 12 mm) were used for analysis. The middle third of the sample was irradiated for 40 s, after which the remaining thirds were irradiated for 40 s each. A LED light-curing unit (Radii cal, SDI, Australia) with an irradiance of 1100 mW/cm^2 was used. The irradiance was checked with a radiometer (L.E.D, Demetron; Kerr Corporation, Orange, CA, USA).

Composite elastic modulus was determined using the Sonelastic® (Atcp Engenharia Física, São Carlos, Brazil). Each sample was set in transverse vibration with a single-pulse excitation generated using small hammer driven by an electromagnet. While vibrating, the signal produced was captured by a microphone underneath the sample by a special signal analyzer. Fundamental frequency under flexure is displayed on the screen of the apparatus. The elastic modulus values (GPa) and Poisson's Ratio obtained were used in the FEA (Table 2).

Table 2
Mechanical properties of the materials used in the tests.

Material/ structure	Elastic Modulus (GPa)	Poisson's Ratio	[a]Coefficient of Thermal Expansion, mm/ºC; Reference Temperature: 25 °C	Reference
Axson F16 Polyurethane	3.6	0.30	–	[31]
Enamel	84.1	0.33	–	[32]
Dentin	18.6	0.31	–	[33]
Pulp	0.002	0.45	–	[34]
Ligament	0.069	0.45	–	[35]
Filtek™ Z350 XT	13.45	0.17	0.00033	[b]
Filtek™ Bulk Fill	13.46	0.18	0.00025	[b]

[a] Assumed value to represent the volumetric shrinkage necessary to thermal analogy simulation.

[b] Information obtained in laboratory tests described previously.

2.2. Post-gel shrinkage measurements

Ten samples were tested for each resin composite. Composite post-gel shrinkage was determined using strain gages (KFGS-1-120-D16-11; KYOWA electronic instruments CO., Ltd., Tokyo, Japan, resistance 119.6 ± 0.4% Ω; gauge length: 1 mm; gauge factor: 2.08 ± 1.0%) [30]. Composite (diameter = 2.0 mm and height = 1.5 mm) was placed on the measuring surface of biaxial strain gage and light-cured for 40 s, using LED unit (Radii cal, SDI, Australia) with the light tip placed at 1 mm distance from the surface of the material. Variations of electrical resistance were converted into microstrain-rate units through an electrical signal conditioning apparatus (Model 5100B Scanner - System 5000 – Instruments Division Measurements Group, Inc. Raleigh, North Carolina, USA). Microstrain resultant from polymerization shrinkage was monitored for 5 min from the beginning of photoactivation in two perpendicular directions, due to the homogeneous and isotropic properties of the materials on a macro scale. The mean shrinkage strain was converted to a percentage and multiplied by three to express the material volumetric shrinkage. Thus, the coefficient of thermal expansion was determined and used to simulate polymerization shrinkage in the FEA (Table 2).

2.3. Residual stress calculation: finite element analysis

A previously validated 3D model simulating a maxillary premolar tooth was used [31]. The three-dimensional linear elastic analysis was performed based on anatomical geometric representations of dentine, pulp, enamel, periodontal ligament and alveolar bone (Fig. 1).

The Class V abfraction lesion, measuring 2.5 mm gingivo-occlusally, 5 mm mesiodistally and 1.5 mm in depth, was created, and respective restorations were simulated using different filling techniques (bulk filling and incremental). The bulk filling technique was used for groups B (NCCL restored with Filtek™ Bulk Fill) and C (NCCL restored with Filtek™ Z350 XT). The incremental technique was subdivided according

Table 1
Technical information about the materials used in the study.

Material	Manufacturer	Shade	Filler content	Resin matrix
Filtek™ Z350 XT	3M ESPE, St. Paul, MN, USA	A2	78.5 wt% (59.5 vol%) Silica, zirconia, aggregated zirconia/silica	Bis-GMA, UDMA, TEGDMA, Dimethacrylate
Filtek™ Bulk Fill	3M ESPE, St. Paul, MN, USA	A2	76.5 wt% (58.4 vol%) Silica, zirconia, ytterbium trifluoride, aggregated zirconia/silica	AUDMA, AFM, UDMA, DDDMA, EDMAB