



UNIVERSIDADE FEDERAL DE UBERLÂNDIA
FACULDADE DE ODONTOLOGIA



RAÍSSA RAMOS MIRANDA

**EFFECT OF SHRINKAGE MEASUREMENT METHOD OF
CONVENTIONAL AND BULK FILL RESIN COMPOSITES ON
RESIDUAL STRESS IN ENDODONTIC TREATED MOLARS**

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CONVENTIONAL AND BULK FILL RESIN COMPOSITES ON
RESIDUAL STRESS IN ENDODONTIC TREATED MOLARS**

Trabalho de conclusão de curso apresentado
a Faculdade de Odontologia da UFU, como
requisito parcial para obtenção do título de
Graduado em Odontologia.

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Pereira.

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DEDICATÓRIA

A Deus,

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CITAÇÃO

“Conheça todas as teorias, domine todas as técnicas, mas ao tocar uma alma humana, seja apenas outra alma humana.”

Carl Jung

SUMÁRIO

Abstract	9
Introduction	10
Material and Methods	11
<i>Study design</i>	11
<i>Compressive and diametral tensile strength</i>	11
<i>Post-Gel Shrinkage</i>	12
<i>Total shrinkage</i>	12
<i>Residual Stress Calculation: Finite Element Analysis</i>	13
<i>Statistical Analysis</i>	14
Results	14
<i>Compressive strength (CS) and diametral tensile strength (DTS)</i>	14
<i>Post-gel shrinkage (Shr) of resin composites</i>	15
<i>Total shrinkage (Tshr) of resin composites</i>	15
<i>Finite element analysis (FEA)</i>	15
Discussion	15
Acknowledgments	18
References	19
Tables	23
Figures	25
Figure Legends	27
Anexo	28

Title: Effect of shrinkage measurement method of conventional and bulk fill resin composites on residual stress in endodontic treated molars.

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Effect of shrinkage measurement method of conventional and bulk fill resin composites on residual stress in endodontic treated molars.

Abstract

Purpose: Analyze the effect of method use for calculating polymerization shrinkage, defined by the total and post-gel shrinkage on the generation of polymerization shrinkage stress.

Materials and Methods: Four composite, 2 conventional: Filtek Supreme (3M-ESPE) - FS; TPH3 Spectrum (Dentsply) – TPH3, and 2 bulk fill composite resins: Filtek Bulk Fill Posterior (3M-ESPE) – FBP; SureFil SDR flow (Dentsply) – SDR were tested for the compression strength (CS) test with 6 x 3 mm and diametral tensile strength (DTS) 4 x 2mm. CS and DTS (n=10) were performed at a universal machine test with 0.5 mm/min. Post-gel shrinkage (Shr) was evaluated by the extensometer technique (n = 10) and total shrinkage (Tshr) was measured by optical method (n = 10). The residual shrinkage stress was evaluated by finite element analysis with 4 restorative techniques: incremental for FS and TPH3; SDR + TPH3 (2 bulk increments + 2 occlusal increments) and 2 bulk increments for FBP. Data were analyzed by ANOVA and Tukey's test ($\alpha = 0.05$).

Results: FS (255a) had higher CS than TPH3 (164b), FBP (169b) and SDR (121c). TPH3 (49a) and FS (47ab) had higher DTS than FBP (42bc) and SDR (39c). The highest Shr and Tshr were showed by SDR, 0.45% and 3.93%, respectively. Bulk-filling method accumulated lower residual shrinkage stress than incremental and Tshr resulted in higher values than Shr.

Conclusion: Shrinkage stress was strongly dependent on the measuring method, type of resin and mechanical properties. Shr seems to be more appropriate to determine the contraction stress generated in restorative protocols.

Introduction

Resin composite materials are widely used in restorative dentistry.²⁴ During the polymerization reaction, the resin undergoes transition from predominantly viscous state to a basically solid state⁵ due to a conversion of monomer molecules in polymer chains (Soares *et al.*, 2013). Volumetric shrinkage is an inherent characteristic of resin-based materials (Tantbirojn *et al.*, 2015). Several factors determine the shrinkage stress, such as mechanical properties, chemical composition, the remaining tooth structure (Bicalho *et al.*, 2014; Al-Ahdal *et al.*, 2015; Tantbirojn *et al.*, 2004), restorative technique and the curing method (Francis *et al.*, 2015). This residual stress may result in enamel cracks propagation, cuspal deflection (Ferracane, 2013), marginal loss, secondary caries and postoperative sensitivity (Tantbirojn *et al.*, 2004).

Various restorative protocols have been advocated to reduce the shrinkage stress such as incremental technique (Versluis *et al.*, 1996), gradual polymerization (Zhu & Platt *et al.*, 2011), and larger increments (Bicalho *et al.*, 2014). Recent trends are focused in modifications of the resin matrix, mainly for developing materials with reduced polymerization shrinkage and consecutively the shrinkage stress (Stansbury, 2012). Bulk fill composites allow application of increments from 4 mm up to 5 mm thickness (Benetti *et al.*, 2015; Par *et al.*, 2015) with a high degree of uniform conversion by all increment, reduced shrinkage and shrinkage stress, available in low or high viscosity (Tarle *et al.*, 2015).

Although several methods has been descripted at literature to evaluate the shrinkage stress as mercury or water dilatometer (Sakaguchi *et al.*, 2004), bonded disc (Sakaguchi *et al.*, 2004) photoelasticity (Oliveira *et al.*, 1990), micro-CT (Sampaio *et al.*, 2017), most of them evaluate only the total shrinkage. The Finite Element Analysis (FEA) is a computational numerical analysis considered as the most comprehensive method to calculate the complex condition of the stress inside materials and structures (Versluis *et al.*, 2004b). This method is one of the reliable tools in biomechanics to evaluate the shrinkage stresses (Versluis *et al.*, 2009). Residual stresses will only be generated when the composite material cannot timely relax anymore, once not all polymerization shrinkage causes shrinkage stresses (Versluis & Tantbirojn, 2009a). Therefore, it is important to distinguish between total shrinkage and the shrinkage that really causes stresses, called the "post-gel shrinkage". Although in terms of shrinkage

stresses, post-gel shrinkage is more relevant for clinicians, most manufacturers only report the total shrinkage values for their materials.

Therefore, the aim of this study was to evaluate the effect of the method used for calculation of polymerization shrinkage, if total or post-gel shrinkage on the shrinkage stress of conventional and bulk-fill composites in restorative protocols in endodontically treated tooth. The null hypothesis was that there would be no difference at residual shrinkage stress using the total shrinkage or post-gel shrinkage values.

2 Materials and methods

2.1. Study design

This study was designed to test the effect of the shrinkage polymerization type, if total or post-gel shrinkage on the shrinkage stress during different restorative protocols to restore endodontic treated molars. Four commercial materials were used in this study, including two conventional composites: TPH3 (Dentsply Sirona, Konstanz, Germany), and Filtek Supreme XT (3M ESPE, St Paul, MN, USA); and two bulk fill composites: a flowable resin composite Bulk Fill Surefil SDR Flow (Dentsply Sirona, Konstanz, Germany), and a regular paste resin composite Filtek Bulk Fill Posterior (3M ESPE, St Paul, MN, USA). The composition was described according to manufacturer's instructions (Table 1).

All resin composites were tested for post-gel shrinkage (Pshr), total polymerization shrinkage (Tshr), diametral tensile strength (DTS) and compressive strength (CS). Ten specimens were tested for each restorative material and method. Shrinkage stresses were analyzed using FEA.

2.2 Compressive and diametral tensile strength

Compressive and diametral tensile strength of each resin composites were tested as described by Rosatto *et al.*, 2015. The resin composite was inserted into a cylindrical Teflon mold for the compressive strength test (6 mm height, 3 mm diameter) or for diametral tensile strength test (2 mm height, 4 mm diameter). The specimens for the compressive test made with bulk-fill composites were polymerized with 4.0 mm for the first increment and 2.0 mm for the second increment. For conventional composite, the specimens were polymerized in three increments of 2.0 mm thick. All materials

were light-cured using a light-emitting diode (LED) unit Bluephase G2, with irradiance of 1200 mW/cm² (Ivoclar Vivadent, Schaan, Liechtenstein) for the recommended curing times. The specimens were stored in distilled water for 24 hours at 37°C. The specimens were submitted to compressive strength and diametral tensile testing in a universal testing machine (DL2000, EMIC) at a crosshead speed of 0.5 mm/min until failure occurred. Compressive strength values (Kgf/cm²) were calculated by dividing the fracture load (F) by the cross-sectional area and converted into MPa. Diametral tensile strength values (Kgf/cm²) were calculated using the equation: $DTS = 2F/\pi dt$, where d is the specimen diameter, and t is the height of the specimen. DTS values were converted into MPa.

2.4 Post-Gel Shrinkage (*Pshr*)

Pshr was determined using the strain gauge method (Sakaguchi *et al.*, 1991). The materials were shaped into a hemisphere on top of a biaxial strain gauge (CEA-06-032WT-120, Measurements Group, Raleigh, NC, USA) that measured shrinkage strains in two perpendicular directions (X and Y-axes). A strain conditioner (ADS0500IP, Lynx, Tecnologia Eletrônica, São Paulo, SP, Brazil) converted electrical resistance changes in the strain gauge to voltage changes through a quarter-bridge circuit with an internal reference resistance. The strain values measured along the two axes were averaged because the material properties were homogeneous and isotropic on a macro scale. All materials were light-cured using a light-emitting diode (LED) unit Bluephase G2 with the light tip held at a 1-mm distance from the surface of the composite and monitored for 10 minutes. The mean shrinkage strain was used as linear post-gel shrinkage input for the finite element analysis and could be converted to the volumetric percentage by multiplying by 3 and 100%.

2.5 Total shrinkage (*Tshr*)

Tshr was calculated using optical method (Tantbirojn *et al.*, 2015). Each resin sample (n = 10) was placed on a platform made of addition silicone (Express, 3M ESPE) in blue color, for a better contrast between resin and surface. Each sample was slightly rounded and placed on the silicon platform. The platform was placed under a microscope coupled to a camera (SZX16 & UC30, Olympus) so that the images could be captured in a standardized way. Once positioned, a photo was taken before photo

activation. The light from the microscope was attached only to capture the images, to avoid premature polymerization of the compound through the optical microscope. Immediately after the first photo before polymerization of the material, the sample was light cured for 40 seconds using the Bluephase G2 (Ivoclar Vivadent), with an intensity of 1200 mW/cm^2 . After polymerization, the samples were monitored and photos were taken after 10 and 60 minutes of the initial light activation. All procedures were performed at room temperature, 22°C . Image J software (Public Domain, National Institute of Health, Bethesda, MD, USA), available free of charge on the Internet, was used to evaluate pre and post polymerization photos. The brightness of the image was adjusted to determine the maximum contrast between the resin sample and the silicon plate. Using the tool "wand tool", the contour of the sample was defined to obtain the total area. Through the photo of the total area of the samples before and after the polymerization, it was possible to calculate the volume change before and after the polymerization.

2.6 Residual Stress Calculation: Finite Element Analysis

In order to calculate total and post-gel residual shrinkage stresses, a two-dimensional (2D) finite element simulation was carried out for a mesial-occlusal-distal restoration of an endodontic treated molar as described by Pereira *et al.*, 2015. The geometric model (Fig. 3A) was based on a digitized buccolingual cross-section of an endodontic treated molar embedded in an acrylic resin cylinder with a simulated periodontal ligament (PDL). The coordinates of points were obtained using public domain ImageJ software (ImageJ 1.48, National Institutes of Health, Bethesda, MD, USA). The mechanical properties of used materials were: enamel elastic modulus (EM) 84 GPa and Poisson's ratio (PR) 0.30 (Craig & Powers, 2002); dentin EM 18 GPa and PR 0.23 (Craig & Powers, 2002; Watts *et al.*, 1987); polystyrene resin EM 13.5 GPa and PR 0.31 and polyether EM 0.05 GPa and PR 0.45 (Soares *et al.*, 2008). For the restorative materials the experimentally determined elastic modulus values, shown in Table 2, were used. The Poisson's ratio was chosen to be the same for all composites at 0.24 (Craig & Powers, 2002). A plane stress elements for the composites and a plane strain condition was assumed for the tooth cross-sections, PDL and acrylic resin cylinder.

The finite element analysis was performed using MSC.Mentat[®] (preprocessor and postprocessor) and MSC.Marc[®] (solver) software. One FEA model was generated for each of the four restorative protocols of the experimental study (Fig. 1A). The Filtek Supreme XT and TPH3 restorations were built and cured in 6 increments (Fig. 1B and 1C, respectively). The bulk fill flowable, SDR was placed in two increments up to 4mm and covered with TPH3 built with 2 increments of 2 mm thick on the occlusal surface (Fig. 1D). The bulk fill paste, Filtek Bulk Posterior was used in 2 increments of up to 5.0 mm (Fig. 1D). Polymerization shrinkage was simulated by thermal analogy. The temperature was reduced by 1°C, while the linear shrinkage value (post-gel shrinkage) or total shrinkage was entered as the coefficient of linear thermal expansion. Nodal displacements were the constraint in the X and Y directions at the bottom and lateral surfaces of the support cylinder. Modified von Mises equivalent stress was used to express the stress conditions, using the ratio of the compressive and tensile strengths. Based on this ratio, tensile stresses are given more weight in a modified von Mises criterion. The compressive-tensile strength ratios for the restorative materials are shown in Table 2 and were calculated using the experimentally determined CS and DTS values. The compressive and tensile strengths of enamel were 384.0 and 10.3 MPa and for dentin 297.0 and 98.7 MPa, respectively (Craig & Powers, 2002).

2.7 Statistical Analysis

The compressive strength, diametral tensile strength, post-gel and total shrinkage data were tested for normal distribution (Shapiro–Wilk, $P > 0.05$) and equality of variances (Levene's test), followed by parametric statistical tests. One-way analysis of variance (ANOVA) was performed for each mechanical property. Multiple comparisons were made using Tukey's test. All tests employed $\alpha = 0.05$ significance level and all analyses were carried out with the statistical package Sigma Plot version 13.1. The modified von Mises stresses values were analyzed qualitatively.

3 Results

3.1 Compressive strength (CS) and diametral tensile strength (DTS)

The mean values of CS and standard deviation for the four resin composites were obtained and are shown at Table 2. One-way ANOVA showed significant difference between resin composites tested ($P < 0.05$). The Tukey's test showed that Filtek Supreme resin has higher compressive strength than FBP, TPH3 and SDR. The

FBP and TPH3 had similar and intermediate CS values, and SDR had the lowest value (Table 2).

The mean values of DTS and standard deviation for the four resin composites were shown at Table 2. One way ANOVA showed significant difference between resin composites ($P < 0.05$). Tukey's test showed that FS had similar DTS than FBP and the higher values than TPH3 and SDR.

3.2 Pshr of resin composites

The Pshr mean values and standard deviations of four composites were shown at Table 2. The ANOVA showed a significant difference between the resin composites ($P < 0.05$). Tukey's test showed that FBP and FS had the highest Shr values, and SDR and TPH3 had lower Shr values (Table 2).

3.3 Tshr of resin composites

Tshr results were shown at the Table 2. The ANOVA test showed a significant difference between the resin composites ($P < 0.05$). SDR showed higher Tshr values than other resin composites (Table 2). FS and TPH3 had similar Tshr values, and FBP had the lowest values.

3.4 FEA results

Shrinkage stresses generated by all tested restorative techniques (modified von Mises stress) are shown in Fig.2 and Fig 3. The SDR/TPH3 bulk filling technique (Fig. 3G), resulted in the lowest stress at composite, enamel and root dentin close to the pulp chamber than FS and TPH3 incremental filling techniques (Fig. 3E and 3F, respectively) or even FBP bulk fill paste filling technique (Fig. 3H). The models generated with input of total shrinkage values (Fig. 3A, B, C and D) resulted in a substantial increasing on shrinkage stress comparing with models with post-gel shrinkage values (Fig. 3E, F, G and H), irrespective of the restorative technique. SDR /TPH3 cover showed the highest value of shrinkage stress when simulating the total shrinkage and the lowest values when simulating the post-gel shrinkage.

4 Discussion

The selection of direct restorative material with high performance and durability has led to the development of new materials. The change from the use of incremental

technique to bulk-filling method may be a result of simplified restorative technique with reduces possibility of errors, less operative steps and clinical spent time (Rosatto *et al.*, 2015). The results of this study confirmed that mechanical properties (CS, DTS), Pshr and Tshr were dependent of material composition, and that Pshr and Tshr values influenced the residual shrinkage stress regardless of restorative technique used; therefore, the tested null hypothesis was rejected.

The mechanical properties of restorative materials are significant indicators of success, in order to support the masticatory and parafunctional forces. Although the posterior teeth are subjected to compressive occlusal loading, tensile stresses are also generated in the tooth structure; the tooth is able to withstand compressive stresses better than the tensile stresses (Versluis *et al.*, 2011). CS of composites plays an important role in the masticatory process (Atalay *et al.*, 2016). The present study showed that compressive strength of conventional resin composite FS was statistically higher. This is due to the higher amount of inorganic filler present in weight and volume compared to TPH, FBP and SDR (Table 1). DTS investigates fragile materials with little or no plastic deformation and can contribute to early material failure (Della Bona *et al.*, 2008). The FS, TPH and FBP resins presented adequate tensile strength, and flowable bulk-fill resin (SDR) had the lowest DTS value, probably due to lower amount of inorganic filler (Table 1). This means that tensile stress components are relatively more critical in FBF restorations than for the other composites. The mechanical properties of composites were directly proportional to filler content (Ilie and Stark, 2015) and seem to be an important parameter governing the mechanical properties of the materials (Leprince *et al.*; 2014). The lower values of mechanical properties for the SDR, support the manufacturer instructions for built an occlusal layer with conventional composite to improve the mechanical performance of this kind of restoration (Puckett *et al.*, 1992).

Volumetric shrinkage is a consequence of polymerization of resin-based materials during formation of a polymer network, causing dimensional changes (Tantbirojn *et al.*, 2015). It is known that not all polymerization shrinkage causes shrinkage stresses (Bowen, 1963). Residual stresses will only be generated when the composite material cannot timely relax anymore, which happens when a more rigid polymer network structure has developed to transfer stresses (post-gel stage). The total shrinkage, measures the entire amount of dimensional change of the composite during polymerization, including the pre-gel stage, capable of flowing by releasing part of its

tension, and post-gel stage (Bausch *et al.*, 1982; Davidson & de Gee, 1984; Versluis & Tantbirojn, 2009; Bicalho *et al.*, 2015). This fact may explain why the percentage of volumetric total shrinkage of all four tested composites in this study presented values significantly higher than percentage results for post-gel shrinkage.

The percentage of polymerization shrinkage is positively influenced by the amount and organic content of the composite (Gonçalves *et al.*, 2011), and negatively by the percentage of inorganic content (Ferracane, 2011). So, analyzing the post-gel volumetric shrinkage the FS and FBP resins were similar and higher than the others due to the high content of filler in the resin matrix. It can be explained by the higher amount of filler that increases the modulus of elasticity and rigidity of the material (Bicalho *et al.*, 2014), which tending to increase the post-gel polymerization shrinkage stress. The change of a resin composite to a solid material, characterized by the development of the elastic modulus, during the polymerization results in rigid restorations and consequently residual shrinkage stresses by the effect of polymerization contraction (Rosatto *et al.*, 2015). The lower post-gel shrinkage value of SDR could be explained by the lower amount of inorganic filler content, attribute of flowable composites (Fronza *et al.*, 2015). Additionally, the SDR resin has a polymerization modulator that acts at propagation of the linear and branched chains of the polymers of the resin, reducing the formation velocity of polymer network, keeping its viscosity longer, providing lower stress compared to traditional composites (Schattenberger *et al.*, 2008). Inversely, SRD presented the highest total shrinkage value, probably due to the smaller amount of filler content. The total volumetric contraction depends on factors such as size of the charge particles and probably also the type of the organic matrix and concentration of monomers (Ellakwa *et al.*, 2007).

Bulk-filling techniques reduce the increments number by using a larger volume of composite, which resulted in lower residual shrinkage stress when compared with the incremental filling techniques. The residual stress concentrated on the tooth structure located at cervical enamel (Bicalho *et al.*, 2014; Rosatto *et al.*, 2015, Schliebe *et al.*, 2016). The stress presented at root dentin close to the pulp chamber was already expected, once the model simulated an endodontically treated teeth with the pulp chamber totally filled with resin composite. Therefore, the bulk fill resin composites show up as an alternative to restore endodontically-treated teeth with lower shrinkage stress than incremental technique, due the lower stress generated at severely compromised dental structure (Schliebe *et al.*, 2016). The highest values of residual

shrinkage stress were verified when was simulated the total shrinkage values comparing with the post-gel values. So, in this way, the shrinkage stresses generated by total shrinkage results are overestimated. Total shrinkage does not reflect shrinkage stress behavior, which is much better characterized by post-gel shrinkage. The post-gel shrinkage concept has turned out to be a useful factor to develop an understanding of the development and calculation of shrinkage stresses.

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References

1. Al-Ahdal K, Ilie N, Silikas N, Watts DC. Polymerization kinetics and impact of post polymerization on the Degree of Conversion of bulk-fill resin-composite at clinically relevant depth. *Dent Mater* 2015;31(10):1207.
2. Atalay C, Yazici AR, Horuztepe A, Nagas E, Ertan A, Ozgunaltay G. Fracture resistance of endodontically treated teeth restored with bulk fill, bulk fill flowable, fiber-reinforced, and conventional resin composite. *Oper Dent* 2016;41(5):E131-E140.
3. Bausch JR, de Lange K, Davidson CL, Peters A, de Gee AJ. Clinical significance of polymerization shrinkage of composite resins. *J Prosthet Dent* 1982;48(?)59-67
4. Benetti Ar, Havndrup-Pedersen C, Honore D, Pedersen MK & Pallesen U. Bulk-Fill Resin Composites: Polymerization Contraction, Depth of Cure, and Gap Formation *Oper Dent* 2015;40(2):190-200
5. Bicalho AA, Pereira RD, Zanatta RF, Franco SD, Tantbirojn D, Versluis A, Soares CJ. Incremental filling technique and composite material - part I: cuspal deformation, bond strength, and physical properties. *Oper Dent* 2014;39(2):E71-82.
6. Bicalho AA, Valdivia AD, Barreto BC, Tantbirojn D, Versluis A, Soares CJ. Incremental filling technique and composite material - part II: shrinkage and shrinkage stresses. *Oper Dent* 2014;39(2):E83-92.
7. Bowen RL, properties of a silica-reinforced polymer for dental restorations. *J Am Dent Assoc* 1963;66(?)57-64
8. Craig RG, Powers JM. Restorative dental materials. Mosby, St., Louis, MO: 2002

9. Davidson CL & de Gee AJ. Relaxation of polymerization contraction stresses by flow in dental composites. *J Dent Res* 1984;63(?):146-148.
10. Della Bona A, Benetti P, Borba M, Cecchetti D. Flexural and diametral tensile strength of composite resins. *Braz Oral Res* 2008;22(1):84-9
11. Ellakwa A, Cho N, Lee IB. The effect of resin matrix composition on the polymerization shrinkage and rheological properties of experimental dental composites. *Dent Mater* 2007;23(?):1229-1235
12. Ferracane JL. Resin composite--state of the art. *Dent Mater* 2011;27(1):29-38.
13. Ferracane JL. Resin-based composite performance: are there some things we can't predict? *Dent Mater* 2013;29(1):51-8.
14. Francis AV, Braxton AD, Ahmad W, Tantbirojn D, Simon JF, Versluis A. Cuspal Flexure and Extent of Cure of a Bulk-fill Flowable Base Composite. *Oper Dent* 2015;40(?):515-523.
15. Fronza BM, Rueggeberg FA, Braga RR, Mogilevych B, Soares LE, Martin AA, Ambrosano G, Giannini M. Monomer conversion, microhardness, internal marginal adaptation, and shrinkage stress of bulk-fill resin composites. *Dent Mater* 2015;31(12):1542-51
16. Gonçalves F, Azevedo CL, Ferracane JL, Braga RR. BisGMA/TEGDMA ratio and filler content effects on shrinkage stress. *Dent Mater* 2011;27(6):520-6.
17. Ilie N, Stark K. Effect of different curing protocols on the mechanical properties of low-viscosity bulk-fill composites. *Clin Oral Investig* 2015;19(2):271-9
18. Leprince JG, Palin WM, Vanacker J, Sabbagh J, Devaux J, Leloup G. Physico-mechanical characteristics of commercially available bulk-fill composites. *J Dent* 2014;42(8):993-1000
19. Oliveira DCRS, Rocha MG, Gatti A, Correr AB, Ferracane JL, Sinhoreti, MAC. Effect of different photo initiators and reducing agents on cure efficiency and color stability of resin-based composites using different LED wavelengths. *J Dent* 2015;43(?):1565-1572
20. Oliveira SAG, Gomide HA. Fotoelasticidade plana. *Material e técnica*. 9º CBECIMAT, Águas de São Pedro 1990, p.606-14.
21. Par M, Gamulin O, Marovic D, Klaric E, Tarle Z. Raman spectroscopic assessment of degree of conversion of bulk-fill resin composites--changes at 24 hours post cure. *Oper Dent* 2015; 40(3):E92-101.

22. Pereira R, Bicalho AA, Franco SD, Tantbirojn D, Versluis A, Soares CJ. Effect of Restorative Protocol on Cuspal Strain and Residual Stress in Endodontically Treated Molars. *Oper Dent* 2016;41(1): 23-33.
23. Puckett A, Fitchie J, Hembree J Jr, Smith J. The effect of incremental versus bulk fill techniques on the microleakage of composite resin using a glass-ionomer liner. *Oper Dent* 1992;17(5):186-91
24. Rosatto CM, Bicalho AA, Veríssimo C, Bragança GF, Rodrigues MP, TantbirojnD, Versluis A, Soares CJ. Mechanical properties, shrinkage stress, cuspal strain and fracture resistance of molars restored with bulk-fill composites and incremental filling technique. *J Dent* 2015 43(12):1519-28.
25. S Zhu and J Platt. Curing Efficiency of Three Different Curing Modes at Different Distances for Four Composites. *Operat Dent* 2011;36(4):362-371.
26. Sakaguchi RL, Versluis A, Douglas WH. Analysis of strain gage method for measurement of post-gel shrinkage in resin composites. *Dent Mater* 1997;13(4):233-9.
27. Sakaguchi RL, Wiltbank BD, Shah NC. Critical configuration analysis of four methods for measuring polymerization shrinkage strain of composites. *Dent Mater* 2004;20(4):388-96
28. Sampaio CS, Chiu KJ, Farrokhmanesh E, Janal M, Puppini-Rontani RM, Giannini M, Bonfante EA, Coelho PG, Hirata R. Microcomputed Tomography Evaluation of Polymerization Shrinkage of Class I Flowable Resin Composite Restorations. *Oper Dent* 2017;42(1):E16-E23
29. Schattenberg A, Lichtenberg D, Stender E, Willershausen B, Ernst CP. Minimal exposure time of different LED-curing devices. *Dent Mater* 2008;24(?):1043-9.
30. Schliebe LRSO, Braga SSL, Da Silva Pereira RA, Bicalho AA, Veríssimo C, Novais VR, Soares CJ. The new generation of conventional and bulk-fill composites do not reduce the shrinkage stress in endodontically-treated molars. *Am J Dent* 2016;29(6):333-338.
31. Soares CJ, Bicalho AA, Tantbirojn D, Versluis A. Polymerization shrinkage stresses in a premolar restored with different composite resins and different incremental techniques. *J Adhes Dent* 2013;15(?):341-350.
32. Soares CJ, Soares PV, de Freitas Santos-Filho PC, Castro CG, Magalhaes D, Versluis A. The influence of cavity design and glass fiber posts on biomechanical behavior of endodontically treated premolars. *J Endod* 2008;34(8):1015-9.

33. Stansbury JW. Dimethacrylate network formation and polymer property evolution as determined by the selection of monomers and curing conditions. *Dent Mater* 2012;28(1):13-22.
34. Tantbirojn D, Pfeifer CS, Amini AN, Versluis A. Simple optical method for measuring free shrinkage. *Dent Mater* 2015;31(11):1271-8.
35. Tantbirojn D, Versluis A, Pintado MR, DeLong R, Douglas WH. Tooth deformation patterns in molars after composite restoration. *Dent Mater* 2004;20(6):535-42.
36. Tarle Z, Attin T, Marovic D, Andermatt L, Ristic M & Tauböcktt. Influence of irradiation time on subsurface degree of conversion band microhardness of high-viscosity bulk-fill resin composites. *Clin Oral Invest* 2015;19(4):831-840.
37. Versluis A, Tantbirojn D. Relationship between shrinkage and stress. In: A., D (ed). *Dental Computing and Applications: Advanced Techniques for Clinical Dentistry*. Hershey, PA: IGI Global 2009; 44-64
38. Versluis A, Versluis-Tantbirojn D. Filling cavities or restoring teeth? *J Tenn Dent Assoc* 2011;91(2):36-42;
39. Versluis A, W.H. Douglas, M. Cross and R.L. Sakaguchi Does an Incremental Filling Technique Reduce Polymerization Shrinkage Stresses? *J Dent Res* 1996;75(?): 871
40. Versluis, A, Tantbirojn, D, Pintado, M. R., De-Long, R., & Douglas, W. H. Residual shrinkage stress distributions in molars after composite restoration. *Dent Mater* 2004; 20(?):554-564.
41. Watts DC, el Mowafy OM, Grant AA. Temperature-dependence of compressive properties of human dentin. *J Dent Res* 1987;66(1):29-32.

Tables:

Table 1. Composition of resin composites

Material	CODE	Shade	Composite Type	Increment size and light activation time	Organicmatrix	Filler	Filler % wt/vol	Manufacturer
TPH3 Spectrum	TPH	A2	Nanohybrid composite	2.0 mm – 20s	BisGMAandBis EMA dimethacrylate	Boro-silicate/aluminium /bariumglassandsi lica	75.27/*	Dentsply
Filtek Supreme XT	Z350XT	A2	Nanofilled composite	2.0 mm – 20s	Bis-GMA, Bis-EMA, UDMA, TEGDMA	Silicaandzirconian anofillers, agglomerated zirconia-silicananoclusters	82/60	3M-ESPE (St. Paul, MN, USA)
SDR	SDR	A2	Bulk-fill flowable composite	4.0 mm – 40s	UDMA, BISGMA, EBPADMA, Procrylatresin	Silane treated ceramic and YbF3	68/44	Dentsply
Filtek Bulk Fill posterior	BFP	A1	Bulk-fill paste composite	5.0 mm – 10s occlusal, 10s buccal and 10s palatal	UDMA, DDDMA, EDMAB	Silicia, zirconia and YbF3	76.5/58.4	3M-ESPE (St. Paul, MN, USA)

*Data not informed for manufacturer

Table 2. Experimentally determined mean (and standard deviation) of Compressive strength, Diametral tensile strength, Volumetric post-gel shrinkage, and .Volumetric total shrinkage and the corresponding Elastic Modulus

Composite Resin	Compressive strength (MPa)	Diametral tensile strength (MPa)	Post-gel shrinkage (%)	Total shrinkage (%)	ElasticModulus (GPa)
Filtek Supreme (FS)	255.7 ± 6.7 ^A	47 ± 4.5 ^{AB}	0.7 ± 0.1 ^A	2.6 ± 0.2 ^B	21.5 ± 0.8 ^A
TPH3 (TPH)	164.7 ± 15.5 ^B	49 ± 3.6 ^A	0.5 ± 0.0 ^B	2.5 ± 1.3 ^{BC}	14.3 ± 0.6 ^B
SDR (SDR)	121.7 ± 10.8 ^C	39 ± 3.3 ^C	0.4 ± 0.1 ^C	3.9 ± 0.8 ^A	10.1 ± 0.4 ^D
Filtek BulkFill Posterior (FBP)	169.7 ± 20.7 ^B	42 ± 6.2 ^{BC}	0.7 ± 0.1 ^A	2.1 ± 0.3 ^C	12.8 ± 0.4 ^C

* Different uppercase letters indicate significant difference between the composites (p<0.05).

Figures:

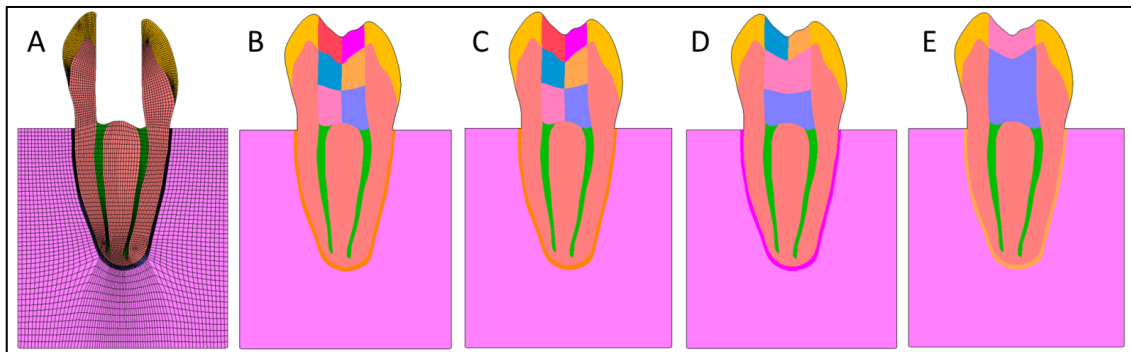


Figure 1.

Figure 1. Two-dimensional FEA model generation. A. Principal model – mesh of endodontically treated tooth with a MOD preparation; B. Incremental technique model restored with Filtek Supreme; C. Incremental technique model restored with TPH3. D. SDR bulk fill flow restoring the dentin and two occlusal increments of conventional composite TPH3 replacing the enamel; E. Filtek BulkFill Posterior replacing the dentin and enamel.

Figure 2.

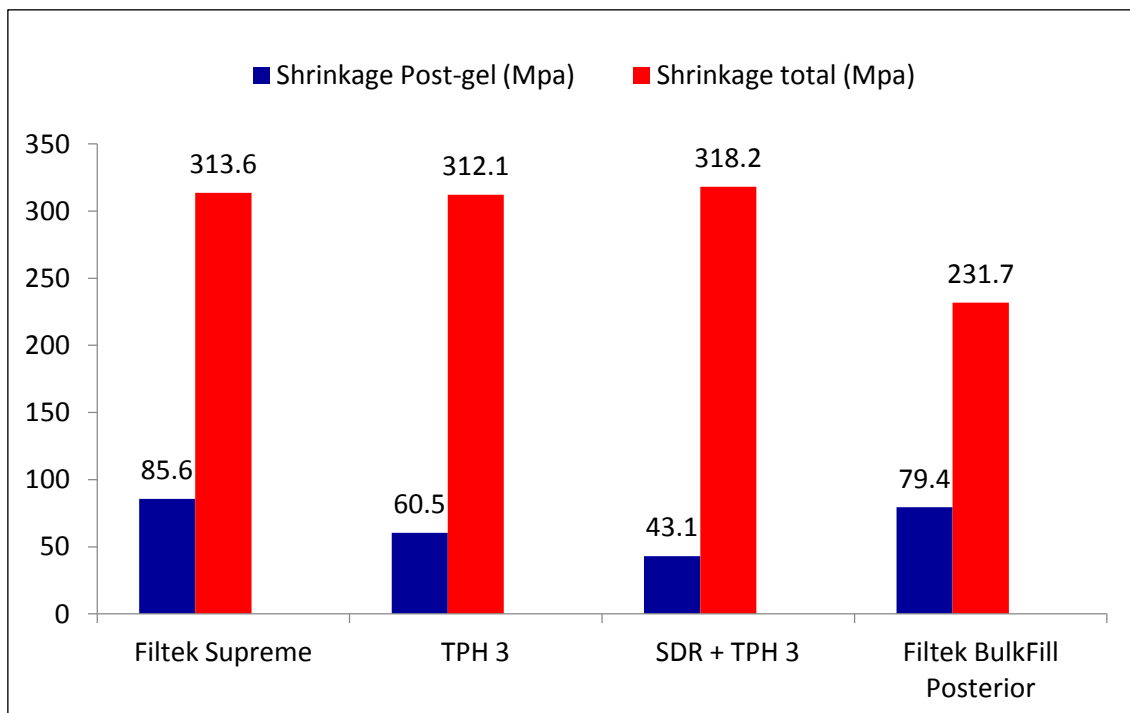


Figure 2. Numerical Modified von Mises polymerization shrinkage stress (MPa) for the different materials and techniques after polymerization.

Figure 3.

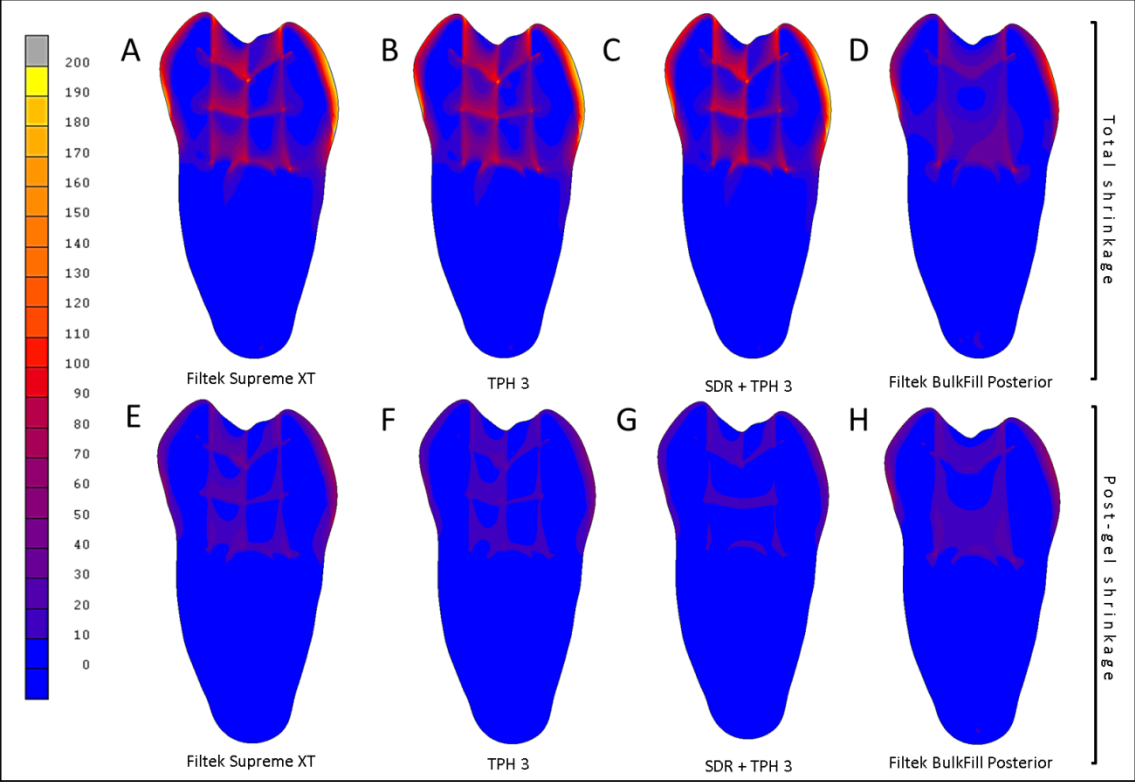


Figure 3. Modified von Mises polymerization shrinkage stress (MPa) distribution for the different restorative materials and techniques after polymerization using total shrinkage value (A, B, C, D) and post-gel shrinkage value (E, F, G, H)