

Erick René Cerda Rizo

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convencionais ou resina bulk fill de viscosidade regular
associada à resina bulk fill fluida.**

*“Bonding interaction and shrinkage stress of conventional or bulk fill
regular viscosity used as occlusal layer on flowable bulk fill base composite
resins”*

Dissertação apresentada à Faculdade de
Odontologia da Universidade Federal de
Uberlândia como requisito parcial para obtenção
do título de Mestre em Odontologia na Área de
Clínica Odontológica Integrada.

Uberlândia,
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Clínica Odontológica Integrada.

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Ata da defesa de DISSERTAÇÃO DE MESTRADO junto ao Programa de Pós-graduação em Odontologia, Faculdade de Odontologia da Universidade Federal de Uberlândia.

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As quatorze horas do dia vinte e dois de fevereiro do ano de 2018 no Anfiteatro do Bloco 4L, Campus Umuarama da Universidade Federal de Uberlândia, reuniu-se a Banca Examinadora, designada pelo Colegiado do Programa de Pós-graduação em janeiro 2018, assim composta: Professores Doutores: Murilo de Sousa Menezes (UFU); Crisnicaw Veríssimo (UFG); e Carlos José Soares (UFU) orientador(a) do(a) candidato(a) **Erick René Cerda Rizo**.

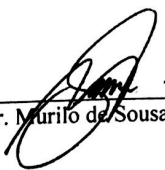
Iniciando os trabalhos o(a) presidente da mesa Dr. Carlos José Soares apresentou a Comissão Examinadora e o candidato(a), agradeceu a presença do público, e concedeu ao Discente a palavra para a exposição do seu trabalho. A duração da apresentação do Discente e o tempo de arguição e resposta foram conforme as normas do Programa.

A seguir o senhor (a) presidente concedeu a palavra, pela ordem sucessivamente, aos (às) examinadores (as), que passaram a arguir o (a) candidato (a). Após a arguição, que se desenvolveu dentro dos termos regimentais, a Banca, em sessão secreta, atribuiu os conceitos finais.

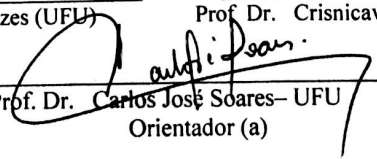
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Esta defesa de Dissertação de Mestrado Acadêmico é parte dos requisitos necessários à obtenção do título de Mestre. O competente diploma será expedido após cumprimento dos demais requisitos, conforme as normas do Programa, a legislação pertinente e a regulamentação interna da UFU.

Nada mais havendo a tratar foram encerrados os trabalhos às 17 horas e 00 minutos. Foi lavrada a presente ata que após lida e achada conforme foi assinada pela Banca Examinadora.


Prof. Dr. Murilo de Sousa Menezes (UFU)


Prof. Dr. Crisnicaw Veríssimo (UFG)


Prof. Dr. Carlos José Soares– UFU
Orientador (a)

DEDICATÓRIAS

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EPÍGRAFE

“Cuidado com o medo, ele pode roubar os seus sonhos... A ponte entre o medo e seus sonhos se chama... ação! ”

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LISTA DE ABREVIATURAS E SIGLAS

μ SBS – Resistência de união
Shr – Contração pós gel
KHN – Microdureza Knoop
E – Módulo de elasticidade
et al. – E colaboradores
FBF – Resina Filtek Bulk Fill Fluida
SDR – Resina Surefill SDR
OPUS – Resina Opus Bulk Fill Fluida
Z350 – Resina Filtek Z350-XT
OPAL – Resina Opallis
TPH3 – Resina TPH3 Spectrum
POST – Resina Filtek Bulk Fill Posterior
mvm – Von misses modificado
bis – GMA – Bisphenol A diglycidylmethacrylate
Bis – EMA – Bisphenol A polyethylene glycol diether dimethacrylate
TEGDMA – Triethyleneglycol dimethacrylate
UDMA – Urethane dimethacrylate
YbF₃ – Ytterbium fluoride
PVC – Policloreto de polivinila
LCU – Unidade de fotoativação – fonte de luz
°C – Unidade de temperatura (Graus celsius)
mW/cm² – Unidade de irradiância (miliwatss por centímetro quadrado)
mm – Unidade de medida (milímetro)
min – Unidade de tempo (minutos)
N – Unidade de pressão – carga aplicada (Newton)
A – Área
 π – Valor de 3.1416
r – Radio do circulo
MPa – Força/área (Mega Paschoal)
 Ω – Unidade de medida da resistência elétrica (Ohm)
% - Porcentagem

Kg – Unidade de pressão – carga aplicada (Quilogramas)

g – Unidade de pressão – carga aplicada (gramas)

2D – Bidimensional

MOD – Cavidade Classe II mésio-ocluso-distal

RESUMO

RESUMO

Resinas bulk fill fluídas são normalmente recobertas na superfície oclusal por resinas convencionais. O uso de resina bulk fill de viscosidade regular é utilizada isoladamente, porém pode ocasionar bolhas no interior da restauração. A efetividade da associação destas duas formulações de resinas bulk fill é incerta. Este trabalho avaliou a tensão de contração, resistência de união (μ SBS) e modo de falha de resinas bulk Fill fluidas: FBF, Filtek Bulk Fill flow (3M-ESPE); SDR, Surefill SDR (Dentsply); e OPUS, Opus Bulk Fill Flow (FGM), em associação à resinas compostas convencionais do mesmo fabricante: Z350, Filtek Z-350XT (3M-ESPE); TPH3, TPH3 Spectrum (Dentsply); e OPAL, Opallis (FGM) em comparação com a associação com uma resina composta bulk fill de viscosidade regular: POST, Filtek Bulk Fill Posterior (3M-ESPE). Cilindros com 4.0mm de diâmetro e 2.0mm de espessura foram construídos com as resinas fluidas. Cilindros de resina para cobertura de 1,0 mm de diâmetro e 4,0 mm de espessura foram confeccionados sobre a resina base para testar a μ SBS. O modo de falha foi analisado. Foram avaliadas a contração pós-gel por meio de extensometria ($n=10$); a microdureza Knoop e módulo de elasticidade ($n=10$), por meio de indentação Knoop para todas as resinas utilizadas. A partir de uma tomografia computadorizada de um molar superior hígido com antagonista foi realizado modelo bidimensional de elementos finitos no software MARC (Marc & Mentat 2010.2 software MSC, Santa Ana, CA, USA). Foi simulada uma cavidade MOD com 6,0 mm de profundidade restauradas com resina base bulk fill fluída no incremento inicial de 4,0mm e recoberto com dois incrementos de 2,0mm FBF/Z350, SDR/TPH3, OPUS/OPAL ou recobrindo com a resina bulk fill de viscosidade regular POST em único incremento de 2,0 mm. Foi avaliado a geração da tensão de contração utilizando critério de von Mises modificado (MPa). Não houve diferença significativa nos valores de μ SBS quando do uso de resina convencional ou bulk fill de viscosidade regular. Falha coesiva da resina fluída foi prevalente para todos grupos. A contração pós-gel da resina bulk fill de viscosidade regular foi significativamente menor que das resinas convencionais. A resina bulk fill de viscosidade regular possui valores de dureza semelhantes às resinas convencionais, no entanto todas as resinas bulk fill fluidas apresentaram valores inferiores. Quando foi empregado resina bulk fill de

viscosidade regular na camada oclusal verificou-se menor concentração de tensão na interface do esmalte que as resinas convencionais. O uso de resina bulk fill de viscosidade regular pode ser uma alternativa viável para restaurar em único incremento a porção oclusal sobre resinas bulk fill fluída, por apresentar boa interação com diferentes resinas fluidas e gerar menores tensões na interface.

Palavras-chave: resina bulk fill; resistência de união; molar; tensão de contração; análise por elementos finitos.

ABSTRACT

ABSTRACT

Bulk-fill Flow resin composites are frequently used in association with a conventional composite resin on the occlusal surface. The effectiveness of the interaction of these two formulations of Bulk-fill resin composites is uncertain. To analyze the shrinkage stress, bonding interaction and failure modes between different flowable bulk-fill resin composites with conventional resin composites produced by the same manufacturing or with a bulk fill regular resin composite used to restore the occlusal layer in posterior teeth. Three flowable bulk fill composite resins (FBF- Filtek Bulk Fill Flow, 3M-ESPE; SDR- Surefill SDR, Dentsply; OPUS- Opus Bulk Fill Flow, FGM) were associated with the conventional composite resins made by the same manufacture (Z350- Filtek Z350 XT, 3M-ESPE; TPH3- TPH3 Spectrum, Dentsply; OPAL- Opallis, FGM) or with bulk fill regular composite resin (POST- Filtek Bulk Fill Posterior, 3M-ESPE) resulting into 6 groups (n=10). The bonding interaction between both composite resin was tested using microshear bond strength (μ SBS). The samples were thermocycled and were tested with 1mm/min crosshead speed and the failure mode was evaluated. The post-gel shrinkage (Shr) of all composite resins was measure using strain-gauge (n=10). The elastic modulus (E) and hardness (KHN) (n=10) were measure using Knoop microhardness. Two-dimensional finite element models were created for analyzing the stress caused by shrinkage and contact loading. The μ SBS, Shr, E and KHN data were analyzed using *t*-Student test and one-way analysis of variance. The failure mode data were subjected to Chi-square test ($\alpha=0.05$). Stress distribution was analyzed qualitatively. No significant difference was verified for μ SBS for all or bulk fill regular paste conventional composite resin for restoring occlusal layer ($P=0.349$). Cohesive failure of bulk fill flowable composite resins was the most frequent failure mode. The SDR showed lower Shr than FBF and OPUS. POST and TPH3 had lower Shr than FZ350 and OPAL. POST, OPAL and TPH-3 had higher KHN values than SDR, FBF and OPUS. The SDR showed higher E value than FBF and OPUS. TPH3 and Z350 had higher E value than OPAL and POST. POST used on occlusal layer reduced the stress on the enamel interface at the occlusal surface. The use of bulk-fill regular composite resin as occlusal layer for flowable bulk fill composite resins to restore the posterior teeth can be a viable alternative

showing similar bonding interaction than conventional composite resin and lower shrinkage stress at enamel margin.

Keywords: resin bulk fill; bond strength; posterior molar; shrinkage stress; finite element analysis.

INTRODUÇÃO E REFERENCIAL TEÓRICO

1. INTRODUÇÃO E REFERENCIAL TEÓRICO

Resinas compostas foram lançadas no final dos anos 40 e início dos 50, com o objetivo de melhorar aos cimentos de silicato, com boa semelhança com os dentes naturais e uma boa insolubilidade aos fluidos bucais. Atualmente estes materiais possuem diferentes componentes que melhoram as propriedades físicas, químicas e mecânicas. Elas são compostas por uma matriz resinosa, partículas de carga, agente de união e por um sistema ativador-inibidor que agem como moduladores da reação de polimerização (Ferracane, 2011; Ibarra *et al.*, 2015).

O bisfenol A glicidil metacrilato (bis-GMA), é o monômero mais utilizado, devido ao elevado peso molecular e alta viscosidade. Este monômero é utilizado em conjunto com outros monômeros como o uretano dimetacrilato (UDMA) e o trietilenoglicol dimetacrilato (TEGDMA), melhorando a conversão monomérica e a reatividade dos componentes (Kalachandra *et al.*, 1993; Sideridou *et al.*, 2002; Khatri *et al.*, 2003; Gajewski *et al.*, 2012). O TEGDMA é utilizado em associação ao bis-GMA para melhorar as características de manipulação, viabilizando a incorporação de partículas maiores de cargas, no entanto ele apresenta limitações como aumento da sorção de água (Sideridou *et al.*, 2007), propriedades mecânicas inferiores (Goncalves *et al.*, 2010) e estabilidade de cor (Janda *et al.*, 2007). O UDMA também é muito utilizado em associação com o bis-GMA, pois possui uma baixa viscosidade, elevada flexibilidade (Floyd & Dickens, 2006), maior resistência à flexão, módulo de elasticidade e dureza (Tanimoto *et al.*, 2005). Como alternativa do bis-GMA é utilizado o dimetacrilato de bisfenol A etoxilado (bis-EMA) com alto peso molecular que tem a vantagem de ser menos viscoso, maior grau de conversão e ótimas propriedades mecânicas (Ogliari *et al.*, 2008). A composição química das resinas bulk fill não diferem substancialmente das resinas compostas convencionais, apresentam como monômeros o bis-GMA, bis-EMA, TEGDMA, UDMA e partículas de cargas de vidro silanizadas. No entanto, resinas compostas bulk fill possuem o UDMA modificado e outros moduladores da reação, que contém grupos fotoativos controlando a cinética de polimerização e retardam a acumulação da tensão de contração da polimerização (Ilie & Hickel, 2011).

As resinas compostas são amplamente utilizadas em dentes anteriores com ótima longevidade (Da Rosa Rodolpho *et al.*, 2011; Opdam *et al.*, 2014; Ástvaldsdóttir *et al.*, 2015; Krämer *et al.*, 2015; Karaman *et al.*, 2017; van Dijken & Pallesen, 2017; Yazici *et al.*, 2017). No entanto, resinas compostas convencionais apresentam algumas limitações como a formação de bolhas e a contração de polimerização que pode levar o material a falhar precocemente (Bicalho *et al.*, 2014a). Com o intuito de otimizar a técnica restauradora, foram introduzidas no mercado as resinas bulk fill, simplificando os passos clínicos e, por conseguinte reduzindo o tempo de cadeira (Rosatto *et al.*, 2015; Gaintantzopoulou *et al.*, 2016).

As resinas bulk fill foram lançadas no mercado em duas apresentações, de viscosidade regular, conhecidas como de alta viscosidade ou esculpível, que pode preencher cavidades em um único passo, restaurando esmalte e dentina até 4 a 5 mm (Ilie *et al.*, 2013; Furness *et al.*, 2014). A outra é em consistência fluida ou de baixa viscosidade, sendo utilizadas como base, preenchendo a cavidade com o objetivo de substituir dentina de até 4 mm de profundidade (Rosatto *et al.*, 2015). Porém elas apresentam baixa resistência ao desgaste, requerendo cobertura de 2 mm com resinas convencionais que apresentam maior resistência ao desgaste (Leprince *et al.*, 2014; Rosatto *et al.*, 2015; Atalay *et al.*, 2016; Alkhudhairy, 2017).

As resinas bulk fill têm demonstrado ter ótimas propriedades físico-mecânicas, promovendo menor contração pós-gel, deformação de cúspide, tensão de contração e uma boa resistência à fratura (Rosatto *et al.*, 2015; Jung & Park, 2017). As resinas de consistência fluida têm sido utilizadas como resinas de base, com bom escoamento proporcionando melhor adaptação nas paredes da cavidade (Gaintantzopoulou *et al.*, 2016) e diminuição de bolhas quando comparadas às resinas convencionais utilizando a técnica incremental (Ibarra *et al.*, 2015; Jarisch *et al.*, 2016; Soares *et al.*, 2017). As resinas bulk fill de consistência regular são utilizadas para preenchimento em incremento único, apresentando dureza e resistência ao desgaste semelhante às resinas convencionais (Flury *et al.*, 2014; Fronza BM *et al.*, 2015). Por outro lado resinas de consistência fluídas têm menor modulo de elasticidade (Rosatto *et al.*, 2015) e por consequência menor dureza (Flury *et al.*, 2014; Rosatto *et al.*, 2015; AL

Shaafi *et al.*, 2016), o que a torna mais frágil quando exposta ao meio bucal. Por outro lado, as resinas bulk fill de consistência regular, que possuem maior módulo de elasticidade e maior dureza possibilitam utilizá-las para substituir dentina e esmalte concomitantemente (Rosatto *et al.*, 2015). Ambos tipos de resinas apresentam ótima resistência de união que confirma a segurança na utilização destes materiais (Flury *et al.*, 2014).

Uma prática frequente realizada pelos cirurgiões dentista, é a associação entre resinas compostas, por exemplo quando da necessidade de realização de reparos em restaurações de resina, onde tem-se demonstrado adequadas propriedades mecânicas entre resinas convencionais (Ribeiro *et al.*, 2008). Nas resinas bulk fill não é a exceção, essa combinação é frequente devido à necessidade de associar uma resina de consistência fluída com uma resina composta convencional (Rosatto *et al.*, 2015; Leprince *et al.*, 2014; Alkhudhairy, 2017). Os fabricantes recomendam o uso de resina convencional para cobrir resinas bulk fill fluidas na superfície oclusal dos dentes posteriores (Do *et al.*, 2014; Tomaszewska *et al.*, 2015; Francis *et al.*, 2015). No entanto, existem dúvidas entre os profissionais se a resina bulk fill de viscosidade regular em associação com as diferentes resinas bulk fill de fluída seria uma boa alternativa, com o intuito de reduzir a tensão de contração e facilitar o procedimento clínico. Porém, pode também ser questionado se a interação química entre diferentes composições pode afeta esta performance.

PROPOSIÇÃO

2. PROPOSIÇÃO

Este tudo teve por objetivo analisar a tensão de contração, a interação adesiva e o padrão de falha entre as diferentes resinas bulk fill fluidas associadas às resinas convencionais produzidos pelo mesmo fabricante ou à uma resina bulk fill regular utilizada como cobertura para restaurar a camada oclusal dos dentes posteriores.

CAPÍTULO ÚNICO

3. CAPÍTULO ÚNICO

Artigo: Bonding interaction and shrinkage stress of conventional or bulk fill regular viscosity used as occlusal layer on flowable bulk fill base composite resins
Erick René Cerda-Rizo, Monise de Paula Rodrigues, Andomar Bruno Fernandes Vilela, Stella Sueli Lourenço Braga, Laís Rani Sales Oliveira, Tales Candido Garcia-Silva, Carlos José Soares

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Bonding interaction and shrinkage stress of conventional or bulk fill regular viscosity used as occlusal layer on flowable bulk fill base composite resins

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Short title: Composite Type of occlusal layer for flowable bulk fill restoration.

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Bonding interaction and shrinkage stress of conventional or bulk fill regular viscosity occlusal layer used with flowable bulk fill base composite resins

Abstract

STATEMENT OF PROBLEM: Flowable Bulk-fill resin composites are frequently used in association with a conventional composite resin on the occlusal surface, however clinicians are replacing the conventional resin with a regular bulk fill resin. The effectiveness of the interaction of these two formulations of Bulk-fill resin composites is uncertain.

PURPOSE: To analyze the shrinkage stress, bonding interaction and failure modes between different flowable bulk-fill resin composites with conventional resin composites produced by the same manufacturing or with a bulk fill regular resin composite used to restore the occlusal layer in posterior teeth.

MATERIALS AND METHODS: Three flowable bulk fill composite resins (FBF- Filtek Bulk Fill Flow, 3M-ESPE; SDR- Surefill SDR, Dentsply; OPUS- Opus Bulk Fill Flow, FGM) were associated with the conventional composite resins made by the same manufacture (Z350- Filtek Z350 XT, 3M-ESPE; TPH3- TPH3 Spectrum, Dentsply; OPAL- Opallis, FGM) or with bulk fill regular composite resin (POST- Filtek Bulk Fill Posterior, 3M-ESPE) resulting into 6 groups (n=10). The bonding interaction between both composite resin was tested using microshear bond strength (μ SBS). The samples were thermocycled and were tested with 1mm/min crosshead speed and the failure mode was evaluated. The post-gel shrinkage (Shr) of all composite resins was measure using strain-gauge (n=10). The elastic modulus (E) and hardness (KHN) (n=10) were measure using Knoop microhardness. Two-dimensional finite element models were created for analyzing the stress caused by shrinkage and contact loading. The μ SBS, Shr, E and KHN data were analyzed using *t*-Student test and one-way analysis of variance. The failure mode data were subjected to Chi-square test ($\alpha=0.05$). Stress distribution was analyzed qualitatively.

RESULTS: No significant difference was verified for μ SBS for all or bulk fill regular or conventional composite resin for restoring occlusal layer (P=0.349).

Cohesive failure of bulk fill flowable composite resins was the most frequent failure mode. The SDR showed lower Shr than FBF and OPUS. POST and TPH3 had lower Shr than FZ350 and OPAL. POST, OPAL and TPH-3 had higher KHN values than SDR, FBF and OPUS. The SDR showed higher E value than FBF and OPUS. TPH3 and Z350 had higher E value than OPAL and POST. POST used on occlusal layer reduced the stress on the enamel interface at the occlusal surface.

CONCLUSIONS: The use of bulk fill regular composite resin as occlusal layer for flowable bulk fill composite resins to restore the posterior teeth can be a viable alternative showing similar bonding interaction than conventional composite resin and lower shrinkage stress at enamel margin.

CLINICAL IMPLICATIONS: The use of bulk fill regular associated with bulk fill flowable composite is presented adequate bonding interaction and result in better margin stability due lower shrinkage stress caused at enamel occlusal margin.

INTRODUCTION

The composite resins are widely used in posterior restorations with optimum longevity.¹⁻⁷ In order to simplify and streamline the restorative process, the bulk fill resin composites were created to reduce the clinical steps and consequently the chair time.^{8,9}

The bulk fill resin composites represent an innovative class of dental composites materials. They are commercialized in regular paste, which has high-viscosity and is easier sculpted, and can fill the cavity up to 4 to 5 mm increment.^{8,10,11} Or in bulk fill flowable resin composites, which have low-viscosity, are usually indicated as a base, filling up to 4.0mm of the dentin portion of the cavity, that need a coverage of 2 mm conventional composite resins, which exhibit higher wear strength and tensile strength.^{8,12-14} The bulk fill flowable resin composites have shown good adaptation to the cavity walls⁹ and lower porosity compared to the conventional composite resin when using incremental technique.¹⁵⁻¹⁷ The mechanical properties of bulk fill composite resins promote a lower polymerization shrinkage stress, better stress distribution and high fracture

resistance.⁸ However this performance is clearly material dependent.^{8,18} The chemical structures do not differ substantially from the conventional composite resins, since they present their base monomers are bisphenol A diglycidylmethacrylate (BisGMA), bisphenol A polyethylene glycol diether dimethacrylate (BisEMA), triethyleneglycol dimethacrylate (TEGDMA), urethane dimethacrylate (UDMA) and silanized glass filler particles. However, bulk fill composite resins containing modified UDMA and other modulators of the reaction, which possesses photoactive groups which control the polymerization kinetics and retard the accumulation of the polymerization shrinkage stress.^{18,19}

A common practice performed by clinicians is the association between resin composites, used in repairs that have adequate mechanical properties (Ribeiro 2008). Combinations between resin composites is becoming more frequent, due to the association of the low-viscosity bulk fill with the conventional resin composite.^{8,12,14} The manufactures recommend the use of conventional resin composite to cover the bulk fill flowable resin composites at occlusal surface of the posterior teeth.²⁰⁻²² However, the clinicians have frequently make questions if the association of the bulk fill regular paste and bulk fill flowable resin composites could be a good alternative, aiming to facilitate the clinical procedure and to reduce the shrinkage stress.¹⁸ However, could be questioned if the chemical interaction between different composition is compromised. No information, in the author's knowledge, are available regarding the interaction between different bulk fill flowable resin composites with the conventional or regular bulk fill composite resins.

Therefore, this study aimed to analyze the shrinkage stress, the bonding interaction and failure modes between different bulk fill flowable resin composites with the conventional resin composites produced by the same manufacture or one bulk fill regular composite resin used for restoring occlusal layer in posterior teeth. The first null hypothesis was that the bulk fill flowable resin composites had similar bond interaction with different conventional composite resins or with bulk fill regular composite resin; the second null hypothesis was that the use the bulk fill regular composite resin would not reduce the shrinkage stress at occlusal margin of the restoration.

MATERIAL AND METHODS

Three bulk fill flowable resin composites, three conventional composite resins made by the same manufactures of each bulk fill flowable resin composites and one bulk fill regular composite resin used for restoring occlusal layer used in this study have characteristics described in Table 1.

Microshear bond strength (μ SBS) test

To test the bonding interaction between flowable composite resins with the conventional composite resins made by the same manufacture or with one regular bulk fill composite resin, Filtek Bulk Fill Posterior (3M-ESPE, St. Paul, MN, USA), the shear bond test was used. The combination between composite resin resulted in six groups (N=10):

- FBF/Z350 - Filtek Bulk Fill Flow (3M-ESPE, St. Paul, MN, USA) and Filtek Z350 XT (3M-ESPE, St. Paul, MN, USA),
- FBF/POST - Filtek Bulk Fill Flow (3M-ESPE, St. Paul, MN, USA) and Filtek Bulk Fill Posterior (3M-ESPE, St. Paul, MN, USA),
- SDR/TPH3 - Surefill SDR (Dentsply, Konstanz, Germany) and TPH3 Spectrum, (Dentsply, Konstanz, Germany);
- SDR/POST - Surefill SDR (Dentsply, Konstanz, Germany) and Filtek Bulk Fill Posterior (3M-ESPE, St. Paul, MN, USA);
- OPUS/OPAL - Opus Bulk Fill Flow (FGM, Londrina, Brazil) and Opallis, FGM (Joinville, Brazil);
- OPUS/POST - Opus Bulk Fill Flow (FGM, Londrina, Brazil) and Filtek Bulk Fill Posterior (3M-ESPE, St. Paul, MN, USA).

Polystyrene resin cylinders were made using a PVC cylinder with 30 mm in height and 20 mm in diameter, and had their base and top surfaces regularized using abrasive grit sandpaper 180, 320 and 600 (Norton, Campinas, Brazil). Using a #1052 diamond bur (KG Sorensen, Barueri, SP, Brazil) a cylindrical cavity with 2 mm in thick and 4 mm in diameter prepared to be filled by the flowable bulk fill resin composites. The flowable composite resins were inserted into the cylindrical cavity and were light cured using broad-spectrum LED light

curing unit (LCU) (VALO, Ultradent, South Jordan, UT, USA) with 1625 mW/cm² for the time recommended by manufacture, checked by using MARC resin calibrator (BlueLight Company, Halifax, Canada). The LCU was rigidly fixed by using supported device (Odeme, Luzema, SC, Brazil) approximately at a distance of 1.0 mm to the cylinder in order to standardize the distance to LCU.

To standardize the size of the specimens and delimit the bonding area, transparent flexible tubes of 1.0mm diameter and 4.0mm height were used (Embramac, Campinas, SP, Brazil). Conventional composite resin or regular bulk fill resin composite was used, they were inserted into the plastic tube, previously positioned over the center of the sample of the flowable bulk fill resin composite and was cured using the protocol described above. Plastic tubes were cut longitudinally with number 12 scalpel blade (Swann Morton, Rio de Janeiro, RJ, Brazil) and carefully removed by the same operator. The samples were thermally cycled (ER 26000, Erios, São Paulo, SP, Brazil), following the protocol of 6000 cycles with the temperature between 5 and 55 ° C simulating 5 years of aging. The specimens were stored at 37.7°C for 24 hours in distilled water before testing.

The specimens were fixed to a specific device attached to a universal testing machine (Microtensile Machine OM 100, Odeme, Luzema, SC, Brazil) so that the resin cylinders long axis parallel to the horizontal plane. A 0.3 mm diameter wire (Morelli - Sorocaba, SP, Brazil) was placed around the resin cylinder over its interface with the surface of the bulk fill flowable composite resin base. A 50N load cell was used in order to apply an increasing parallel force to the adhesive area, with speed of 1 mm/min until the specimen failure occurred. At the time of fracture, the force was recorded (N), and was divided by the area ($A = \pi r^2$, mm) corresponded to the interface between the both composite resins, resulting in μ SBS values in MPa.

Failure mode analysis

After μ SBS test, the specimens were analyzed using stereomicroscopy at 40X magnification (Mytutoyo, Osaka, Japan) to classify the failure mode as follows: Type I, adhesive failure between both composite resins; Type II, cohesive failure of the covering resin bulk fill regular or conventional; Type III,

cohesive failure of the base resin (bulk fill flow resin); Type IV, mixed failure involving part of the resin bulk fill flow and cover resin (Fig. 1).

Post-gel shrinkage (Shr)

The post-gel shrinkage was calculated for all tested composite resins (n=10), using the strain gauge method.²³ The materials were shaped into semi-sphere on the top of a biaxial strain gauge (CEA-06-032WT-120, Measurements Group, Raleigh, NC, USA) that measured shrinkage strains in two perpendicular directions. A strain conditioner (ADS05000IP, 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 (120 Ω). The strain values measured along the two axes were averaged since the material properties were homogeneous and isotropic on a macro scale. All materials were light-cured using a LED LCU (VALO, Ultradent) with the light tip held at 1 mm distance from the surface of the composite. The strain values were collected for 5 minutes. The maximum shrinkage strain at 5 minutes was used as linear post-gel shrinkage input for the finite element analysis, and could be converted to volumetric percentage by multiplying by 3 and 100%.

Knoop microhardness (KHN) measurements

For calculating the elastic modulus and hardness of the tested resin composites (n=10), the Knoop Hardness test was used.²⁴ A microhardness tester (Microhardness tester FM-700, Future-Tech Corp., Kanagawa, Japan) was used with a diamond indenter to apply a static charge of 100 g (0.98 N) for 10 seconds. For each specimen, the averages of five indentations are used on the top surface. The following formula was used $KHN = 14.229 * Load (kg) / (long diagonal in mm)$.²⁴ Besides the hardness determination, Knoop indentations were also used to determine the elastic modulus.²⁴ The decrease in the length of the indentation diagonals caused by elastic recovery of a material are related to the hardness: modulus ratio H/E by the equation:

$$b'/a' = b/a - \propto 1(H/E),$$

where b/a is the ratio of the diagonal dimensions a and b in the fully loaded state, given by a constant 0.140647. b'/a' is the ratio of the altered dimensions when fully recovered and $\propto 1 = 0.45$ is a proportionality constant.²⁵

Two-dimensional modeling of dynamic finite element molar

Two-dimensional (2D) models were created for finite element analysis (FEA) simulating a model of a maxillary human first molar in occlusal conditions with antagonist contact from a transverse cone beam tomographic image of a bank of images of the Dental School of a patient with normal occlusion. An occlusal cavity with 6 mm in depth was simulated. The coordinates and points of the structures were drawn using processing software (IMAGEJ, public domain, National Institute of Health, Bethesda, MD, USA) and imported into a finite element analysis package (Marc & Mentat 2010.2 software MSC, Santa Ana, CA, USA). Cube spline curves were then created through these coordinates to recreate the contours of the structures for the model.

The models were generated following two conditions: 1- cavity restored with 4.0mm of bulk-fill flowable composite resins to replace dentin and covered with 2.0 mm of a bulk fill regular resin composite in single increment; 2- molar restored with 4.0mm of bulk-fill flowable composite resins to replace dentin and covered with two increments of 2.0 mm of conventional resin composite. The mesh created through a manual process that used isoparametric four-node arbitrary quadrilateral deformation plane strain with reduced integration (one integration point per element), using number 115 element type in the software Marc. All interfaces were attached considering bonded interfaces. Displacement was limited at the nodes of the base of the maxillary and mandibular molar in the X and Y directions. All materials were considered linear, isotropic and homogeneous. The applied mechanical properties are listed in Table 2. It was simulated the insertion of the resin composite layers and their Shrinkage values previously calculated. The occlusal contact of 100 N of the lower mandibular molar with the maxillary molar, and then a sliding movement was simulated by using friction contact between lower and upper occlusal surfaces (Frictional Coefficient – 0.5). Stress distributions were analyzed using modified von Mises stresses, which integrate all stress components in one equivalent value.

Statistical analysis

The μ SBS, Shr, E and KHN data were tested for normal distribution (Shapiro–Wilk) and equality of variances (Levene's test), followed by parametric statistical tests. The *t*-Student test was performed for μ SBS values. One-way analysis of variance (ANOVA) was performed for KHN, E and Shr values. Multiple comparisons were made using Tukey's test. The failure mode data were subjected to Chi-square test. All tests employed $\alpha=0.05$ significance level and all analyses were carried out with the statistical package Sigma Plot version 13.1 (Systat Software Inc, San Jose, CA, USA). Stress distribution was analyzed descriptively.

RESULTS

The μ SBS mean and standard deviation values between flowable bulk fill composite resins associated with conventional composite resin made by the same manufacture and Filtek Bulk Fill Posterior resin are shown on Fig. 2. The *t*-student test showed no significant difference on bonding strength between conventional composite produced by the same manufacture or bulk fill regular. The failure mode distributions for tested samples are shown on Fig. 3. No significant difference was found for failure mode among groups ($P=0.134$). Cohesive failure of bulk fill flowable resin composite was the prevalent failure mode observed for all groups.

The Shr mean and standard deviation values for all composites are shown in Fig. 4. One way ANOVA showed that the SDR had lower Shr values than FBF and OPUS. POST and TPH3 had similar Shr values and lower values than FZ350 and OPAL resin composites.

The KHN mean and standard deviation values for all composites are shown in Fig. 5. One-way ANOVA showed that Z350 had higher KHN values than OPAL and POST and similar values of TPH3 ($P<0.01$). POST, TPH3 and OPAL had similar KHN values ($P = 0.231$). Comparing the flowable bulk fill composite resins, ANOVA one-way showed that OPUS had lower KHN values than FBF and SDR ($P<0.01$).

The E mean and standard deviation values for all composites are shown in Fig. 6. Comparing the flowable bulk fill composite resins, one-way ANOVA showed that the SDR showed higher E value than FBF and OPUS ($P<0.01$). Comparing the composite resins used for occlusal layer, TPH3 and Z350 had higher E value than OPAL and POST.

Stress distributions during restoration and at 100N occlusal loading (modified von mises stress) are shown in Fig. 7. The use of bulk fill regular (POST) on occlusal layer resulted in lower shrinkage stress concentration at enamel interface than when was used conventional composite resins inserted incrementally, irrespective of the tested composite resin combinations. The OPAL resin had higher critical von Mises stress at the enamel interface and restoration, mainly on the lingual cusp, than all others conventional composite (Fig. 7).

The stress distributions during restoration and occlusal function in enamel, dentin, flowable composite resin and occlusal composite resin layer are shown in Fig. 8. The maximum peak of the stress was observed on enamel structure during the restoration procedure and the antagonist tooth contact the enamel/composite resin interface. The stress level into the enamel and dentin structures were lower when POST was used to restored the occlusal layer. The MVM stress recorded at 18 points along the composite resin/tooth structure interface are shown in Fig. 9. The use of bulk fill regular composite resin for restoring occlusal layer reduced the stress at the margin of the restoration.

DISCUSSION

The bond strength between bulk fill flowable resins and bulk fill regular or a conventional resin were similar therefore the first null hypothesis was accepted. However, the shrinkage stress generated at the enamel/restoration occlusal margins was lower when using bulk fill regular composite resin for covering bulk fill flowable, therefore the second null hypothesis was rejected. The combination of the different bulk fill flowable composite resins with regular bulk fill composite or conventional composite resin used to cover the occlusal surface had no influence on the bonding interaction between these materials. Although, the bulk fill composite resins have same chemical modifications in their composition to facilitate the deep polymerization, the monomers interaction with the bulk fill flowable was similar when compared with conventional composite resins

produced by the same manufacture. The tested composite resins present same variation of the monomers and modulators in their compositions. However, the UDMA and Bis-GMA or Bis-EMA monomers are presented in the most composite facilitating the interactions between different flowable and occlusal layer composite resins.²⁶⁻²⁸ The present study confirmed that the interaction with conventional and bulk fill composite performed similarly to the interaction between bulk fill regular composite resin.

The microshear method allows small areas to be effectively tested, but during the test the stress are most concentrated into the base substrate,^{29,30} in this study represented by flowable composite resin. These facts induce premature failure on specimens.³⁰⁻³² The lower filler content presented into bulk fill flowable composite resins reflect on their mechanical properties, resulting in lower elasticity modulus and hardness values.^{10,11,33} These aspects may explain the high frequencies of the observed failure mode involving bulk fill flowable composite resins. In this study, no difference on failure mode for all tested combinations was found, probably because the great similarity on the filler content of the flowable bulk fill resins.

During the polymerization of the composite resin, the elastic modulus develops when the material becomes rigid, and its original capability for plastic flow as a paste decreases.^{34,35} Shrinkage stress is generated when the composite material becomes solid enough to transfer stresses that can no longer be relieved by flow.^{18,24} Elasticity modulus tend to correlate with the hardness of the material, as well with the filling content.^{30-32,36} The post-gel shrinkage and the modulus of elasticity of the material can influence the magnitude of the stress generated during polymerization.²⁴ Manufacturers incorporate inorganic fillers in composites with the aim of improving the mechanical properties of composites. Bulk fill resins have a chemical composition similar to conventional resins, both in the organic and inorganic matrix. However, these materials have modulators of the reaction that could explain the lower of post-gel shrinkage and a low modulus of elasticity values compared with conventional resin composites. Bulk fill flowable composite resin exhibited the lowest post-gel shrinkage and elasticity modulus, because the lower filler content and higher capacity of intrinsic deformation, releasing the stress generated during polymerization shrinkage.⁸

The shrinkage stress calculated at final restoration is the combination of the performance of both composite resins used in each group. The SDR/TPH3 or SDR/POST were the groups with lower shrinkage stress, probably because the combination between lowest shrinkage of SDR among flowable bulk fill composite resins and lower Shr values of TPH3 spectrum and Filtek bulk fill posterior.

Considering that shrinkage stresses are concentrated at the occlusal margin,^{37,38} the combination of shrinkage stresses and occlusal loading may be a determining factor in the mechanical performance of a restorative complex.³⁸ The stress concentrated at enamel occlusal margin may determine the marginal fracture or marginal debonding.¹⁸ If the occlusal contact is located at the margin of a composite restoration, the increased stress concentration may increase the risk of marginal fracture. Retrospective clinical study showed that fracture of restorations was the main reason for failure in “occlusal-stress- risk” patients.³⁹ Even if marginal deterioration is small to be perceived clinically, it may increase retention of pigments, increasing marginal discoloration. As marginal staining can be confused with marginal caries, such restorations may be replaced prematurely.⁴⁰

Low viscosity bulk fill resin composites frequently have been indicated that should be covered with a 1.5 to 2.0 mm layer with conventional resin.^{8,10,11} The hardness of the material is one of the factors for the selection of the material when restoring posterior teeth,^{8,10,11} as well as wear resistance.^{36,41} It has been reported that bulk fill resins have adequate polymerization and hardness of the material not only on the surface of the resin but also in the depth of the restoration,^{8,42} which was demonstrated in the present study where the high viscosity bulk fill composite had KHN values similar to conventional resin composites. However, the low viscosity bulk fill composite had lower KHN values, which can be attributed to the low modulus of elasticity and content of filling in its chemical composition. The results of the present study confirmed by the difference of KHN hardness that the lower values for flowable composite resins reflect the necessity of the covering preventing wear and bulk fracture.⁴²⁻⁴⁴ Additionally, this study demonstrated that the use of bulk fill regular could be an adequate alternative for restoring the occlusal surface of posterior restoration.

This study has same limitation, because tested only one regular composite resin. Unless all factors can be modeled, the results of a finite element analysis should still be carefully interpreted within the clinical context.²⁴ Observing these clinical procedures with an understanding of the balance between mechanical properties offered by various composites may improve the clinical performance of posterior composite restorations. The use of bulk fill flowable composite that result in better adaptation and lower bubbles formation,¹⁷ associated with bulk fill regular past for restoring occlusal surface tend to be a good option for posterior restorations.

CONCLUSIONS

Within the limitations of this in vitro study, the following conclusions were drawn:

1. There is no difference in bond strength between conventional resins or bulk fill regular viscosity composite resins with bulk fill flowable resin. The cohesive failure mode was the most frequent for all groups.
2. Bulk fill regular viscosity composite resin had lower Shr values than conventional resins.
3. The elastic modulus varied substantially among the composite resin used as a cover and the bulk fill flowable resins.
4. Bulk fill regular viscosity composite resin (Filtek bulk fill posterior) has similar KHN values than conventional composite resin normally recommended to fill occlusal surface of bulk fill flowable composite resin.
5. Bulk fill flowable composite resins had lower KHN values than regular bulk fill and conventional composite resins.
6. The use of bulk fill regular viscosity composite resin on the occlusal layer resulted in a lower stress concentration at the enamel interface than conventional composite resins inserted incrementally.

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Table 1. Composites used in this study.

Material	CODE	Composite type	Organic Matrix*	Filler*	Filler% wt/Vol*	Manufacturer	Lot number
Filtek Z350XT	Z350	Nanofilled	Bis-GMA, Bis-EMA, UDMA, TEGDMA.	Silica and zirconia nanofillers, agglomerated zirconia-silica nanoclusters.	78.5/63.3	3M ESPE (St. Paul, MN, USA)	N603650
TPH-3	TPH3	Nanohybrid	BIS-EMA, Bis-GMA.	Barium glass, Barium aluminum silicate and silica.	75/57	Dentsply (Konstanz, Germany)	157722H
Opallis	OPAL	Nanohybrid	Bis-GMA, Bis-EMA, TEGDMA, UDMA.	Barium aluminum silicate and silica	79/58	FGM (Joinville, Brazil)	300316
Filtek Bulk Fill Posterior	POST	Bulk-fill regular	UDMA, DDDMA, EDMAB.	Silica, zirconia and YbF3.	76.5/58.4	3M ESPE (St. Paul, MN, USA)	N690323
Surefil SDR Flow	SDR	Bulk-fill flowable	Modified UDMA, dimethacrylate and difunctional diluents.	Barium and strontium aluminosilicate glasses.	68/44	Dentsply (Konstanz, Germany)	1508283 / 150831
OPUS Bulk Fill Flow	OPUS	Bulk-fill flowable	TEGDMA, Bis-EMA, UDMA.	Silica with Urethane dimethacrylate, salinized silica dioxide, Barium salinized, YbF3.	68/-	FGM (Londrina, Brazil)	060616
Filtek bulk fill flow	FBF	Bulk-fill flowable	UDMA, BISGMA, EBPADMA, Procrylat resin.	Silane treated ceramic and YbF3.	64/42.5	3M ESPE (St. Paul, MN, USA)	N768439

*Composition as given by manufacturers; Bis-GMA: bisphenol A diglycidylmethacrylate; BisEMA: bisphenol A polyethylene glycol diether dimethacrylate; TEGDMA: triethyleneglycol dimethacrylate; UDMA urethane dimethacrylate; YbF3: ytterbium fluoride.

Table 2. Mechanical properties applied for the dental structures and materials.

Structure / Materials	Elastic Modulus (MPa)	Poisson's ratio	Compressive strength (MPa)	Diametral tensile Strength (MPa)	References
Enamel	84100	0.30	-	-	(45)
Dentine	18600	0.30	-	-	(46)
Pulp	2	0.45	-	-	(47)
FBF	-	0.24*	229.1	43.8	(48)
OPUS	-	0.24*	152.5	34.3	(48)
SDR	-	0.24*	182.3	43.5	(8)
Z350 XT	-	0.24*	257	47.3	(8)
OPALLIS	-	0.24*	141	42.1	(48)
TPH3	-	0.24*	136.2	40.5	(48)
POST	-	0.24*	169.3	42.4	(48)

FIGURES

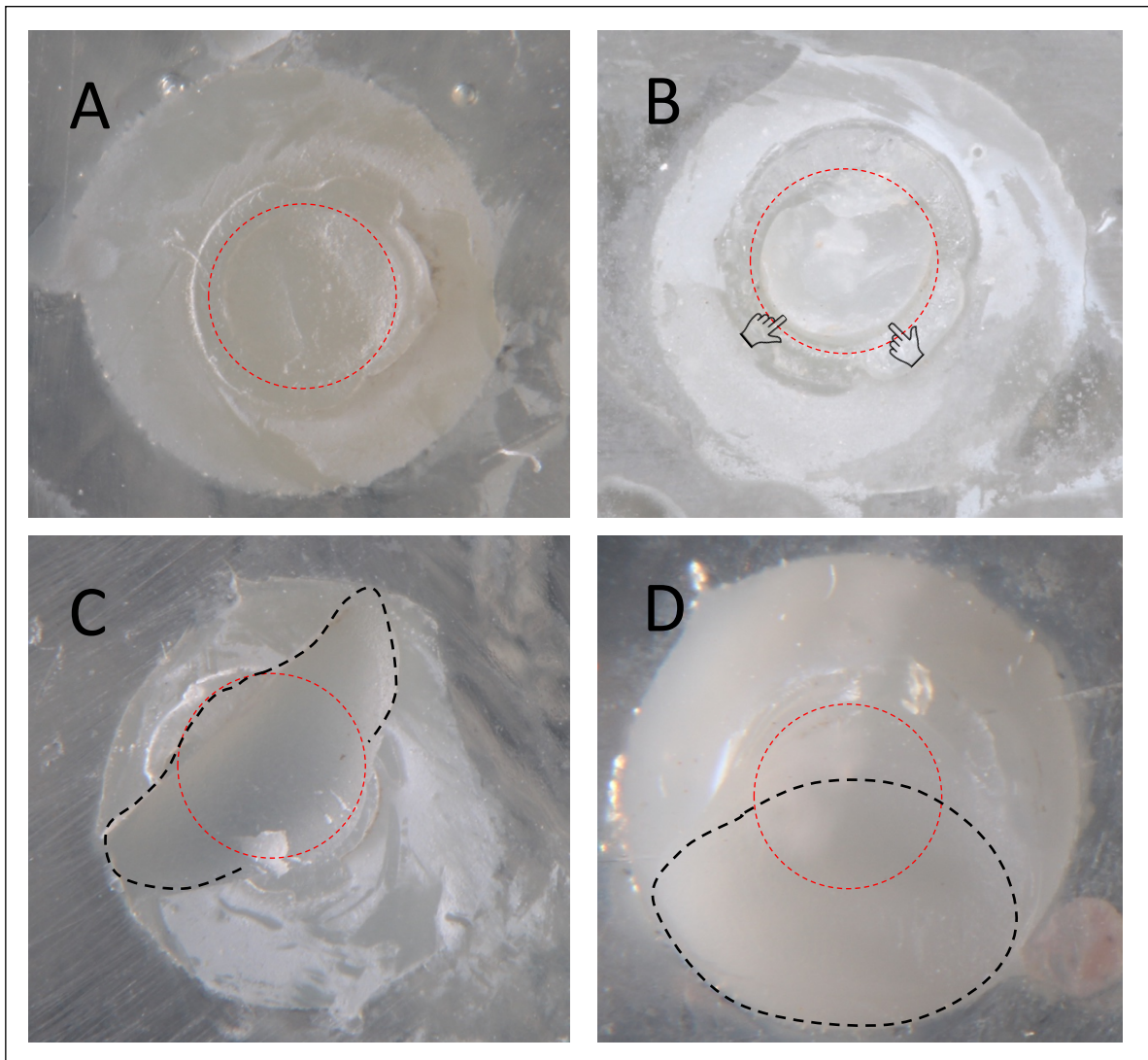


Figure 1. Failure modes: A. Adhesive failure; B. Cohesive failure of occlusal composite resin layer; C. Cohesive failure of bulk fill flow base composite resin; D. Mixed failure involving cohesive failure and adhesive failure.

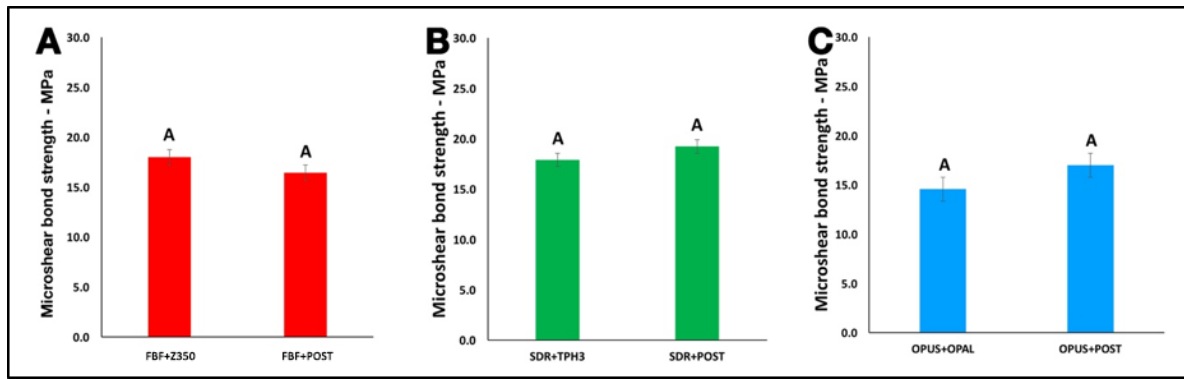


Figure 2. Mean and standard deviation μ SBS for the two experimental conditions tested for each bulk fill flowable composites, A. FBF; B. SDR; C. OPUS covered by conventional composite resins (Z350, TPH3 and OPAL, respectively) or bulk fill regular composite resin (POST). Different letters indicate significant difference tested by *t*-Student test ($P < 0.05$).

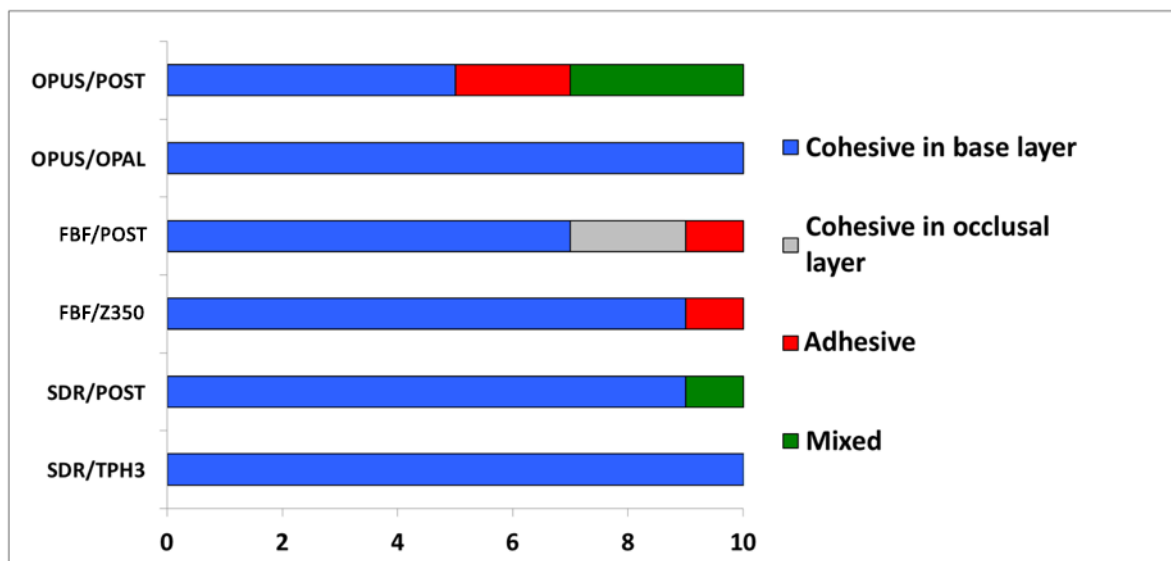


Figure 3. Distribution of failure modes for the different experimental conditions.

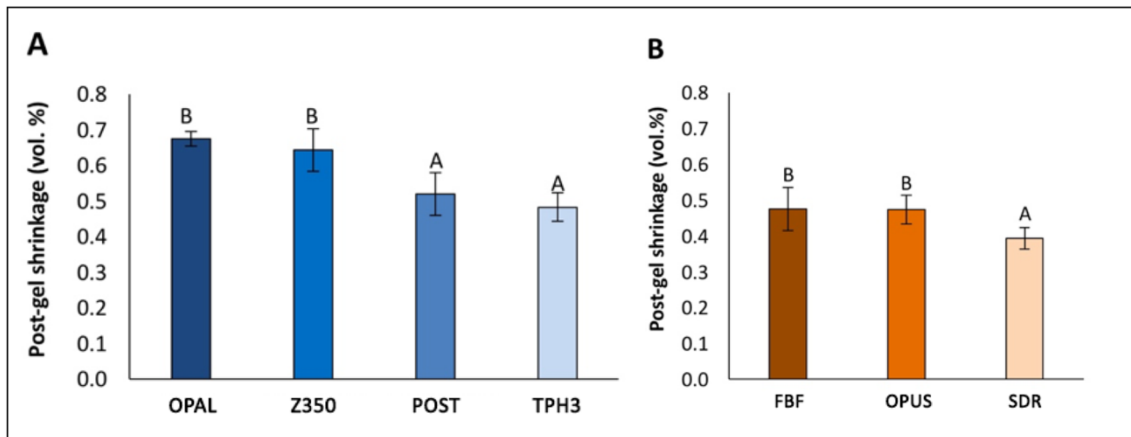


Figure 4. Mean and standard deviation of post-gel shrinkage; A. Conventional composite resins and bulk fill regular composite resin; B. Bulk Fill Flow composite resins. Different letters demonstrate significant difference among tested composite resins for each group (Flowable or regular composite resin).

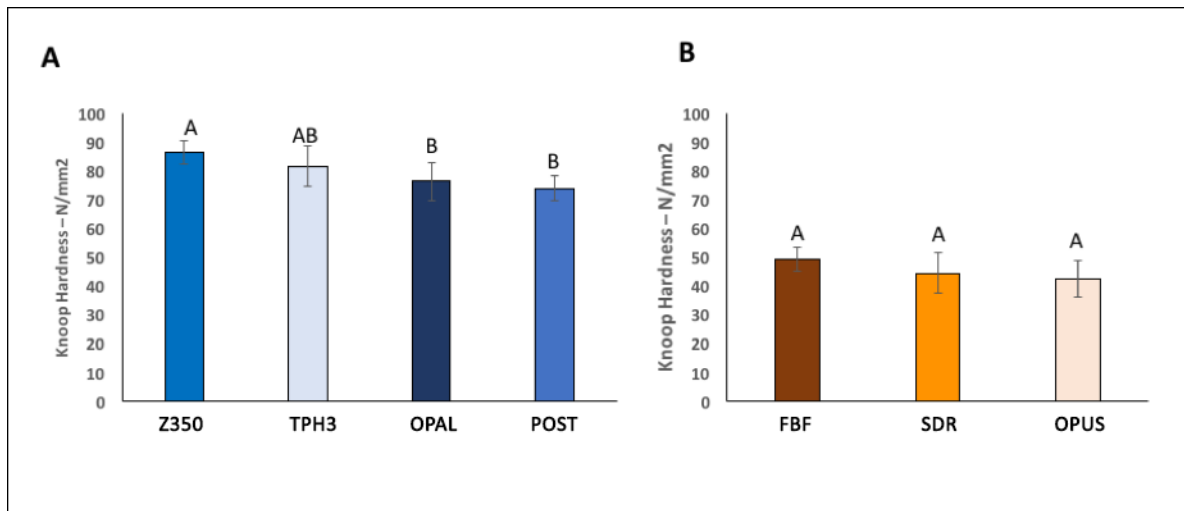


Figure 5. Means and standard deviation of microhardness Knoop (KHN) of the composites. A. Conventional composite resins and bulk fill regular composite resin; B. Bulk Fill Flow composite resins. Different letters demonstrate significant differences among tested composite resins for each group (Flowable or regular paste composite resin).

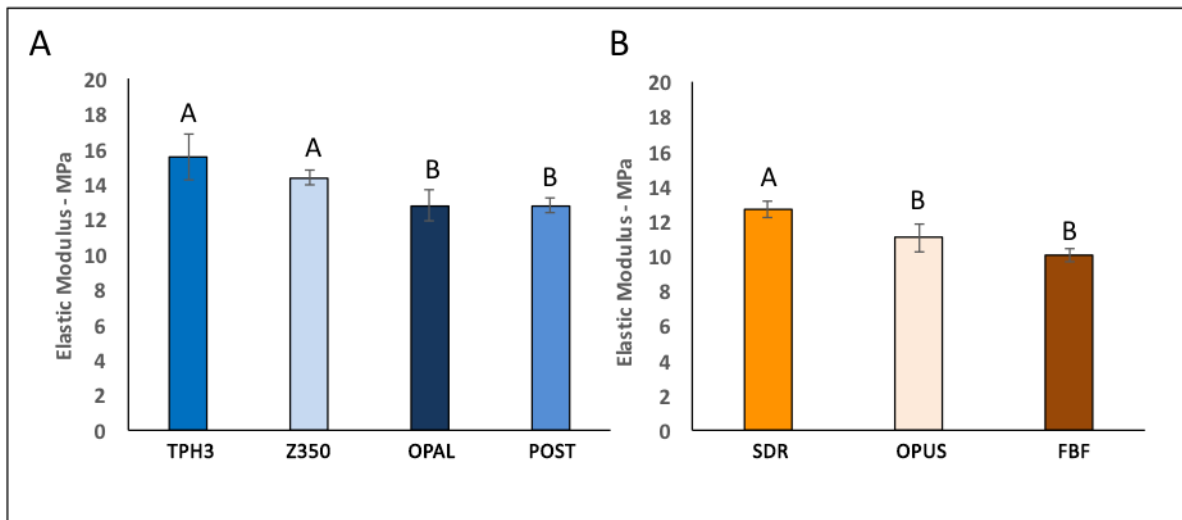


Figure 6. Mean and standard deviation of Elastic Modulus; A. Conventional composite resins and bulk fill regular composite resin; B. Bulk Fill Flow composite resins. Different letters demonstrate significant difference among tested composite resins for each group (Flowable or regular paste composite resins).

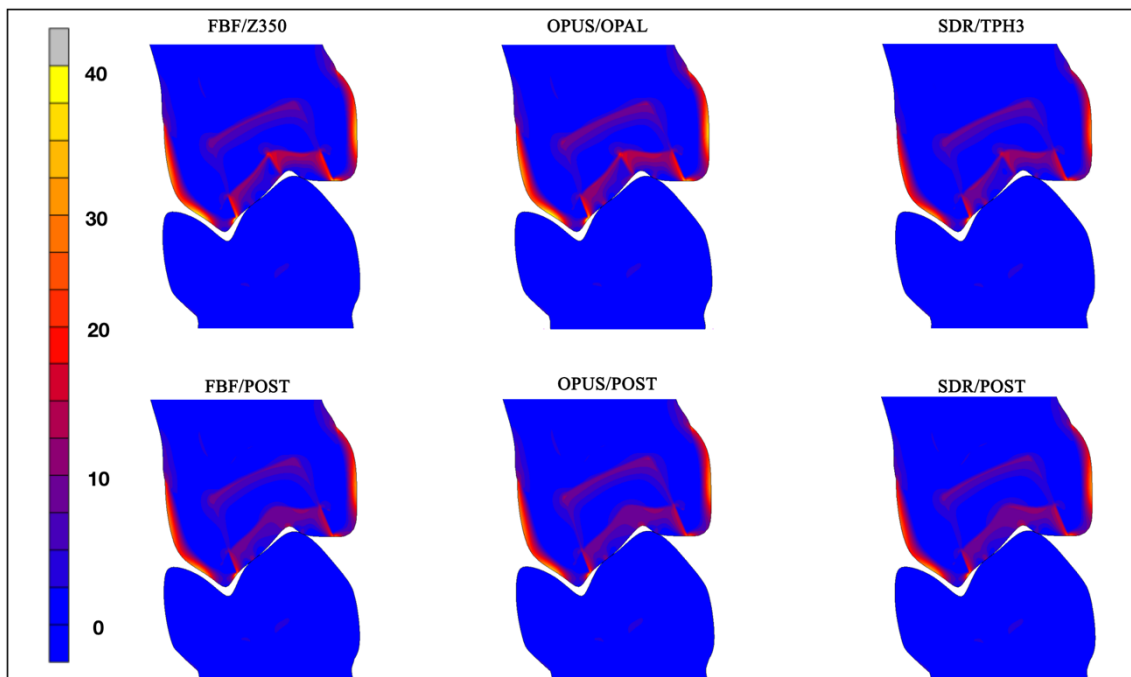


Figure 7. Modified von Mises stress distribution generated by shrinkage and occlusal loading for different composite resin combinations tested at the maximum intercuspitation of the molar teeth.

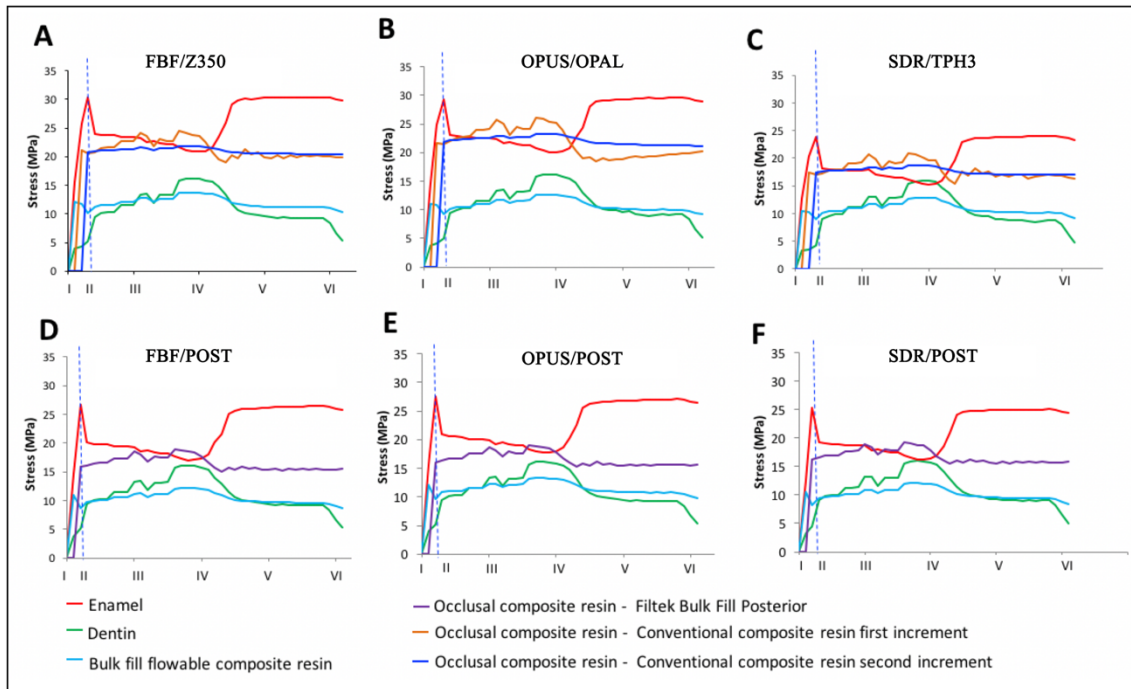


Figure 8. The 10% highest values of Modified von Mises stress generate on enamel, dentin, bulk fill flowable composite resin and occlusal composite resin, caused by shrinkage and occlusal loading for different composite resin combinations. A. FBF/Z350, B. OPUS/OPAL, C. SDR/TPH3, D. FBF/POST, E. OPUS/POST, SDR/POST. I-II: stress generated by the shrinkage of materials; II- IV: stress generated by contact with the opposing tooth, only in the enamel of the palatal cusp; IV-VI: stress generated by transition from occlusal loading of enamel to restoration, until a second contact is found and stopped.

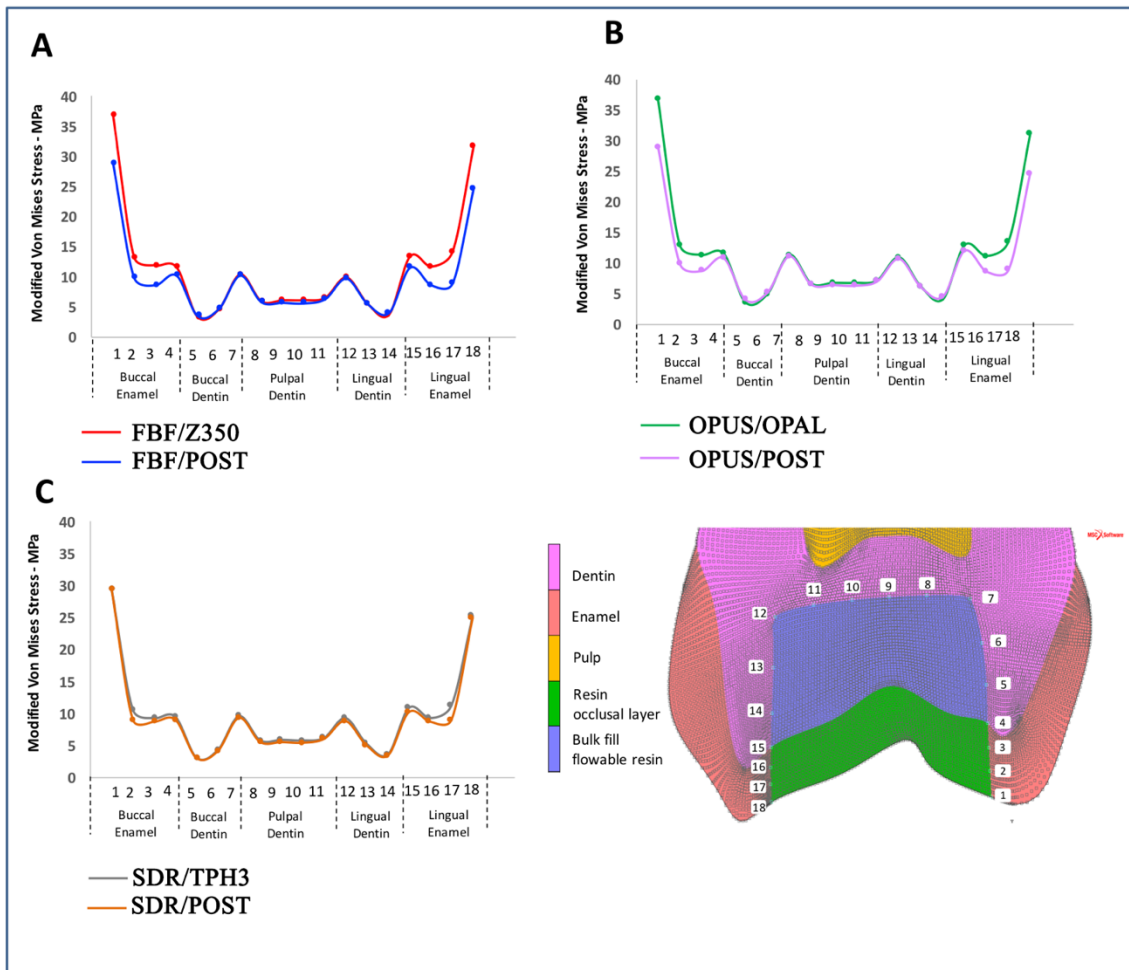


Figure 9. The values of Modified von Mises stress generate at the tooth structure/composite resin interface caused by shrinkage and occlusal loading for different composite resin combinations.

CONSIDERAÇÕES FINAIS

4. CONSIDERAÇÕES FINAIS

Frente as limitações do delineamento experimental estabelecido para este estudo “in vitro”, pode se inferir que:

- Não houve diferença na resistência da união e no padrão de falha entre as associações de resinas convencionais ou resinas bulk fill regular com diferentes resinas bulk fill fluidas.
- O padrão de falha coesiva da base foi o mais frequente para todos os grupos, demonstrando maior fragilidade mecânica da resina fluída e inferior às resinas convencionais e bulk fill regular.
- A resina bulk fill regular possui valores de contração inferiores às resinas convencionais.
- O módulo de elasticidade variou substancialmente entre as resinas empregadas na cobertura oclusal de resinas bulk fill fluídas.
- A resina bulk fill regular testada neste estudo (Filtek Bulk Fill Posterior) demonstrou valores de dureza semelhantes às resinas convencionais, o que a qualifica para recobrir a camada oclusal quando associado às resinas bulk fill fluídas.
- Resinas bulk fill fluidas possuem valores de dureza inferiores às resinas convencionais e resina bulk fill regular, comprovando a necessidade de recobrimento oclusal para evitar desgaste indesejável.
- O uso de resina bulk fill regular na camada oclusal resulta em menores concentração de tensão na interface do esmalte que as resinas convencionais inseridas pela técnica incremental. Sugerindo possível redução de abertura de fenda marginal e consequente manchamento que pode inadequadamente ser confundido com cárie secundária e por isso determinar a substituição destas restaurações precocemente.

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RELEASE PARA IMPRENSA

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Milhares de restaurações dentárias são feitas no dia a dia nos consultórios pelos profissionais utilizando resina composta que apresenta cor semelhante à do dente. Estas resinas são disponíveis em pastas e quando ativadas pela luz azul se tornam rígidas. Porém esta contração pode causar diversos problemas clínicos como manchamento da margem da resina que pode ser confundida por cárie, e assim determinar troca inadequada da mesma com maior custo individual ou ao serviço público. Com a busca de diminuir o tempo de cadeira, as empresas têm desenvolvidos novos materiais, “resinas bulk fill”, que são inseridas de uma única vez e assim diminuir o tempo de cadeira no consultório. Estas resinas podem ser fluidas, que escoam mais facilmente, que devem ser recobertas na superfície do dente para evitar desgaste; ou em pastas, que são mais rígidas e podem ser usadas isoladamente. Frente a esta condição, propusemos este estudo usando diferentes metodologias laboratoriais e de simulação em computadores para testar novas associações visando diminuir o tempo de cadeira e problemas nas margens das restaurações de resina que podem determinar a substituição das mesmas. Foi comprovado que a associação de resinas bulk fill fluida e de pasta mostrou ser uma alternativa viável e promissora. Com isso este estudo mostra que esta alternativa pode facilitar a técnica ao dentista e reduzir os problemas de substituições de restaurações diretas em resinas em dentes posteriores.