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Raissa Albuquerque de Deus

Efeito do tempo de fotoativação e irradiância de fonte de luz multi-espectros no desempenho de resinas compostas bulk fill de baixa e alta viscosidade

Effect of light activation time and irradiance of multi-peak light curing unit on flowable and high viscosity bulk fill resin composites

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.

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Orientador: Prof. Dr. Carlos José Soares

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Uberlândia, 2020

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DEDICATÓRIA

Dedico este trabalho aos amores da minha vida:

meus pais, minha irmã e meu namorado.

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“Suba o primeiro degrau com fé.

Não é necessário que você veja toda a escada.

Apenas dê o primeiro passo.”

Martin Luther King

SUMÁRIO

RESUMO

RESUMO

O uso de resinas compostas bulk fill para confecção de restaurações posteriores tem crescido nos últimos anos. No entanto, se as resinas compostas receberem menos energia do que necessitam, elas serão insuficientemente polimerizadas e, consequentemente, terão suas propriedades alteradas. Portanto, a fonte de luz é essencial no processo de polimerização das resinas compostas, especialmente acerca da interação entre tempo de ativação, irradiância e características das resinas compostas. O objetivo deste estudo foi avaliar o efeito do tempo de fotoativação e da irradiância de uma fonte de luz multi-espectro nas resinas compostas bulk fill de viscosidade regular e fluida por meio de testes laboratoriais e computacionais. Este estudo foi dividido em três objetivos específicos que caracterizam os capítulos dessa dissertação; ***objetivo 1***: avaliar o efeito do tempo de ativação (10, 20 e 40s) e da irradiância (400, 800 e 1200 mW/cm^2) nas propriedades físico-mecânicas expressas por radiopacidade, contração pós-gel, grau de conversão, dureza e módulo de elasticidade de resina compostas bulk fill; ***objetivo 2***: avaliar, por meio de análise por elementos finitos, o efeito dos parâmetros recomendados pelos fabricantes acerca do tempo de fotoativação para uma fonte de luz com 1200 mW/cm^2 e ainda, o efeito do tempo (10, 20 e 40s) na irradiância de 1200 mW/cm^2 e a variação da irradiância (400, 800 e 1200 mW/cm^2) associada ao tempo de 40s de fotoativação na geração de tensões de contração durante a confecção da restauração e tensões residuais durante o carregamento oclusal fisiológico (100N) em molares restaurados com diferentes resinas bulk fill; ***objetivo 3***: analisar o efeito de diferentes níveis de irradiância na transmissão da luz através de resinas bulk fill de viscosidade fluida e regular durante a polimerização e após a cura das resinas compostas. Cinco resinas compostas bulk fill de consistência fluida (Tetric N-Flow Bulk Fill, Ivoclar Vivadent; Filtek Bulk Fill Flow, 3M Oral Care; Opus Bulk Fill Flow APS, FGM; Admira Fusion x-base, VOCO; e SureFil SDR Flow, Dentsply) e cinco de consistência regular (Tetric N-Ceram Bulk Fill, Ivoclar Vivadent; Filtek One Bulk Fill, 3M Oral Care; Opus Bulk Fill APS, FGM; Admira Fusion x-tra, VOCO; e SonicFill 2, Kerr) foram fotoativadas com VALO Cordless, variando a irradiância de 1200, 800 e 400 mW/cm^2 definidas pelo distanciamento de 1, 5 e 13 mm, das amostras, respectivamente. Os métodos experimentais utilizados foram extensometria para cálculo de contração pós-gel, FTIR para grau de conversão, teste de indentação para cálculo da dureza Knoop e módulo de elasticidade, radiografia digital para mensurar a radiopacidade, análise por elementos finitos 2D para avaliar tensões de contração e tensões residuais durante carregamento oclusal, e câmera a laser para medir o perfil do feixe de luz transmitida através do material. Após análise dos dados, pode-se concluir que a irradiância teve mais influência nas propriedades mecânicas dos materiais testados do que o tempo de fotoativação; o uso de 1200 mW/cm^2 com 20s ou 40s é uma estratégia clínica mais indicada ao invés de utilizar tempo de fotoativação reduzido, como recomendado por alguns fabricantes; o tempo de fotoativação e a irradiância não influenciaram a radiopacidade dos materiais testados. Foram observadas menores tensões em molares restaurados com resinas bulk fill flow associada a resinas de consistência regular; a irradiância influenciou a geração de tensões em molares restaurados com diferentes resinas compostas bulk fill mais significativamente do que o tempo de fotoativação; o nível de irradiância afetou a transmissão de luz através de resinas compostas bulk fill; as resinas bulk fill de consistência regular e fluida apresentam translucidez diferentes após a polimerização.

PALAVRAS-CHAVE: resinas compostas bulk fill, irradiância, fonte de luz, propriedades mecânicas, radiopacidade, tensões de contração, análise por elementos finitos, transmissão de luz, opacidade

Abstract

ABSTRACT

The use of bulk fill resin composites to posterior restorations has increased in recent years. However, if resin composites receive less energy than required, they will be insufficiently polymerized and, consequently, have their properties impaired. Therefore, the light curing unit (LCU) is an essential part in the polymerization process of resin composites, and more studies about the interaction between light activation time, irradiance of LCU and characteristics of resin composites are necessary. The aim of this study was to evaluate the effect of light activation time and irradiance of multi-peak LCU on flowable and high viscosity bulk-fill resin composites though laboratory and computational tests. This study was sctutured into three specific objectives; ***objective 1:*** to evaluate the effect of light activation time (10, 20, 40s) and irradiance (400, 800, 1200 mW/cm^2)of multi-peak LCU on physical-mechanical properties expressed by radiopacity, degree of conversion, post-gel shrinkage, hardness and elastic modulus of bulk-fill resin composites; ***objective 2:*** to evaluate, by finite element analysis, the effect of the parameters recommended by manufacturers about light activation time for a LCU with 1200 mW/cm^2; and also the effect of time (10, 20 and 40s) on the irradiance of 1200 mW/cm^2 and the irradiance variation (400, 800 and 1200 mW/cm^2) associated with 40s of light activation time in the generation of shrinkage stresses during the restoration and residual stresses during physiological occlusal loading (100N) in restored molars with different bulk fill resins; ***objective 3:*** to analyze the effect of the different irradiance and the real time light translucency on the light transmission of flowable and high viscosity bulk-fill resin composites. Five flowable bulk-fill resin composites (Tetric N-Flow Bulk Fill, Ivoclar Vivadent; Filtek Bulk Fill Flow, 3M Oral Care; Opus Bulk Fill Flow APS, FGM; Admira Fusion x-base, VOCO; e SureFil SDR Flow, Dentsply) and five high viscosity bulk-fill resin composites (Tetric N-Ceram Bulk Fill, Ivoclar Vivadent; Filtek One Bulk Fill, 3M Oral Care; Opus Bulk Fill APS, FGM; Admira Fusion x-tra, VOCO; e SonicFill 2, Kerr) were light cured, using VALO Cordless, varying the irradiances of 1200, 800 and 400 mW/cm^2, according to distances of 1, 5 and 13 mm, respectively. The methods used on the all studies were post-gel measurements by strain gage test, degree of conversion using FTIR, indentation test for calculation of hardness Knoop and elastic modulus, digital radiographic to calculate radiopacity, finite element analysis 2D to evaluate shrinkage stresses and residual occlusal stress and a laser beam profiler camera to measure light beam profile of light transmitted. After data analysis it can be concluded that the irradiance level had more influence on mechanical properties than light activation time; the use of 1200 mW/cm^2 with longer light activation time is a better strategy than the reduced light activation time recommender by some manufactures; the light activation time and irradiance had no influence on radiopacity for all tested resin composites; lower shrinkage and residual stresses were observed on molar tooth restored with flowable associated with high viscosity bulk fill resin composites; irradiance level influences the generation of shrinkage and residual stresses on molar teeth restored with different bulk fill resin composites more significantly than light activation time; the irradiance level affected the light transmission of bulk fill resin composites; flowable and high viscosity bulk fill resin composite had different light transmission after cured.

KEYWORDS: bulk fill resin composites, irradiance, light curing unit, mechanical properties, radiopacity, shrinkage stresses, finite element analysis, light transmission, opacity

Introdução e Referencial teórico

1. INTRODUÇÃO E REFERENCIAL TEÓRICO

A contração por polimerização é uma característica inerente às resinas compostas devido à conversão de monômeros em cadeias poliméricas, resultando em aproximação das moléculas e redução de volume (Marchesi *et al*., 2010; Jafarpour *et al*., 2012). Quando o material contrai, tesões de contração e, consequentemente, deformações estruturais e falhas na interface dente/restauração podem ocorrer (Versluis & Tantbirojn, 2009). Clinicamente, as tensões de contração se manifestam como sensibilidade pós-operatória, microtrincas no esmalte, pigmentação e infiltrações marginais (Burgess & Carkir, 2010; Ferracane & Hilton, 2016; Soares *et al.,* 2017a). As cargas mastigatórias podem gerar processo de fadiga que contribui para a concentração de tensões no complexo dente/restauração, acentuando a ocorrência desses sinais e sintomas (Versluis & Versluis-Tantbirojn, 2011; Soares *et al.,* 2017a).

O uso das resinas compostas bulk fill para restaurar dentes posteriores cresceu nos últimos anos devido à vantagem de reduzir as tensões de contração em comparação com as resinas compostas convencionais (Rosatto *et al*., 2015). De acordo com alguns fabricantes, as resinas compostas bulk fill são consituídas por diferentes tipos de partículas de carga e monômeros capazes de atenuar as tensões geradas na reação de polimerização. As resinas compostas bulk fill podem ser classificadas de acordo com a consistência em flow (baixa viscosidade) ou regular (alta viscosidade) (Rosatto *et al*., 2015).

A escolha correta da fonte de luz é essencial para a confecção de restaurações de resina composta bulk fill de maneira eficiente (Soares *et al*., 2017b). Diferentes fontes de luz apresentam variações no diâmetro interno da ponta, no perfil do feixe de luz, no espectro de emissão, na potência e na irradiância, o que pode levar a diferentes resultados na polimerização das resinas compostas (Price *et al*., 2015; Soares *et al*., 2017b). A potência está relacionada à quantidade de luz emitida pela fonte de luz, sendo importante para a geração de radicais livres que iniciam a reação de polimerização (Shimokawa *et al*., 2016). A irradiância depende da área da superfície que está recebendo luz, e a concentração de saída em área específica da ponta da fonte de luz (Price *et al*., 2015). Se as resinas compostas recebem menos energia do que necessitam, elas serão insuficientemente polimerizadas e, consequentemente, terão propriedades mecânicas inferiores (Shimokawa *et al.,* 2018).

A distância entre a fonte de luz e a superfície da restauração também pode influenciar na energia recebida pelo material e, consequentemente, na qualidade da polimerização (Price *et al*., 2011). Esse aspecto ganhou maior importância para as resinas compostas bulk fill pois trata-se de material que pode ser inserido em incrementos de até 4-5 mm, característica que contribui para a redução no tempo clínico de confecção das restaurações posteriores (Rosatto *et al.,* 2015). Uma preocupação sobre esse material é se a luz tem a capacidade de penetrar o material até o fundo da restauração para que ocorra polimerização adequada (Durner *et al*., 2012). Para garantir maior profundidade de polimerização, as resinas bulk fill possuem maiores partículas de carga (Ilie & Hickel, 2011), modificações nos monômeros e moduladores de reação, e ainda aumento na translucidez para que a luz passe com maior eficiência pelo material (Besegato *et al*., 2019). Além disso, diferentes tempos de ativação da luz podem resultar em diferentes propriedades dos compósitos (Bennett & Watts, 2004), e as recomendações dos fabricantes sobre o tempo de ativação da luz podem não ser apropriadas (Jafarpour *et al*., 2012). Um maior tempo de fotoativação pode induzir a melhor polimerização da resina composta desde que não tenha atingido a conversão máxima de monômeros em polímeros (Ilie & Stark, 2014).

O espectro de emissão pode influenciar na transmissão da luz emitida pela fonte de luz através das restaurações de resina composta bulk fill (Shimokawa *et al*., 2017). Maiores comprimentos de onda – 460 nm (azul) – possuem maior poder de penetração através do material do que comprimentos de onda menores, como o de 400 nm (violeta) (Price *et al*., 2010). Alguns fabricantes inseriram novos fotoiniciadores em resinas bulk fill para garantir a polimerização em grandes profundidades (Rueggeberg *et al*., 2017). O Ivocerin é um fotoiniciador mais reativo comparado à canforquinona, porém seu espectro de absorção não é emitido por fontes de luz *monowave* (Shimokawa *et al*., 2017). As tensões de contração dependem de vários fatores, incluindo a intensidade e o tempo da fotoativação (Versluis *et al*., 1996; Calheiros *et al*., 2014). Maiores tempos de ativação e o uso de fontes de luz com maiores irradiâncias podem resultar em melhores propriedades do material, porém podem ao mesmo tempo gerar maiores tensões de contração de polimerização (Feng & Suh, 2006). O estabelecimento de equilíbrio entre esses dois pilares, contração de polimerização e adequadas propriedades mecânicas e ópticas é o grande desafio dos fabricantes e dos clínicos. A energia que chega à superfície da amostra associada ao tempo de fotoativação influenciam na qualidade da polimerização de resinas compostas (Shimokawa *et al.,* 2018). Um material restaurador polimerizado de forma inadequada determina propriedades mecânicas inferiores, aumentando as chances de fratura do material e do remanescente dental quando fragilizado (Palagummi *et al.,* 2019). A avaliação das propriedades mecânicas dos materiais restauradores é importante para melhor entender o comportamento biomecânico durante as cargas mastigatórias. Quando o dente é submetido a carga oclusal de compressão, tensões de tração também são geradas na estrutura dental; no entanto, o dente é capaz de resistir melhor às tensões de compressão do que às tensões de tração (Versluis *et al.,* 1996). As resinas compostas também mantêm esse comportamento durante carregamento oclusal (Rosatto *et al.,* 2015). Porém, quando o material restaurador não é adequadamente polimerizado, os dentes posteriores não suportarão adequadamente as tensões e as forças de tração causadas pelas cargas mastigatórias fisiológicas.

O módulo de elasticidade é uma propriedade física ligada à rigidez do material, associada ao desenvolvimento de tensões (Soares *et al*., 2017a; Han *et al*., 2019). Materiais com alto módulo de elasticidade tendem a gerar maior contração de polimerização e, consequentemente, causar maiores tensões nas estruturas adjacentes (Soares *et al.,* 2013). No entanto, se o módulo de elasticidade é baixo, o material pode não recuperar a integridade estrutural do dente para aplicar cargas mastigatórias (Soares *et al.,* 2013). As resinas compostas bulk fill de viscosidade regular tendem a ter valores mais altos de módulo de elasticidade e dureza em relação às resinas bulk fill de viscosidade fluida (Rosatto *et al*., 2015). Essa diferença de propriedades mecânicas indica que as resinas compostas bulk fill flow apresentam maior fragilidade quando expostas ao meio bucal (Tauböck *et al.,* 2019) e, quando utilizadas para restaurar a região oclusal de dentes posteriores, requerem uma camada final (2 mm) de resina convencional ou de resina bulk fill de consistência regular, que apresentam maior resistência ao desgaste (Rosatto *et al*., 2015, Cerda-Rizo *et al.,* 2019). Então, as melhores estratégias para restaurar dentes posteriores se baseiam na polimerização adequada do material, que deve proporcionar um equilíbrio entre boas propriedades mecânicas e tensões de contração reduzidas (Bicalho *et al*., 2014a, 2014b; Soares *et al.,* 2017a).

Resinas compostas bulk fill apresentam maior translucidez em relação às resinas compostas convencionais, ou seja, proporcionam maior transmissão de luz através do material (Bucuta & Ilie, 2014). Embora seja essencial para promover a polimerização no fundo da restauração, maior translucidez pode comprometer a capacidade de mascarar a cor da dentina esclerótica ou a pigmentação do substrato manchado por amálgama (Miletic *et al*., 2019). As resinas bulk fill flow apresentam maior translucidez quando comparadas com às resinas de viscosidade regular devido à menor concentração de partículas de carga (Ilie & Hickel, 2011). No entanto, a consequência dessa modificação na composição resulta em menor resistência ao desgaste do material (Flury *et al.,* 2012).

Os materiais usados para restaurar cavidades em dentes posteriores devem apresentar radiopacidade adequada para permitir o diagnóstico de cáries secundárias, ausência de contato com dentes adjacentes, falhas na adaptação marginal, fendas e bolhas (Fonseca *et al.,* 2006; Fronza *et al.,* 2015). Embora as resinas compostas bulk fill apresentem radiopacidade suficiente para facilitar a detecção desses defeitos (Soares *et al*., 2017c), não há estudos na literatura que analisaram a influência da qualidade da polimerização na radiopacidade de resinas compostas bulk fill de viscosidade regular ou fluida.

Portanto, são necessários estudos que avaliem o efeito da irradiância e do tempo de fotoativação nas propriedades físico-mecânicas, na contração de polimerização e tensões residuais durante o carregamento oclusal, e na transmissão de luz e opacidade e radiopacidade de resinas compostas bulk fill, tendo em vista os aspectos mencionados anteriormente para melhor orientar ao clínico na tomada de decisões que envolva seleção de materiais, escolha de tempo adequado de fotoativação e da irradiância adequada para que as diferentes resinas possam entregar aos profissionais e seus pacientes o que se propõem.

Capítulos

2. CAPÍTULO 1

ARTIGO 1

Light activation time and irradiance level on flowable and high viscosity bulk fill resin composites – Part 1: effect on the physical-mechanical properties

***Artigo a ser enviado para o periódico Operative Dentistry**

Light activation time and irradiance on flowable and high viscosity bulk fill resin composites – Part 1: effect on the physical-mechanical properties

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Running title: Physical-mechanical properties of bulk fill resin composites

Keywords: bulk fill resin composite, irradiance, mechanical properties, post-gel shrinkage, Knoop hardness, elastic modulus, degree of conversion, radiopacity

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Light activation time and irradiance on flowable and high viscosity bulk fill resin composites – Part 1: effect on the physical-mechanical properties

ABSTRACT

Objectives. To evaluate the effect of light activation time and irradiance of multi-peak light curing unit (LCU) on physical-mechanical properties expressed by radiopacity, post-gel shrinkage, degree of conversion, hardness and elastic modulus of bulk-fill resin composites.

Methods. Five flowable bulk-fill resin composites (Tetric N-Flow Bulk Fill, Ivoclar Vivadent; Filtek Bulk Fill Flow, 3M Oral Care; Opus Bulk Fill Flow APS, FGM; Admira Fusion x-base, VOCO; SureFil SDR Flow, Dentsply Sirona) and five high viscosity bulk-fill resin composites (Tetric N-Ceram Bulk Fill, Ivoclar Vivadent; Filtek One Bulk Fill, 3M Oral Care; Opus Bulk Fill APS, FGM; Admira Fusion x-tra, VOCO; SonicFill 2, Kerr) were light activated using VALO Cordless for 10, 20 and 40s with irradiance of 1200, 800 and 400 mW/cm^2. Post-gel shrinkage (Shr) was calculated using strain-gauge test. Degree of conversion (DC, %) was calculated using FTIR; Knoop hardness (KNH, N/mm^2) and elastic modulus (E, Mpa) using Knoop indentation on top and bottom surfaces. Radiodensity was calculated using digital radiographic.

Results. Increasing light curing time and irradiance higher mechanical properties expressed by KNH, E and DC values were observed. However, higher Shr was also obtained. Lower mechanical properties and post-gel shrinkage were observed for flowable than high viscosity bulk fill resin composites. All bulk fill resin composite resin had higher radiopacity level than 3 mm of aluminum step wedge.

Conclusion. The irradiance level had more influence on mechanical properties than light activation time. The use of 1200 mW/cm^2 with longer irradiation time is better strategy than the reduced light activation time recommender by some manufactures. All bulk fill resin composite resin had higher radiopacity level than 3 mm of aluminum. The light activation time and irradiance had no influence on radiopacity for all tested resin composites.

Clinical Significance. *High irradiance (1200mW/cm^2) with longer light activation time (20s and 40s) improved the mechanical properties of flowable and high viscosity bulk-fill resin composites. The radiopacity level of tested bulk fill resin composites fill the recommendations for posterior restorations.*

INTRODUCTION

Polymerization shrinkage is an inherent problem of resin composite due to the conversion of monomers into polymeric chains, resulting in approximation of molecules and volume reduction.[1,2] When the material contracts, shrinkage stresses and, consequently, structural deformation and failures at tooth/restoration interface can be occurred.[3] Clinically the resin shrinkage stress manifest as postoperative sensitivity, enamel cracks, pigmentation and infiltrations marginal.[4-6] Chewing loads can generate fatigue process that contributes to stress concentration in the restorative and interfaces, accentuating the occurrence of these signs and symptoms.[7]

Bulk fill resin composites have been gained popularity due the time reduction and also due the advantage to reduce shrinkage stresses compared to conventional resins,[8] and the use of these materials to restore posterior teeth has increased in recent years.[9] According to manufacturers, bulk fill resin composites have different filler types and monomers able to soften stresses generated in polymerization reaction.[10] They also can be classified according to consistency in flowable (low viscosity) or high viscosity resin composites. Flowable resin composites require a final layer of high bulk-fill or conventional resin composites to restore occlusal layer restorations because they have lower mechanical properties.[8]

The irradiance, power and time of light activation are essential parts in the polymerization process of resin composites.[11] If resin composites receive less energy than required, they will be insufficiently polymerized and consequently have lower mechanical properties.[12] The distance of the light curing unit (LCU) to the resin composite surface can influence on the energy received and consequently to the quality of polymerization.[13] This aspect gained more importance for bulk fill resin composite that are inserted in unique increments of up to 4-5 mm.[8] This characteristic results in a reduction in clinical time; however, a concern about these materials is whether light has the ability to penetrate the resin composite to the bottom surface of the restoration for correct polymerization.[13,14] Manufacturers have modified the components of bulk fill resin composites,[13] increasing the size of filler particles to ensure a greater polymerization depth.[15] Each resin composite needs an amount of energy necessary for adequate polymerization, and the speed with that energy is given to the material can influence its mechanical properties.[16] Different light activation times may result in different properties of resin composites,[17] and the manufacturers instructions about light activation time may not be appropriate.[1] Longer light activation time can induce to better resin composite polymerization as long as it has no achieved its maximum conversion of monomers to polymers.[19] New strategies have been recommended by manufactures reducing substantially the light activation time, expecting that all clinicians will use high irradiance.

Materials used to restore cavities in posterior teeth must provide proper radiopacity to allow for the diagnosis of secondary caries, defects in adaptation, the contour of a restoration, contact with adjacent teeth, interfacial gaps, and voids in the restoration.[20,21] Bulk fill resin composites have sufficient radiodensity to facilitate detection of secondary caries in marginal defects located at the proximal areas.[22] However, no prior studies have analyzed the influence of polymerization quality on radiopacity of flowable or high viscosity bulk fill resin composites.

Studies about the interaction between light activation time, irradiance of LCU and resin composites are necessary. Therefore, the aim of this study was to evaluate the physical-mechanical properties expressed by radiopacity, post-gel shrinkage, hardness and elastic modulus of bulk-fill resin composites influenced by the light activation times and irradiance levels of multi-peak LCU. The null hypotheses tested were: 1) post-gel shrinkage, degree of conversion, Knoop hardness and elastic modulus of bulk fill resin composites will be not influenced by the light activation time and irradiance level of multi-peak LCU; 2) radiopacity of bulk-fill resin composites will be not influenced by the light activation time and irradiance level of LCU.

METHODS AND MATERIALS

Study design

Five flowable bulk-fill resin composites (Tetric N-Flow Bulk Fill, Ivoclar Vivadent; Filtek Bulk Fill Flow, 3M Oral Care; Opus Bulk Fill Flow APS, FGM; Admira Fusion x-base, VOCO; SureFil SDR Flow, Dentsply Sirona) and five high viscosity bulk-fill resin composites (Tetric N-Ceram Bulk Fill, Ivoclar Vivadent; Filtek One Bulk Fill, 3M Oral Care; Opus Bulk Fill APS, FGM; Admira Fusion x-tra, VOCO; SonicFill 2, Kerr) were tested in this study. The compositions of the 10 resin composites were listed in Table 1. All materials were light activated using a multi-peak LCU (VALO Cordless; Ultradent, South Jordan, UT, USA) for 10, 20 and 40 seconds with irradiance of 1200, 800 and 400 mW/cm^2, obtained from the distance between LCU and sample surface of 1, 5 and 13 mm, respectively. The distance equivalent to each irradiance was determined by using a MARC resin calibrator. Post-gel shrinkage (Shr, %) was calculated using strain-gauge test. Degree of conversion (DC, %), Knoop hardness (KNH, N/mm^2) and elastic modulus (E, Mpa) were tested on top and bottom surfaces of the resin composite specimens. Radiodensity was calculated using digital radiography and compared with the aluminum step wedge.

Post-gel shrinkage (Shr)

The post-gel linear shrinkage was determined using the strain gauge method with 5 for each group.[23] The materials were shaped into a hemisphere (1mm thick and 2mm x 2mm) on top of a biaxial strain gauge (CEA-06-032WT-120) that measured shrinkage strains in two perpendicular directions. A strain conditioner (ADS0500Ipg) converted electrical resistance changes in the strain gauge to voltage changes through a quarter-bridge circuit with an internal reference resistance. 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 inserted in by the same operator and light activated using VALO Cordless, with 1, 5 or 13 mm of distance between LCU and sample surface, determining the referred irradiance levels. All tests were performed in a dark room with yellow light to avoid any effect on polymerization reaction. The strain values were collected for ten minutes after light activation to monitor the real time measurement of shrinkage strain. The mean shrinkage strain, which represented the linear shrinkage, was converted to volumetric percentage by multiplying by 3 and 100%.

Sample preparation

The samples of each group (n=3) were prepared using plastic ring molds (with an internal aperture of 8 mm diameter and depth of 4 mm) in a dark room with yellow light. To minimize the presence of bubbles and obtain a smooth surface, the ring mold was placed on a glass plate and a polyester strip was positioned between the glass plate and ring mold. Then the resin composite was inserted with a condenser to better adaptation of the material, another polyester strip was placed over the resin composite, and a second glass plate was used to press the material in order to force out excess resin composite. The samples were positioned directly on the surface of the MARC-RC bottom sensor, so the LCU was activated.

Degree of conversion (DC)

The degree of conversion of resin composites at the top and bottom of samples were assessed after 24 hours. They were stored dry at 37 ºC protected from light. The DC were assessed using Fourier transform infrared (FTIR) spectroscopy (Vertex 70, Bruker Optik GmbH, Ettlingen, Germany) with attenuated total reflectance sampling, mid-infrared (MIR) and deuterated triglycine sulfate detector elements (Bruker Optics). The spectra were obtained between internal standard aromatic C=C bonds stretching vibrations (1608 cm^{-1}) and aliphatic C=C bonds stretching vibrations (1638 cm^{1}), at a 4 cm^{-1} resolution and 32 scans were averaged. All analyses were performed under controlled temperature (25±1ºC) and humidity (60±5%) conditions. DC was calculated from the equivalent aliphatic (1638 cm^{-1}) and aromatic (1608 cm^{-1}) ratios of cured © and uncured (U) resin composites. Admira x-base, Admira x-tra and SDR do not include an aromatic C=C bond peak and were measured without this internal standard.[24] Filtek One does not contain Bis-GMA or Bis-EMA, so the 1450 cm^{-1} peak was used an alternative internal standard.[25] The formula used to calculate the degree of conversion was: DC (%) = (1-C/U) x 100.

Knoop hardness (KNH) and elastic modulus (E)

After measuring degree of conversion, the samples from each group were used for analysis of KNH (N/mm^2) and E (MPa) of the resin composites at top and bottom surfaces. The surfaces were polished with metallographic diamond pastes (6, 3, 1 and 0.25 µm; Arotec, São Paulo, SP, Brazil). The Knoop indentation values were determined with a microhardness tester (FM700; FutureTech Corp., Kawasaki, Japan) by applying a load of 500 g for 15 s. Five indentations were made on the middle of each surface with interval of 1 mm between them to obtain an average value. The elastic modulus was calculated from Knoop indentations and the relationship for the decrease in the length of the indentation diagonals by elastic recovery: b'/a' = b/a - μ(H/E), where b/a is the ration of the diagonal dimensions a and b, in the fully loaded state, given by a constant 0.140647. b'/a' is ratio of the altered dimensions when fully recovered and μ=0.45 is a proportionality constant.

Radiopacity

The samples of each group were positioned over a phosphor plate. The aluminium step wedge (Odeme, Lucerna, SC, Brazil) was also placed on phosphor plate and the set was positioned inside a device developed for the standardization for in vitro studies. The radiographic exposure was performed using Timex 70 E (Gnatus, Ribeirão Preto, Brazil) with exposure of 0.28s at 70kV and 7.0 mA. The phosphor plate was placed 20 centimeters away from radiographic cylinder. The radiographs were transferred from the phosphor plate to a computer using a digital scanner (VistaScan, Dürr Dental, Bietigheim-Bissingen, Germany). Radiopacity was determined using the resident software provided by the manufacturer (DBSWIN). Five points were previously defined on each sample where the mouse cursor was positioned to collect the value of radiopacity. The mean of the five calculated values was used as radiopacity level for each resin composite sample. The final value of each group was obtained from the mean of the three radiodensity values.

Statistical analysis

The Shr, DC, KHN, E, and Radiopacity data were tested for normal distribution (Shapiro–Wilk) and equality of variances (Levene's test), followed by parametric statistical tests. Three-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.

RESULTS

Shr (%) of resin composites

The Shr mean and standard deviation values of flowable and high viscosity resin composites activated using different irradiance levels and light activation times are shown in Figure 1. Three ANOVA showed significant difference between the resin composites (*P* <0.001), between irradiance level (*P* <0.001), and between light activation time (*P* <0.001).'Tukey's test showed that for flowable resin composites, the Admira x-base had the highest and Opus Flow had the lowest Shr values. For high viscosity resin composites, the Tetric N-Ceram had the highest and SonicFill 2 had the lowest Shr values. In general, increasing the light curing time and also the irradiance level increased Shr values were observed, with more sensitivity for flowable than high viscosity resin composites.

E (MPa) and KHN (N/mm^2) of resin composites

The E mean and standard deviation values of flowable and high viscosity resin composites activated using different irradiance and time are shown in Figure 2. Three ANOVA showed significant difference between the resin composites (*P* <0.001), between irradiance level (*P* <0.001), and between light curing time (*P* <0.001) and also for the interaction between the three study factors (*P* <0.001). 'Tukey's test showed that for flowable resin composites, the SDR had the highest and Admira x-base had the lowest E values. For High viscosity resin composites, the Tetric N-Ceram had the highest and SonicFill 2 had the lowest E values. In general, the E values were higher in the top than at the bottom; when using 40s curing time and 1200mW/cm^2 of irradiance this difference was not observed for Admira x-base, Tetric N-Ceram, Filtek One, Opus APS and SonicFill 2. Increasing the irradiance level increased E values were observed for both groups of bulk fill resin composites; these differences were slightly reduced when used 40s associated with irradiance of 800 and 1200mW/cm^2. The light curing time significantly influence negatively the E values mainly in the bottom region when was used 400 mW/cm^2. The use of 10s of light activation time used 800 and mainly 400 mW/cm^2 reduced significantly the E values at the top for the most tested and at the bottom for all resin composites. The use of 40s with 1200mW/cm^2 tended to maintain the E values between top and bottom for all High viscosity resin composites, exception for Admira x-tra.

The KHN mean values and standard deviations of flowable and high viscosity resin composites activated using different irradiance and time are shown in Figure 3. Three ANOVA showed significant difference between the resin composites (*P* <0.001), between irradiance level (*P* <0.001), and between light curing time (*P* <0.001) and also for the interaction between the three study factors (*P* <0.001). Tukey's test showed that for flowable resin composites, the Tetric N-Flow had the highest and Admira x-base had the lowest KHN values. Regarding high viscosity resin composites, the Tetric N-Ceram had the highest and SonicFill 2 had the lowest KHN values. The KHN values were always significantly higher at the top than at the bottom. Increasing the irradiance level increased KHN values were observed for both groups of bulk fill resin composites. These differences were more clearly observed when used irradiance of 400mW/cm^2 for all tested resin composites, except for Admira x-base and Admira x-tra. The light curing time significantly influence negatively the E values mainly in the bottom region when was used 400 mW/cm^2. The use of 10s of light activation time used 800 and mainly 400 mW/cm^2 reduced significantly the KHN values for the most resin composites.

DC% of resin composites

The DC mean and standard deviation values of flowable and high viscosity resin composites activated using different irradiance and time are shown in Figure 4. Three ANOVA showed significant difference between the resin composites (*P* <0.001), between irradiance level (*P* <0.001), and between light curing time (*P* <0.001) and also for the interaction between the three study factors (*P* <0.001). Tukey's test showed that for flowable resin composites, the Filtek Flow had the highest and Opus Flow had the lowest DC values. For high viscosity resin composites, the Admira x-tra had the highest and Filtek One had the lowest DC values. DC values were significantly higher in the top than at the bottom for all resin composites activated using all tested conditions, expect for Admira x-tra when activated for 40s. In general, increasing the irradiance level and light activation time, increased DC values were observed for both groups of bulk fill resin composites. The light activation reduction time significantly influence negatively the DC values mainly in the bottom region when was used 400 mW/cm^2. The use of 10s of light activation time used 800 and mainly 400 mW/cm^2 reduced significantly the DC values at the top for the most tested and at the bottom for all resin composites.

Radiopacity of resin composites

The radiopacity mean and standard deviation values of flowable and high viscosity resin composites activated using different irradiance and light activation times are shown in Figure 5. Three ANOVA showed significant difference between the resin composites (P <0.001), however no difference was found between irradiance level (P =0.426), between light curing time (P =0.709) and neither for the interaction between the three study factors (P =0.360). 'Tukey's test showed that, for flowable resin composites, the SDR had the highest followed by Tetric N-Flow, Filtek Flow, Admira x-base and Opus Flow had the lowest DC values (Figure 6). All flowable resin composites demonstrated radiopacity level similar or higher than 4mm of aluminum step-wedge, except for and Opus Flow that was similar to 3mm of aluminum step-wedge. For high viscosity resin composites, Tetric N-Ceram, followed by Admira x-tra, SonicFill 2, Filtek One and Opus APS had the lowest radiopacity values (Figure 6). All high viscosity resin composites demonstrated radiopacity level similar or higher than 5mm of aluminum step-wedge. The activation time and irradiance had no influence on radiopacity level for all tested resin composites.

DISCUSSION

The results of the present study confirmed that post-gel shrinkage, degree of conversion, Knoop hardness and elastic modulus of flowable and high viscosity viscosity bulk fill resin composites were affected by the light activation time and irradiance of LCU. Therefore, the first null hypothesis was rejected.

Polymerization shrinkage is an inherent problem associated with light-cure resin composites, which depends on the filler concentration, light curing protocols, volume of increments and cavity size.[26] Resin composites contain an inorganic phase, composed by filler particles the main component that determine the mechanical properties of the material, and an organic phase that is responsible for network formation and consequently the polymerization shrinkage.[27] Although SonicFill 2 has a methacrylate-based matrix, which can have up to 12.5% volumetric shrinkage,[28] this material had the lowest Shr values because a greater amount of filler was used in its composition.

To ensure proper polymerization of restorative materials, sufficient radiant energy emitted by LCU associated with the material characteristics is required.[19] An inadequate polymerization of resin composites can cause decreasing in their mechanical properties.[19] and less volumetric shrinkage of the material.[29] Low irradiance associated with a shorter light curing time resulted in lower Shr values because there is a decrease in degree of conversion, increasing the number of residual monomers. Although resin composites with low Shr values provide lower stresses on interface with dental substrate, reducing the appearance of clinical signs such as marginal clefts, postoperative sensitivity, the degree of conversion is directly related to mechanical properties of the material; therefore, a lower degree of conversion leads to insufficient mechanical properties.

The DC represents the conversion of monomers to polymers during the polymerization reaction of resin composites. Unsatisfactory polymerized resin composite restorations have low degrees of conversion, and consequently, a large number of residual monomers, which are soluble substances that can affect the pulp and periodontal tissue health.[30]

Since the initiation of polymerization reaction occurs from the activation of photoinitiators by photons, it depends on the power density and emission spectrum that arrives in material.[31] As light goes through the material, there is a reduction in the number of photons that reach photoinitiators due to absorption and scattering, mainly caused by inorganic particles, which compromises the polymerization depth.[32] This study showed significantly high DC values in the top when compared to DC values in the bottom for all resin composites activated using all tested conditions. Increasing the amount of filler in material composition is a method that has been used to reduce the polymerization shrinkage, but the material become more rigid.[33] Resin composites with higher elastic modulus are less able to deform during polymerization due to difficulty of rearranging the molecules, which reduces the possibility of stress relief.[34] The elastic modulus similar to dentin is essential to obtain an adequate resistance of the tooth/restoration complex.[34] Thus, an elastic modulus value between 12 and 20 MPa is critical for the longevity of restorations in oral cavity.[35] A restorative material with a low elastic modulus, especially when placed in areas subjected to high loads, can suffer significant deformation and consequently lead to major failures.[36] In this study, flowable resin composites showed significantly lower E values than high bulk fill composites. Therefore, flowable resin composites should not be used to restore posterior cavities without an additional layer of bulk fill resin composites with high viscosity to ensure greater wear resistance to restoration.

There is a direct correlation between hardness measurement and the degree of conversion of resin composites.[37] Lower hardness and degree of conversion at the bottom surface of the samples were observed, which is caused by light attenuation and lower energy received by resin composites. This effect is accentuated when was used lower irradiance and lower light activation time. It occurs because light does not adequately reach deeper depths, and polymerization is impaired, resulting in lower mechanical properties. Larger number of residual monomers can be present in the depth areas close to pulp tissues resulting consequently in lower biocompatibility.[14]

The success of a resin composite restoration may be directly associated with mechanical properties such as hardness and elastic modulus.[38] Hardness is linked to the restoration ability to resist chewing forces, while elastic modulus reflects on generation of shrinkage stresses that are dissipated through the tooth/restoration complex.[26] The results of this study confirm that bulk fill resin composites with high consistency have higher elastic modulus and greater hardness, and bulk fill resin composites with flowable consistency have lower elastic modulus and hardness. Therefore, flowable resin composites are more fragile when exposed to the oral environment, and only high viscosity resin composites can be used to replace at the same time dentin and enamel concurrently.[8]

The Shr, DC, E and KNH values obtained in this study show that light activation time and irradiance level are factors that influence the mechanical properties of bulk fill resin composites tested. Considering an irradiance of 1200 mW/cm^2, it is possible to observe that in general, no significant changes in the mechanical properties of these materials at different times of light activation. However, significant lower mechanical properties of the bulk fill resin composites were observed when they light activation with 400 mW/cm^2 was used, regardless of the light activation time. These results confirm that the adequate irradiance level is essential for the proper polymerization of the bulk fill resin composite. Light activation protocols that delivered to top and also to the entire cavity depth, expressed by use of high power LCU associated with careful follow of bulk fill resin composite clinical guideline, are fundamental for doing satisfactory bulk fill restorations.

The polymerization reaction is self-limiting; as the material polymerizes, there is a reduction in the mobility of remaining monomers and forming polymer chains. The consequence of this is that, considering a high irradiance level, an increase in light activation time is not effective to increase the degree of conversion due to polymerization saturation, limiting the optimization of mechanical properties.[39] Longer light activation time can lead to better material polymerization if it has not reached its maximum degree of conversion, so the light activation time becomes a less significant factor in the polymerization process when the clinical advocates the use of LCU that can be provide a sufficient amount of energy.

The second null hypothesis was accepted; the results confirmed that radiopacity was not affected by the light activation time and irradiance of LCU. Radiopacity is an important property for restorative material, enabling detection of marginal integrity and secondary caries.[22] Several factors can affect the radiodensity of posterior tooth restorations, such as material properties and x-ray intensity and direction.[38,40] However, in this study, the results showed that the radiopacity of the materials is not influenced by irradiance or light activation time. The present study confirmed that all bulk fill resin composites have adequate radiopacity for posterior restorations, similar to 3-5 mm of aluminum step-wedge. International organizations recommend procedures for quantifying the radiopacity of resin composite using an aluminum step as a reference.[41] Although resin composites tested in this study show differences in radiopacity, they all reach the expected and desired minimum limit of radiopacity for resin composites used in posterior tooth, which is 1 mm of aluminum step-wedge.[42]

The results of this study also showed that there is a significant difference in radiopacity level among materials tested. The degree of radiopacity of resin composites depends on the amount, type and size of particles, filler volume and polymer thickness and density,[40] but a factor that can most affect radiopacity is an inorganic phase of the material,[40,43] Tetric N-Ceram groups presented higher radiodensity values than others high viscosity resin composites groups, as well as SDR groups, which radiodensity values were significantly higher than others flowable resin composites groups. This finding can be explained by the type of fillers used in both materials, which have barium glass in composition, a highly radiopaque glass.[44] Opus APS showed lower radiodensity values than others high viscosity resin composites groups, as well as Opus Flow APS, which radiodensity values were significantly lower than others flowable resin composites groups. This result can be explained by the reduced capacity of silicon dioxide to absorb x-ray.[45] Additionally, the results of the present study showed that flowable resin composites had lower radiopacity values because the radiopacity level increases with the amount of filler present on material composition and flowable resin composites tend to have a smaller amount of filler to ensure their low viscosity.

It is essential the clinical understands the effects of irradiance level and light activation time on the polymerization process of resin composites and consequently on their mechanical properties. Evaluating the mechanical properties of resin composites is an important tool for estimating the performance of materials subjected to large chewing efforts, such as bulk fill resin composites, which are used in posterior tooth. Thus, light activation protocols that consider high irradiance level (1200mW/cm^2) and light activation time (20 or 40s) provide efficient restoration, so should be prioritized.

CONCLUSION

The polymerization of bulk fill resin composites was influenced by light activation time and irradiance level. In general, high irradiance level (1200 mW/cm^2) associated with a longer light activation time (20 or 40s) result in greater mechanical properties, including degree of conversion, hardness and elastic modulus. However, in consequence result also in higher post-gel shrinkage. The radiopacity depends on composition of bulk fill resin composites was not influenced by light activation time and irradiance level. All resin composites tested presented adequate radiopacity required for posterior restorations. Flowable bulk fill resin composites presented lower mechanical properties, lower post-gel shrinkage and lower radiopacity than high viscosity bulk fill resin composites.

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Conflict of Interest

The authors of this manuscript certify that they have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in this article.

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Table 1. Resin composites composition.

Material	**Shade**	**Increment size and light activation time**	**Organic Matrix**	**Filler**	**Filler % (wt)**	**Manufacturer**
Tetric N-Ceram Bulk Fill	IVA	4.0 mm – 10 s	Dimetacrylates	Barium glass, prepolymer, ytterbium trifluoride, mixed oxides	75-77	Ivoclar Vivadent, Schaan, Liechtenstein, Germany
Filtek One Bulk Fill	A3	4.0 mm 20 s - >1000 mW/cm^2 40 s - <1000 mW/cm^2	AUDMA, diurethane-DMA, 1,12-dodecane-DMA	Silica, zirconia, ytterbium trifluoride	76.5	3M-ESPE, St. Paul, MN, USA
Opus Bulk Fill APS	A3	5.0 mm – 40s	Urethanedimethacrylate	Silicon dioxide	79	FGM, Joinville, SC, Brasil
Admira Fusion x-tra	Universal	4.0 mm – 20s	ORMOCER®	Silicon dioxide	84	VOCO, Cuxhaven, Germany
Sonic*Fill 2*	A3	5.0 mm 10 s - >1000 mW/cm^2 20 s - <1000 mW/cm^2	Bis-GMA, TEGDMA, EBPADMA	Silicon dioxide, oxides, glass	83.5	Kerr Corporation, Orange, CA, USA
Tetric N-Flow Bulk Fill	IVA	4.0 mm – 10 s	Monomethacrylates, dimethacrylates	Barium glass, ytterbium trifluoride, copolymers	68.2	Ivoclar Vivadent, Schaan, Liechtenstein, Germany.
Filtek Bulk Fill Flow	A3	4.0 mm – 20 s	Bis-GMA, UDMA, Bis-EMA, Procrylat	Silica, zirconia, ytterbium trifluoride	64.5	3M-ESPE, St. Paul, MN, USA.

Opus Bulk Fill Flow APS	A3	5.0 mm – 40 s	Urethanedimethacrylate	Silicon dioxide	68	FGM. Joinville, SC, Brasil.
Admira Fusion x-base	Universal	4.0 mm – 20 s	ORMOCER®	Silicon dioxide	72	VOCO, Cuxhaven, Germany
SureFil SDR Flow	Universal	4.0 mm – 20 s	Modifed UDMA, Dimethacrylate and difunctional diluents	Barium and strontium alumino-fluoro-silicate glasses	68	Dentsply, Konstanz, BW, Germany.

Abbreviations: Bis-GMA: bisphenol-A glycol dimethacrylate; Bis-EMA: bisphenol-A hexaethoxylated dimethacrylate; TEGDMA, triethylene glycol dimethacrylate; UDMA, urethane dimethacrylate; EBPADMA, ethoxylated bisphenol A dimethacrylate; AUDMA, aromatic dimethacrylate; DMA, dimethacrylate

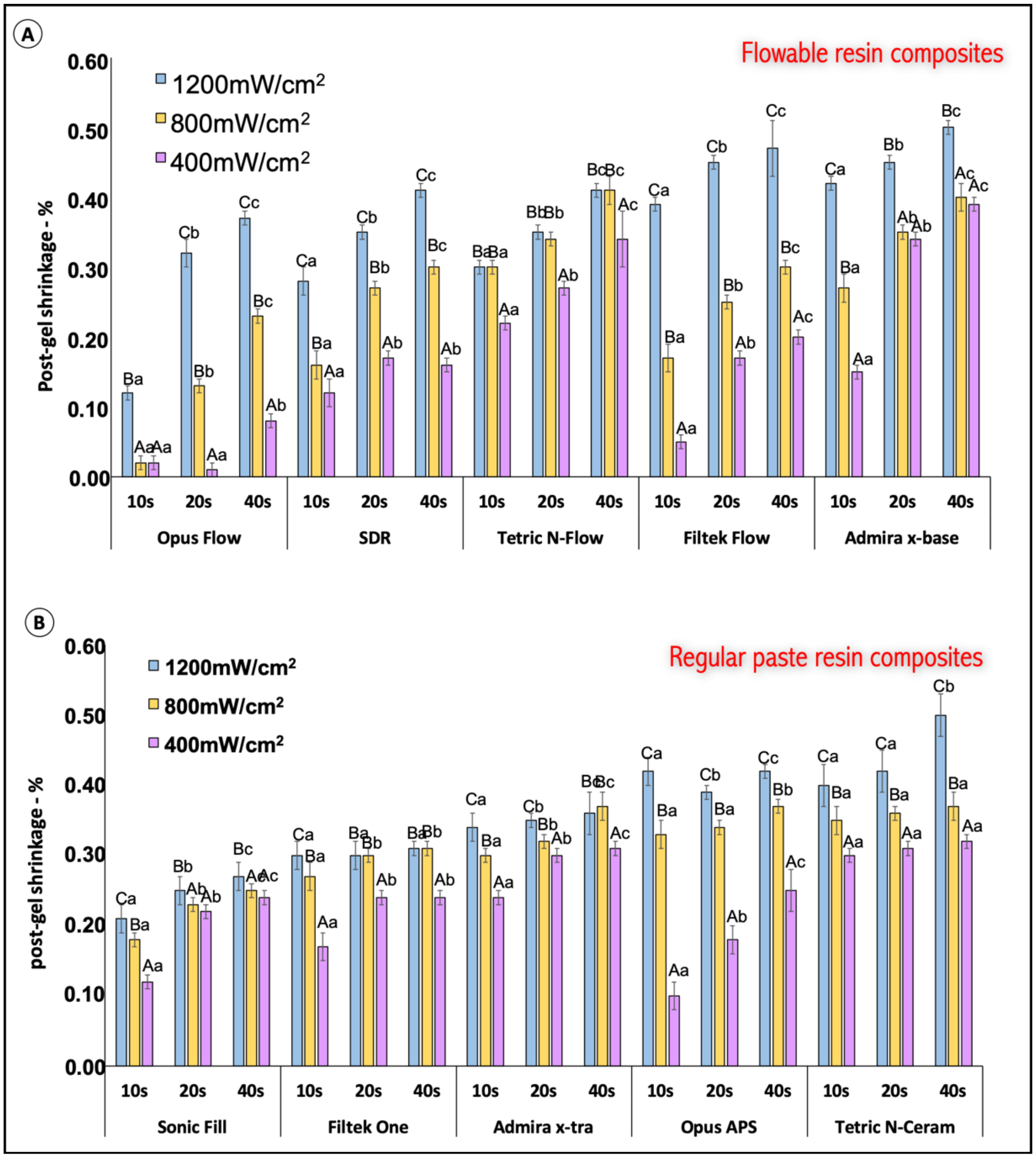

Figure 1. A. Means and standard deviation of post-gel shrinkage of flowable resin composites. **B.** Means and standard deviation of post-gel shrinkage of high viscosity resin composites. Different letters indicate significant difference – upper case used for comparing irradiance level and lowercase letters used for comparing light curing time, $P < 0.001$.

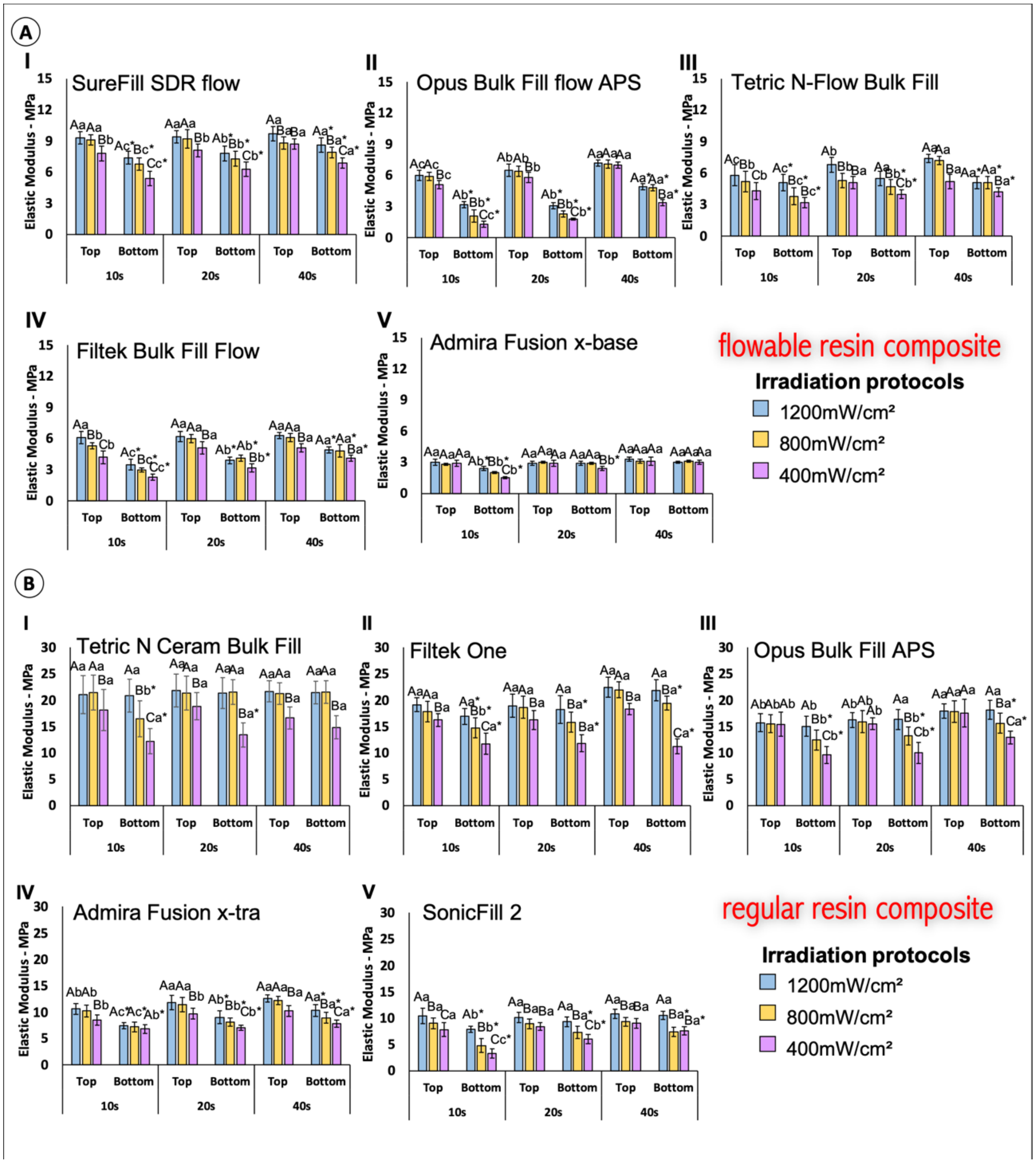

Figure 2. A. Means and standard deviation of elastic modulus of flowable resin composites. **B.** Means and standard deviation of elastic modulus of high viscosity resin composites. Different letters indicate significant difference – upper case used for comparing irradiance level and lowercase letters used for comparing light curing time. * means interaction between the three study factors, $P < 0.001$.

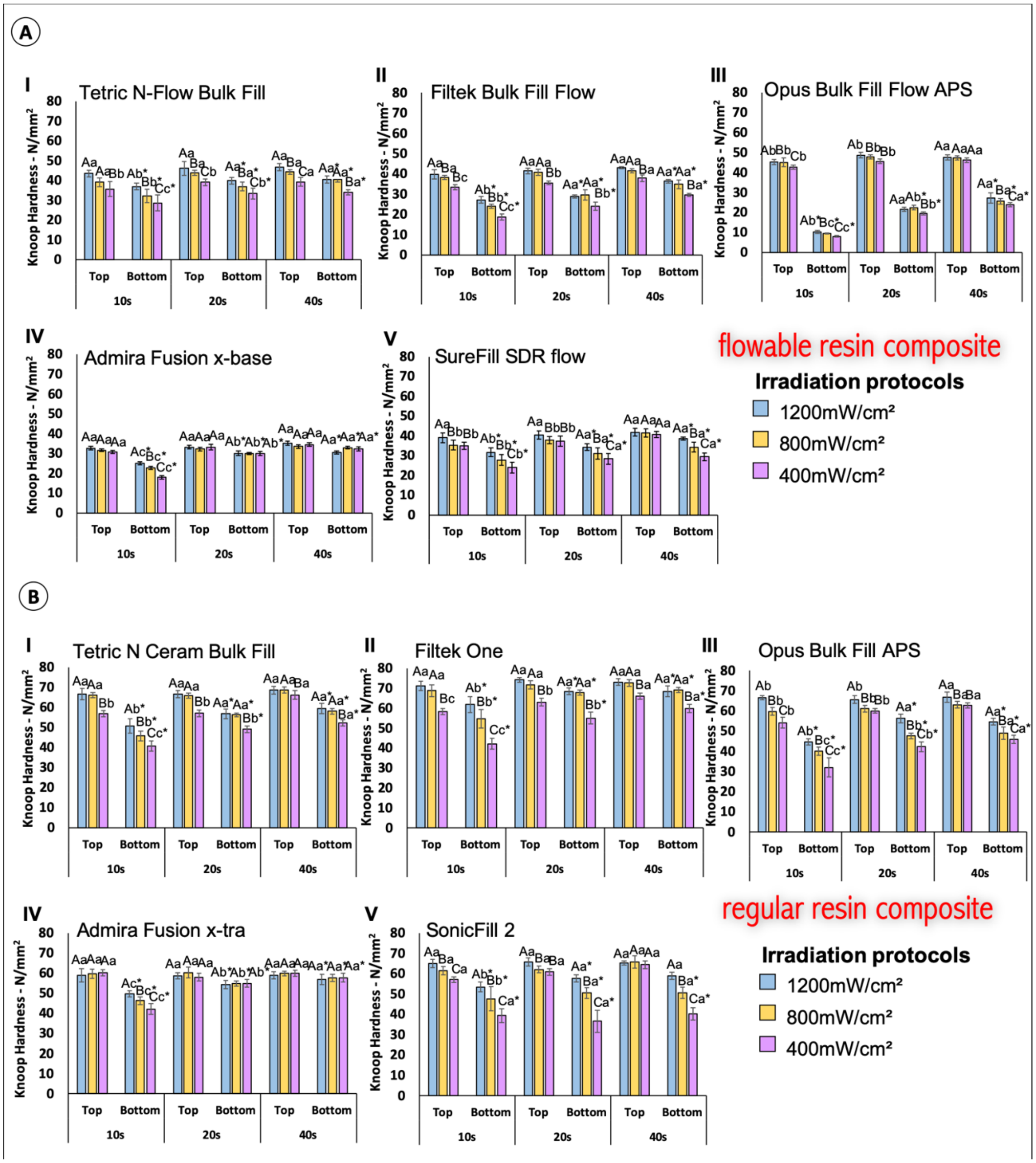

Figure 3. A. Means and standard deviation of Knoop hardness of flowable resin composites. **B.** Means and standard deviation of Knoop hardness of high viscosity resin composites. Different letters indicate significant difference – upper case used for comparing irradiance level and lowercase letters used for comparing light curing time (*P* <0.001). * means interaction between the three study factors, *P* <0.001.

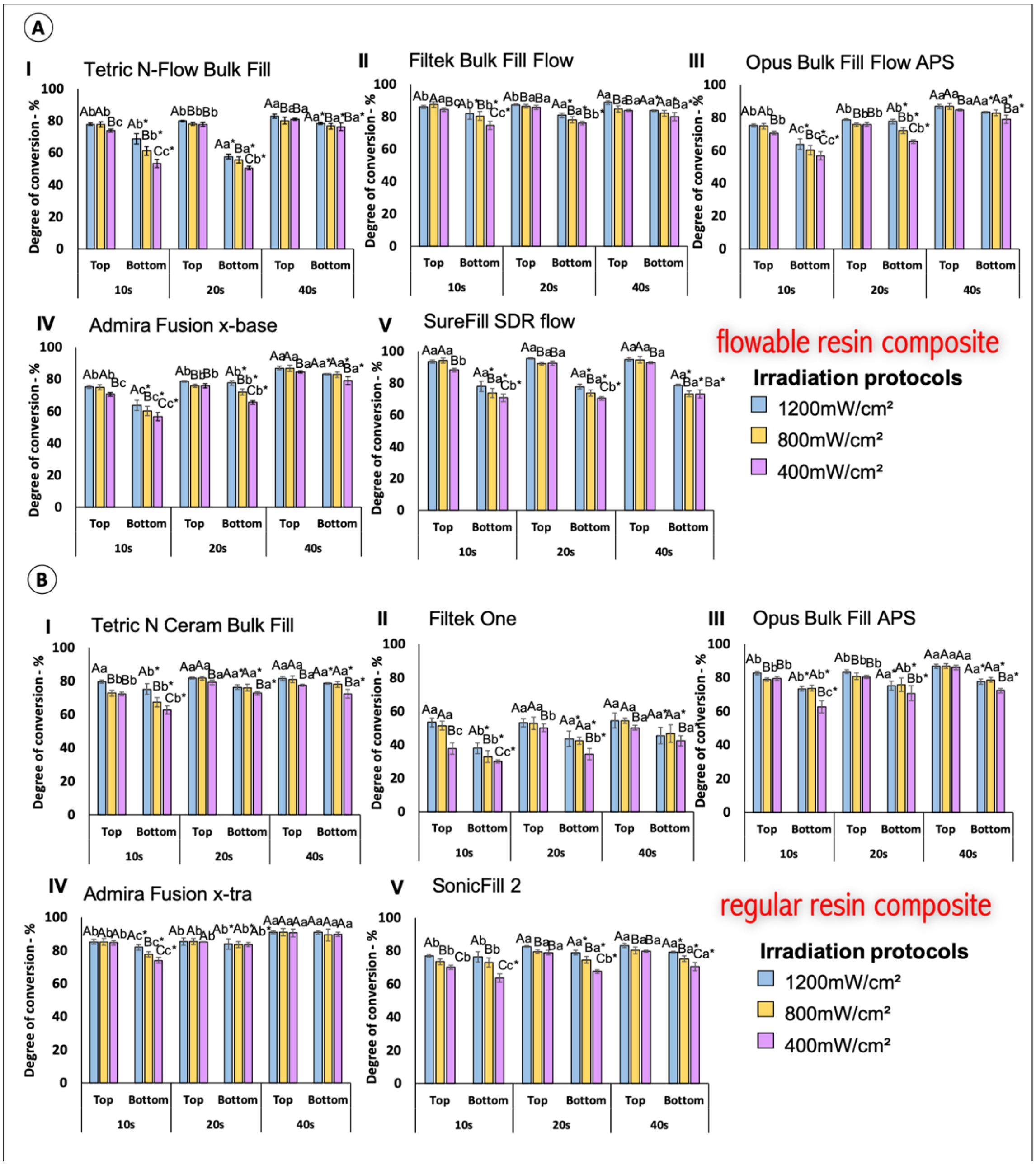

Figure 4. A. Means and standard deviation of degree of conversion of flowable resin composites. **B.** Means and standard deviation of degree of conversion of high viscosity resin composites. Different letters indicate significant difference – upper case used for comparing irradiance level and lowercase letters used for comparing light curing time (P <0.001). * means interaction between the three study factors, P <0.001.

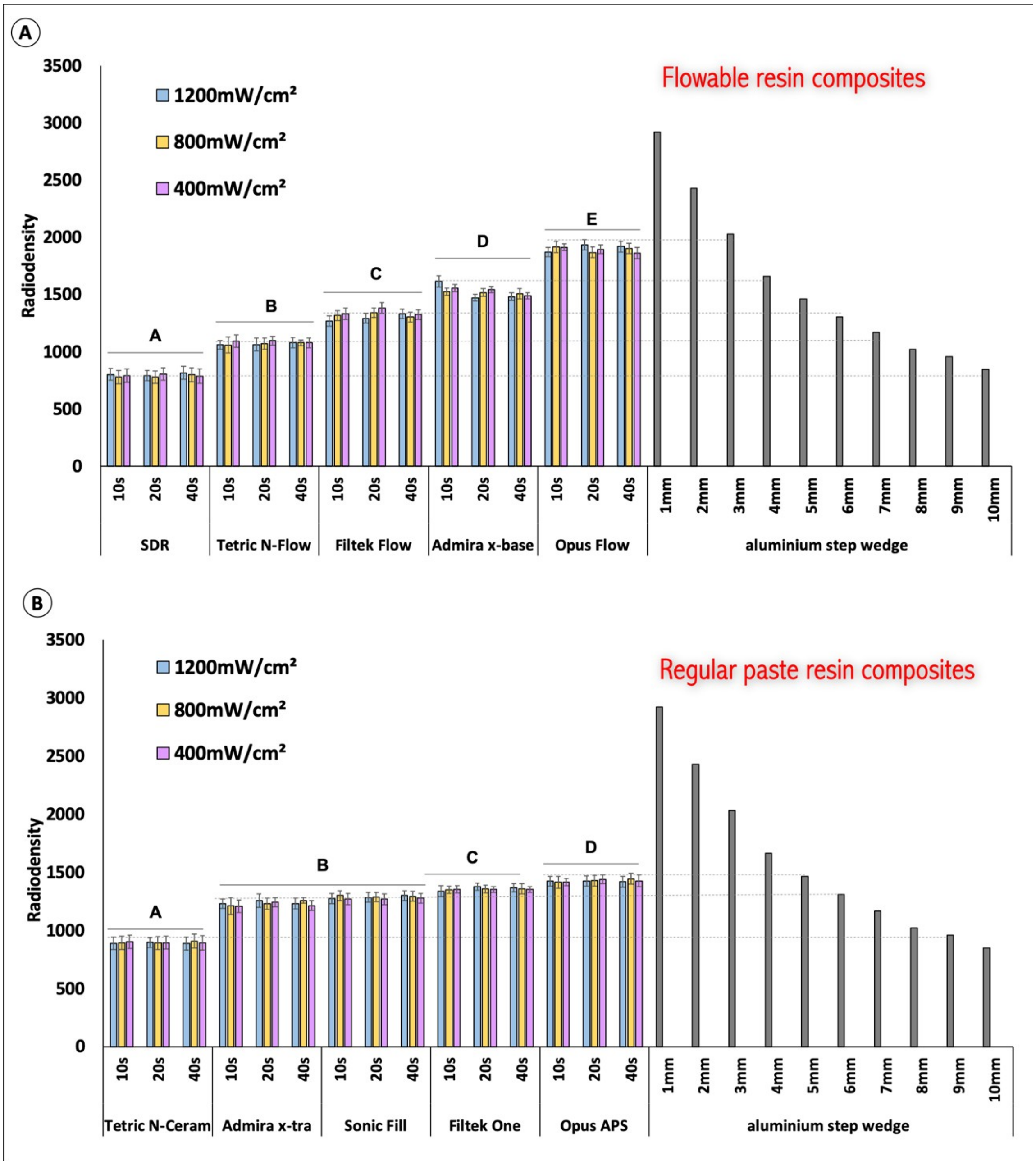

Figure 5. A. Means and standard deviation of radiopacity of flowable resin composites. **B.** Means and standard deviation of radiopacity of high viscosity resin composites. Different letters indicate significant difference between the resin composites, *P* <0.001.

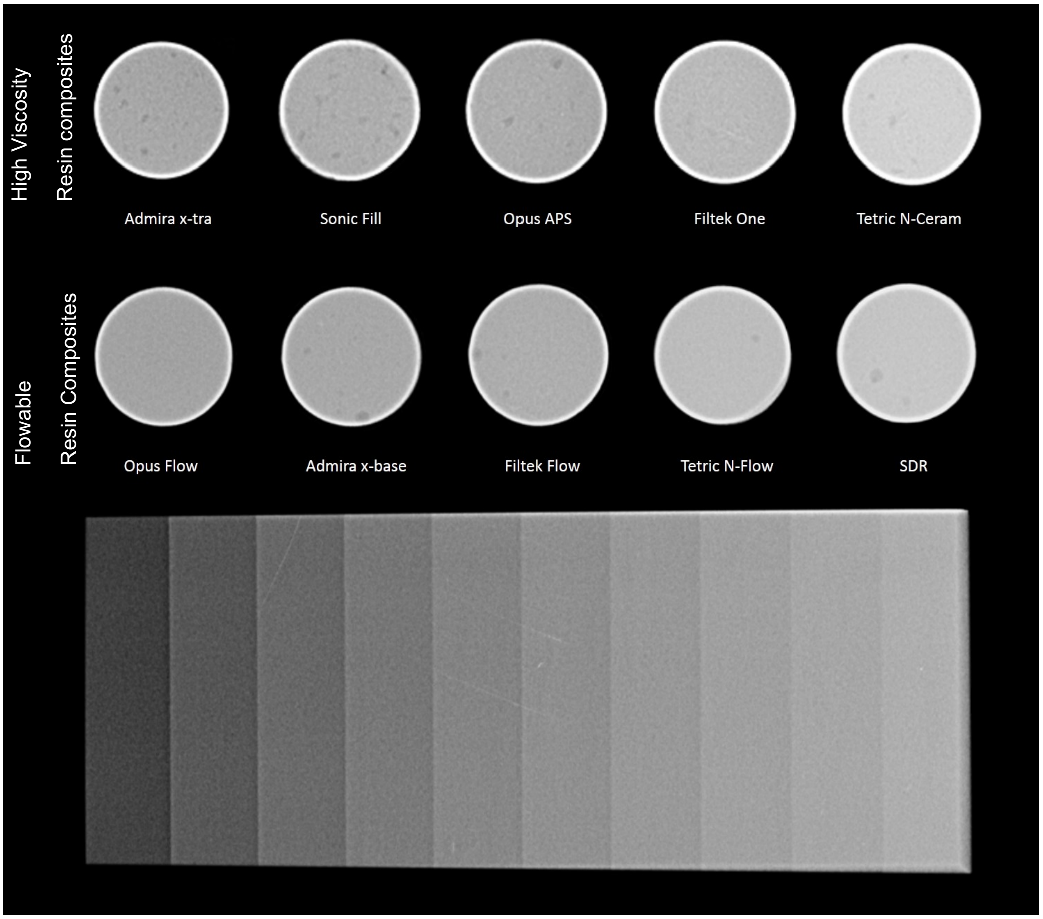

Figure 6. Radiography of bulk fill resin composites and aluminum step-wedge. All materials were light activated with 1200 mW/cm^2 for 40s.

3. CAPÍTULO 2

ARTIGO 2

Light activation time and irradiance on flowable and high viscosity bulk fill resin composites - Part 2: effect on the shrinkage stress and residual occlusal stress

***Artigo a ser enviado para o periódico Operative Dentistry**

Light activation time and irradiance on flowable and high viscosity bulk fill resin composites - Part 2: effect on the shrinkage stress and residual occlusal stress

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Running title: Light activation time and irradiance on shrinkage stress

Keywords: bulk fill resin composite, irradiance, shrinkage stress, residual stress, finite element analyses

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Light activation time and irradiance on flowable and high viscosity bulk-fill resin composites - Part 2: effect on the shrinkage stress and residual occlusal stress

ABSTRACT

Objectives. Evaluate the effect of different light activation time and irradiance levels on shrinkage stresses and residual occlusal stress in molars restored with different bulk fill resin composites using finite element analysis (FEA).

Methods. Molar tooth restored with five flowable/high viscosity bulk fill resin composites (Tetric N-Flow Bulk Fill/ Tetric N-Ceram Bulk Fill; Filtek Bulk Fill Flow/ Filtek One Bulk Fill, Opus Bulk Fill Flow APS/ Opus Bulk Fill APS, Admira Fusion x-base/Admira Fusion x-tra, SureFil SDR Flow/SonicFill 2) and with only high viscosity bulk fill resin composites (Tetric N-Ceram Bulk Fill, Filtek One Bulk Fill, Opus Bulk Fill APS, Admira Fusion x-tra, SonicFill 2) were simulated in a two-dimensional FEA. Post-gel shrinkage and elastic modulus for different light activation time and irradiance levels were measured in study - Part 1. Compressive strength and diametral tensile strength were measured by laboratory tests. Shrinkage stress and residual occlusal stress were expressed in modified von Mises.

Results. Admira x-base/Admira x-tra and SonicFill 2 showed the lowest and Tetric N-Flow/Tetric-Ceram and Tetric N-Ceram the highest stress concentration regardless the moment of analysis (shrinkage or 100N occlusal loading moments). Molar tooth restored with different flowable/high viscosity bulk fill resin composites result in lower shrinkage and residual stresses when compared with molar tooth restored with only high viscosity bulk fill resin composites. The irradiation level influenced in more intensity the shrinkage stress than the light curing time. The irradiance of 400mW/cm^2 resulted in significantly lower shrinkage stress than 800 and 1200 mW/cm^2.

Conclusion. Lower shrinkage and residual stresses were observed on molar tooth restored with different flowable/high viscosity bulk fill resin composites. Irradiance level influences the generation of shrinkage and residual stresses on molar teeth restored with different bulk fill resin composites more significantly than light activation time.

Clinical Significance. *High irradiance (1200mW/cm^2), regardless of light activation time, results in higher shrinkage and residual stresses on molar teeth restored with different bulk fill resin composites.*

INTRODUCTION

Bulk fill resin composites have been developed to reduce time, and also to decrease polymerization shrinkage and its clinical effects,[1-3] such as microcracks and fractures in tooth structure, marginal staining, microleakage and secondary caries.[4-6] Shrinkage polymerization is an inherent feature of polymeric materials, that reflects negatively on the tooth/restoration interface and also on the weakened tooth structure mainly in posterior teeth.[7] Polymerization stress causes residual stresses that could modify the behavior of restored teeth, even if they are not in chewing function.[8]

Shrinkage stresses depend on several factors, including the intensity and light activation time used during resin composite polymerization.[9,10] The energy that arrives at sample surface associated with light activation time also influence the polymerization quality of bulk fill resin composites.[11] Improperly polymerized restorative material determines inferior mechanical properties, increasing the chance of material fracture.[12,13] Evaluating mechanical properties of restorative materials is important to better understand biomechanical behavior during occlusal loading. When the tooth is subjected to a compressive occlusal load, tensile stresses are also generated in the tooth structure, however the tooth is better able to resist compressive stresses than tensile stresses.[9] Resin composites also keep this behavior during an occlusal loading.[14] However, when the resin composite is not adequately polymerized the restored posterior teeth will not support properly the stress/strain caused by physiologic loading.

The elastic modulus is a physical property linked to hardness of the material, which is associated with the development of stress.[15,16] Materials with high elastic modulus tend to generate higher polymerization shrinkage and consequently causing higher stresses in adjacent structures.[17] However, if the elastic modulus is low, the material cannot recover the structural integrity of the tooth to apply as chewing loads.[17] High viscosity bulk fill resin composites tend to have higher elastic modulus and hardness than flowable resin composites.[14,15] These mechanical properties difference determines more fragility for flowable material when exposed to the oral environment.[18] Then, they need 2 mm covering with conventional or high viscosity bulk fill resin composites,[19] which have greater wear resistance.[14] The adequate balance between properly polymerization which generate expected mechanical properties which lower shrinkage stress as possible is the best strategies for restoring posterior teeth.[7,15,20]

A previous study referred to as Part I evaluated the effect of light activation time and irradiance on post-gel shrinkage, degree of conversion, Knoop hardness and elastic modulus of flowable and high viscosity bulk fill resin composites. It was found that bulk fill resin composites have better mechanical properties when light activated with longer time (20s or 40s) and with higher irradiance (1200 mW/cm^2). However, the influence of these factors on the shrinkage stress inside the restorative material, into the tooth structures and along the tooth/restoration interface could not be determined by laboratory tests. Therefore, the aim of this study was to evaluate the effect of the elastic modulus and polymerization shrinkage calculated experimentally when used different light activation time and irradiance levels of flowable covered by high viscosity or restored by only high viscosity bulk fill resin composites on shrinkage stresses and residual stresses during occlusal generated by physiologic load by using finite element analysis (FEA). The null hypotheses were: 1) molar tooth restored with different flowable/high viscosity bulk fill or restored with high viscosity bulk fill resin composites would result in similar shrinkage and residual stresses; 2) different elastic modulus and polymerization shrinkage values obtained using low and high activation time and low and high irradiation would not influence the shrinkage and residual stresses on molar teeth restored with different bulk fill resin composites.

METHODS AND MATERIAL

Study design

Ten restorative protocols were tested in this study generated by using 5 flowable associated with 5 high viscosity bulk fill resin composites (Tetric N-Flow Bulk Fill/ Tetric N-Ceram Bulk Fill, Ivoclar Vivadent AG; Filtek Bulk Fill Flow/ Filtek One Bulk Fill, 3M-ESPE; Opus Bulk Fill Flow APS/ Opus Bulk Fill APS, FGM; Admira Fusion x-base/Admira Fusion x-tra, VOCO; SureFil SDR Flow, Dentsply/ SonicFill 2, Kerr) and restored only with 5 high viscosity bulk fill resin composites (Tetric N-Ceram Bulk Fill, Ivoclar Vivadent; Filtek One Bulk Fill, 3M-ESPE; Opus Bulk Fill APS, FGM; Admira Fusion x-tra, VOCO; SonicFill 2, Kerr). Considering a high irradiance level (1200mW/cm^2), and according to the manufacturer directions, Tetric N-Ceram and Tetric N-Flow were light cured in increments up to 4 mm thick for 10s; Filtek One and Filtek Flow were light-cured in increments up to 4 mm thick for 20s; Opus APS and Opus Flow APS were light-cured in increments up to 5 mm thick for 40s; Admira Fusion x-tra and Admira Fusion x-base were light-cured in increments up to 4 mm thick for 20s; SonicFill 2 was polymerized in increments up to 5 mm thick for 10s; and SureFil SDR was light-cured in increments up to 4 mm thick for 20s. Additionally, to evaluate the effect of the light activation time and irradiance level, was simulated the post-gel shrinkage and elastic modulus values obtained in study - Part 1, when was used 3 light activation time (10s, 20s and 40s) with the higher irradiance level (1200mW/cm^2) and 3 irradiance levels (400mW/cm^2, 800mW/cm^2, and 1200mW/cm^2) with the higher light activation time (40s) for the shrinkage stress analyses. All resin composites were tested for compressive strength and diametral tensile strength, which were used to determine the modified von Mises stresses by using a 2D finite element analysis.

Compressive and diametral tensile strength

Compressive and diametral tensile strength of each resin composite were obtained experimentally (n=10). The resin composite was placed into a cylindrical metallic mold for the compressive strength test (6mm height x 3mm diameter) and into another mold for the diametral tensile strength test (4mm height x 2mm diameter). The samples for the compressive test were light activated with 4 or 5mm for the first increment and 2 or 1mm for the second increment, according to manufacturer's instructions. The LCU used was VALO Cordless (Ultradent, South Jordan, UT, USA), following recommended curing times. The samples were stored for 24h at 37 ºC in dark box. The samples were tested in an universal testing machine (DL2000, EMiC, São José dos Pinhais, PR, Brazil) at a crosshead speed of 0.5mm/min until failure. Compressive strength values (N/mm^2) were calculated by dividing the fracture load (F) by the cross-sectional area (πr^2), using $CS = F/\pi r^2$, and converted into MPa. Diametral tensile strength values (N/mm^2) were calculated using the equation $DTS = 2F/\pi dh$, where *d* is the sample diameter, and *h* is the height of the sample. DTS values were converted into MPa.

Finite elements stress analysis

A two-dimensional (2D) finite element analysis was carried out of an occlusal cavity with the cavity floor in dentin of a maxillary human first molar in occlusal conditions with antagonist contact (Figure 1A). The models were created by using a sagittal cross-sectional tomography image as a template. This image was imported to ImageJ software (National Institutes of Health) and the coordinates were drawn by using multi-point tool, the scale was set according to real measure of first molar of tomography image and imported to FEA software (MSC.Marc/Mentat; MSC Software Corporation). Thirty models were generated simulating cavity with 4mm in depth restored with a single increment of each high viscosity bulk fill resin composite (Figure 1B). Other 30 models were generated simulating cavity with 6mm in depth restored with 4mm of each flowable bulk fill resin composites and covered with 2mm of high viscosity bulk fill resin composites (Figure 1C).

The mesh using four-node isoparametric quadrilateral elements was created manually. The number of elements on the entire mesh of flowable/high viscosity bulk fill finite element models was 74620 and 74635 elements for models restored only with high viscosity bulk fill resin composites. Plane strain condition was assumed for tooth and plane stress elements for the resin composites.[17,21] Using MARC subroutines, polymerization shrinkage was simulated by thermal analogy reducing temperature by 1°C. The linear post-gel shrinkage and the elastic modulus values obtained with resin composites light-activated for 10s, 20s and 40s with irradiance of 1200 mW/cm^2 and with irradiance 400, 800 and 1200 mW/cm^2 for 40s, obtained in the experiments of part 1 study were applied as the coefficient of linear thermal expansion (Table 1-5).[17,21] A total of 60 finite element models were created.

After polymerization shrinkage simulation, the models were submitted to an occlusal contact of 100 N of the mandibular molar with the maxillary molar, then a sliding movement was simulated by using contact between lower and upper occlusal surfaces. Displacement was limited at the nodes of the base of the maxillary and mandibular molars in X and Y directions. The contact condition was applied between enamel, resin composite structures of maxillary molar touching the enamel of mandibular molar. All structure interfaces were defined as glued contacts. The models were performed with 50 increments of load steps. Since the materials have higher strength in compression than in tension, a failure criterion that considers strength differential effect (SDE) ≠

1 should be used.[22] The modified von Mises (mvm) criterion considering the difference between compressive and tensile strength was used as parameter for stress comparison. The SDE was obtained by the division of CS by DTS values. The SDE data are presented on Table 1. The compressive and tensile strengths of enamel were 384.0 and 10.3 MPa and for dentin 297.0 and 98.7 MPa.[23]

The occlusal contact of 100N of the mandibular molar with the maxillary molar, followed by a sliding movement, was simulated by using friction contact between the lower and upper occlusal surfaces (Frictional Coefficient – 0.5). The mvm stress distributions were visualized using a linear color scale in which blue indicates the lowest stress values, and yellow and light gray the highest values (MPa) representing shrinkage stress (light-curing moment) and residual occlusal loading stress (100N occlusal load). The mvm stress values were recorded in the integration points of each element and in isolated nodes along material interfaces. The mean values of the 10% highest stresses were determined for the enamel, dentin, and resin composite structures.

RESULTS

Modified von Mises stress distribution at shrinkage and occlusal contact final movement on finite element models restored flowable/high viscosity bulk fill resin composites and with only high viscosity bulk fill resin composites when light-cured following the recommended time by manufacture using 1200 mW/cm^2 are shown in Figure 2. Regarding the flowable/high viscosity bulk fill resin composites technique, Admira x-base/Admira x-tra showed the lowest and Tetric N-Flow/Tetric-Ceram the highest stress concentration regardless the moment of analysis (shrinkage stress or residual stress of 100N occlusal load). Regarding the high viscosity resin composites technique, Tetric N-Ceram showed the highest and SonicFill 2 the lowest stress concentration regardless the moment of analysis (shrinkage stress or residual stress of 100N occlusal load). The residual stress generated with 100N occlusal load had similar values of shrinkage stress at the restoration material and at the interface. However, the residual occlusal stress concentrated at enamel structure and at the pulp chamber ceiling were clearly higher than shrinkage stress only, irrespective of bulk fill resin composite type.

The mean values of the 10% highest mvm shrinkage stresses concentrated in the enamel and dentin at shrinkage and occlusal contact final movement on finite element models restored flowable/high viscosity bulk fill resin composites and with only high viscosity bulk fill resin composites when light-cured following the recommended time by manufacture using 1200mW/cm^2 are shown in Figure 3. The occlusal contact generated high stress concentration at the enamel/resin composite occlusal interface, the stress level ranking of resin composites followed the same sequence of the intensities verified for shrinkage stress, irrespective of bulk fill resin composite type. The mean values of the 10% highest bulk stresses concentrated in the enamel was always higher than concentrated in dentin structure, irrespective of resin composite and moment of evaluation. Comparing the moment of analysis, the peak values were slightly lower during restorative procedure (shrinkage stress) than during occlusal contact load (residual occlusal contact stress) in the enamel and dentin. All flowable/high viscosity resin composites demonstrated similar stress concentration in dentin, however regarding the moment of evaluation the stress concentration was higher during occlusal loading than during restorative procedure. No difference was observed in the stress concentration in dentin for high viscosity resin composite, irrespective of the moment of analysis. Regarding the enamel structure, the resin composite type influenced clearly the stress concentration, irrespective of moment of evaluation. Regarding flowable/high viscosity bulk fill resin composite techniques, Tetric N-Flow/Tetric N-Ceram showed the highest and SDR/SonicFill 2 the lowest stress concentration. Regarding high viscosity bulk fill resin composite technique, Tetric N-Ceram showed the highest and SonicFill 2 the lowest stress concentration (Figure 3).

The mean values of the 10% highest mvm concentration along the interface at shrinkage on finite element models restored flowable/high viscosity bulk fill resin composites and with only high viscosity bulk fill resin composites when light cured following the recommended time by manufacture using 1200mW/cm^2 are shown in Figure 4. The stress concentration along the interface was higher at enamel than at dentin, with the highest peak verified at the occlusal margin of the restoration. The differences between the resin composites when using flowable/high viscosity bulk fill resin were clearly evidenced at the enamel/restoration margins. Tetric N-Flow/Tetric N-Ceram showed the highest and SDR/SonicFill 2 the lowest stress concentration at the interface. However, for high viscosity resin composites, differences were evidenced in the enamel and dentin interfaces. Tetric N-Ceram showed the highest and SonicFill 2 the lowest stress concentration along the interface.

Modified von Mises stress distribution and the 10% highest stresses concentrated in the enamel and dentin at shrinkage on finite element models when light cured using 1200mW/cm^2 with 10, 20 and 40s and using 40s with 400, 800 and 1200mW/cm^2 are shown in Figure 5 and 6 (models restored flowable/high viscosity bulk fill resin composites) and Figure 7 and 8 (models restored with high viscosity bulk fill resin composites), respectively. The irradiation level influenced in more intensity the shrinkage stress than the light curing time. For models restored with flowable/high viscosity bulk fill resin composite, higher irradiance used for 40s resulted in higher shrinkage stress for all resin composites, except for Admira x-base/Admira x-tra group. When using 1200mW/cm^2, increasing the light activation time also increased the shrinkage stress was verified with more intensity for Tetric N-Flow/Tetric N-Ceram and when compared 10s with 40s for Opus Flow APS/Opus APS and Surefill SDR/SonicFill 2 (Figure 5 and 6). The variation of light activation time and irradiance caused more increasing on shrinkage stress in enamel than in dentin (Figure 6). The increasing of light activation time and mainly the irradiance resulted in more shrinkage stress mainly for Tetric N-Ceram, Opus APS (Figure 7 and 8). The light activation time had lower influence on the shrinkage stress for Filtek One. In general, the increasing of irradiance level when used 40s the use of 400mW/cm^2 resulted in significant lower shrinkage stress than 800 and 1200mW/cm^2. The variation of light activation time and irradiance caused more increasing on shrinkage stress in enamel than in dentin (Figure 8).

DISCUSSION

The results of the present study confirmed that molar tooth restored with different flowable/high viscosity bulk fill or restored only with high viscosity bulk fill resin composites, light cured with 1200 mW/cm^2 for 10, 20 or 40s, or even when followed the manufacturer recommendation time, do not present similar shrinkage and residual stresses, therefore, the first null hypothesis was rejected.

Bulk fill resin composites are available in two presentations: high and flowable viscosity. Flowable resin composite provide better adaptation to restored cavity walls due to good flowability,[28] besides presenting lower post-gel shrinkage values, as can be seen in results of Part I. It means reduction on stress generation in the tooth/restoration complex during polymerization. Consequently, the occurrence of symptoms and clinical signs such as marginal clefts, propagation of enamel microcracks, postoperative sensitivity, infiltration and secondary caries are also dimished.[29] However, flowable bulk fill resin composites have lower mechanical properties according to the Knoop hardness and elastic modulus values obtained in part I, which makes it more fragile when exposed to the oral environment. Therefore, it is recommended to use a layer of high viscosity to cover these resin composites in posterior tooth restorations. High viscosity resin composites have higher resistance to wear,[14,30] as well as greater elastic modulus and greater hardness according to the results shown in part I; on the other hand, higher polymerization shrinkage values are also observed for these resin composites. Therefore, stress distribution at shrinkage and occlusal contact final movement was lower on finite element models restored with flowable/high viscosity bulk fill resin composites than with only high viscosity bulk fill resin composites.

The residual stress generated with 100N occlusal load had similar values of shrinkage stress generated during the restoration in the enamel, dentin or at the interface, irrespective of bulk fill resin composite type. Chewing loads can generate fatigue process that contributes to stress concentration in restorative complex and interfaces.[23] However, when a tooth is subjected to normal occlusal loading (100N), the stresses and deformations generated are dissipated by the material if the adhesive integrity between tooth and restoration is maintaned.[14] Different elastic modulus and polymerization shrinkage values obtained using low and high activation time and low and high irradiance influenced the shrinkage and residual stresses on molar teeth restored with different bulk fill resin composites. So, the second null hypothesis was rejected.

The elastic modulus and the volumetric shrinkage are important properties that influence the generation of stresses and strain in dental structured due to the polymerization shrinkage of the material or the functional occlusal loading.[31] A rigid material (high elastic modulus), as the enamel, has lower flowability capacity during polymerization, resulting in higher stress generation. However, the elastic modulus similar to dentin leads to a decrease in polymerization shrinkage transferred to dental structure.[20,32] Materials with low elastic modulus also allow greater strain under load, which results in adequate strength of the tooth/restoration complex.[33] As well as the present study, several studies also show a significant positive correlation between elastic modulus and stress. Higher elastic modulus values of the material cause higher shrinkage stresses.[34] In part I, Admira x-base, Admira x-tra and SonicFill 2 present low values of elastic modulus; Tetric N-

Ceram and Tetric N-Flow present high values of elastic modulus. Therefore, Admira x-base/Admira x-tra and SonicFill 2 presented the lowest stress concentration in both moments of analysis (shrinkage stress or residual strees of 100N occlusal load), while Tetric N-Ceram and Tetric N-Flow/Tetric-Ceram showed the highest values.

Higher irradiance values may lead to more stresses during the polymerization reaction.[35,36] The reaction happens faster and stresses relief is not possible as when using low irradiance. The present study shows that shrinkage stress distribution in finite element models restored with flowable/high viscosity and restored with only high viscosity bulk fill resin composites increased with irradiance level, considering the same light activation time. The present study also showed higher shrinkage stress distribution when was used flowable/high viscosity and restored with only high viscosity bulk fill resin composites with high irradiance level (1200mW/cm^2), regardless of light activation time. It is important to consider that irradiance level may influence the clinical performance of the material.

Characterizing mechanical properties of restorative materials is important to better understand biomechanical behavior during oral function. Associate data extracted from the post-gel shrinkage of resin composites and elastic modulus,[7,20] and combined with finite element models using these values can be a more comprehensive analysis for developing products, techniques and clinical protocols. FEA studies have allowed a considerable progression of our understanding about the development of stresses within materials, on interfaces with the dental structure and within enamel and remaining dentin,[37] since stresses are quantified indirectly.[38] Therefore, a validated finite element model can be used to predict mechanical failures or answer questions that is not possible to access with laboratory tests.[39] Part I and part II of this study illustrated that the clinical success of bulk fill restorations in posterior teeth depends on the balance between the mechanical properties of the materials. High elastic modulus ensures better wear resistance, while lower shrinkage values result in lower stresses. It is crucial that clinicians understand that different clinical light activation protocols influence the mechanical properties of materials, and consequently the biomechanical performance of restorations. High irradiance promotes proper restoration polymerization, resulting in good mechanical properties, but higher residual stresses are generated. So, the quality of the materials used and the light activation clinical protocols can interfere in the quality of the treatment.

Clinical failures in posterior teeth are much more related to poor mechanical properties than higher shrinkage stress.[4] The results of the part II of this study should be interpreted with caution and never considered isolated without considering the results demonstrated in part I. Is always expected that resin composites present lower shrinkage as possible, however this information should always be accompanied by higher mechanical properties as possible, which is mandatory for posterior resin composite restorations present long-term survival.

CONCLUSION

Molar tooth restored with different flowable/high viscosity bulk fill resin composites result in lower shrinkage and residual stresses when compared with molar tooth restored with only high viscosity bulk fill resin composites, regardless of light activation time and irradiance level. Additionally, irradiance level and light activation time influence the generation of shrinkage and residual stresses on molar teeth restored with different bulk fill resin composites, however irradiance level affects more significantly than light activation time, high irradiance results in higher shrinkage and residual stresses on molar teeth restored with different bulk fill resin composites, regardless of light activation time. The combination of adequate mechanical properties with low shrinkage is an important approach and is essential to justify the use of high irradiance (1200mW/cm^2) associated with at least 20s for resulting in good balance for posterior restorations.

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Conflict of Interest

The authors of this manuscript certify that they have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in this article.

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Table 1. Properties applied for dental structures and resin composites (light cured with $1200mW/cm^2$ using the light curing tome recommended by manufactured).

Materials/ Structures	Elastic Modulus (MPa)*	Poisson's Ratio	Compressive strength (MPa)	Tensile strength (MPa)	SDE*	Shr*
Enamel	84100 [24]	0.33 [24]	384.0 [23]	10.3 [23]	37.3	-
Dentin	18600 [24]	0.31 [24]	297.0 [23]	98.7 [23]	3.0	-
Pulp	2 [25]	0.45 [25]	2.9 [26]	2.9 [26]	1.0	-
Tetric N-Ceram	21600	0.24 [27]	273.5	48.4	5.7	0.42
Filtek One	18300	0.24 [27]	238.2	64.6	3.7	0.30
Opus APS	18100	0.24 [27]	216.8	46.1	4.7	0.42
Admira x-tra	10600	0.24 [27]	187.2	27.8	6.7	0.35
SonicFill2	9800	0.24 [27]	163.0	34.5	4.7	0.21
Tetric N-Flow	5800	0.35 [24]	212.6	45.4	4.7	0.30
Filtek Flow	5400	0.35 [24]	323.9	68.6	4.7	0.45
Opus Flow	6200	0.35 [24]	262.9	50.1	5.2	0.37
Admira x-base	2900	0.35 [24]	207.2	42.6	4.9	0.45
SDR	8400	0.35 [24]	223.2	49.7	4.5	0.35

* Resin composite values obtained from laboratorial tests of part I.

Table 2. Mechanical properties (E, Elastic Modulus - GPa; and Shr, Post-gel shrinkage - %) applied for dental resin composites light cured for 40s with the irradiance of 400, 800 and 1200mW/cm^2 when used flowable/ viscosity technique.

Resin Composite		Thickness	1200mW/cm²		800mW/cm²		400mW/cm²	
			E	Shr	E	Shr	E	Shr
Admira x-tra/ Admira x-base	Admira x-tra	0-2mm	12.6 - 11.7	0.37	12.2 - 10.9	0.36	10.2 - 9.2	0.31
	Admira x-base	0-4mm	3.3 - 2.9	0.50	3.1 - 3.1	0.40	3.1 - 3.0	0.39
Filtek Flow/ Filtek Flow	Filtek Flow	0-2mm	6.3 - 4.9	0.47	6.10 - 4.80	0.30	5.10 - 4.10	0.20
	Filtek One	0-4mm	22.4 - 22.2	0.31	21.9 - 20.5	0.31	18.3 - 15.5	0.31
SDR/ SonicFill 2	SDR	0-2mm	9.8 - 8.6	0.41	8.8 - 7.9	0.30	8.7 - 6.9	0.16
	SonicFill 2	0-4mm	10.8 - 10.7	0.27	9.3 - 8.5	0.25	9.0 - 8.7	0.24
Tetric N-Flow/ Tetric N-Ceram	Tetric N-Flow	0-2mm	7.4 - 5.1	0.37	7.2 - 5.1	0.41	7.0 - 3.4	0.34
	Tetric N-Ceram	0-4mm	21.6 - 21.5	0.50	21.5 - 21.4	0.37	16.6 - 15.9	0.32
Opus Flow APS/ Opus APS	Opus Flow APS	0-2mm	7.2 - 4.9	0.37	7.1 - 4.8	0.23	7.0 - 3.4	0.10
	Opus APS	0-4mm	18.1 - 18.0	0.42	17.8 - 17.0	0.37	17.5 - 16.6	0.25

*Values obtained from laboratorial tests of part I.

Table 3. Mechanical properties (E, Elastic Modulus - GPa; and Shr, Post-gel shrinkage - %) applied for dental resin composites light cured with irradiance of 1200mW/cm^2 for 10s, 20s and 40s when used flowable/ viscosity technique.

Resin Composite		Thickness	40s		20s		10s	
			E	**Shr**	**E**	**Shr**	**E**	**Shr**
SDR/ SonicFill 2	SDR	0-2mm	9.7 - 8.6	0.41	9.4 - 7.8	0.35	9.3 - 7.4	0.28
	SonicFill 2	0-4mm	10.8 - 10.7	0.27	10.1 - 9.9	0.25	10.4 - 9.9	0.21
Opus Flow APS/ Opus APS	Opus Flow APS	0-2mm	7.2 - 4.9	0.37	6.5 - 3.1	0.32	6.0 - 3.2	0.12
	Opus APS	0-4mm	18.1 - 18.0	0.42	16.3 - 16.2	0.39	15.7 - 15.6	0.38
Tetric N-Flow/ Tetric N-Ceram	Tetric N-Flow	0-2mm	7.4 - 5.1	0.41	6.8 - 5.5	0.35	5.8 - 5.1	0.30
	Tetric N-Ceram	0-4mm	21.6 - 21.5	0.50	21.5 - 21.4	0.37	16.6 - 16.3	0.32
Filtek Flow/Filtek Filtek Flow	Filtek Flow	0-2mm	6.3 - 4.9	0.47	6.2 - 3.9	0.45	6.1 - 3.5	0.39
	Filtek One	0-4mm	22.4 - 22.3	0.31	18.9 - 18.6	0.30	19.1 - 18.7	0.30
Admira x-base/ Admira x-tra	Admira x-base	0-2mm	3.3 - 2.9	0.50	2.9 - 2.9	0.45	3.0 - 2.4	0.42
	Admira x-tra	0-4mm	12.6 - 12.2	0.36	11.8 - 11.3	0.35	10.6 -10.0	0.34

*Values obtained from laboratorial tests of part I.

Table 4. Mechanical properties (E, Elastic Modulus - GPa; and Shr, Post-gel shrinkage - %) applied for dental resin composites light cured for 40s with the irradiance of 400, 800 and 1200mW/cm^2 when used viscosity technique.

Resin Composites	40s		20S		10s	
	E	Shr	E	Shr	E	Shr
Tetric N-Ceram	21.6 - 21.4	0.50	21.5 - 21.2	0.37	16.6 - 14.8	0.32
Filtek One	22.4 - 21.8	0.31	21.9 - 18.3	0.31	18.3 - 11.2	0.24
Opus APS	18.1 - 17.9	0.42	17.8 - 15.7	0.37	17.5 - 12.9	0.25
Admira x-tra	12.6 - 10.3	0.37	12.2 - 8.9	0.36	10.2 - 7.8	0.31
SonicFill 2	10.8 - 10.5	0.27	9.3 - 7.4	0.25	9.0 - 7.6	0.24

*Values obtained from laboratorial tests of part I.

Table 5. Mechanical properties (E, Elastic Modulus - GPa; and Shr, Post-gel shrinkage - %) applied for dental resin composites light cured with irradiance of 1200mW/cm^2 for 10s, 20s and 40s when used viscosity technique.

Resin Composites	40s		20S		10s	
	E	Shr	E	Shr	E	Shr
Tetric N-Ceram	21.6 - 21.4	0.50	21.5 - 21.3	0.42	21.0 - 20.8	0.40
Filtek One	22.4 - 21.8	0.31	18.9 - 18.2	0.30	19.1 - 16.9	0.30
Opus APS	18.1 - 17.9	0.42	16.3 - 16.2	0.39	15.7 - 15.0	0.38
Admira x-tra	12.6 - 10.3	0.36	11.8 - 9.0	0.35	10.6 - 7.4	0.34
SonicFill 2	10.8 - 10.5	0.27	10.1 - 9.3	0.25	10.4 - 7.9	0.21

*Values obtained from laboratorial tests of part I.

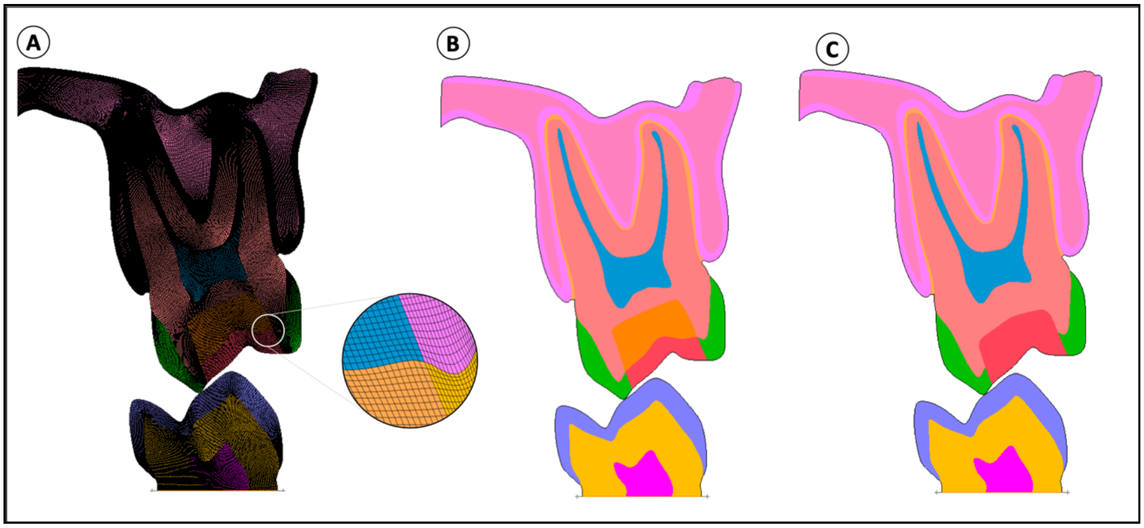

Figure 1. A. Finite element mesh. **B.** Two-dimensional strain model of simulating cavity with 6mm depth restored with 4mm of each flowable bulk fill resin composites and covered with 2mm of high viscosity bulk fill resin composites. **C**. Two-dimensional strain model of simulating cavity with 4mm in depth restored with a single increment of each high viscosity bulk fill resin composite.

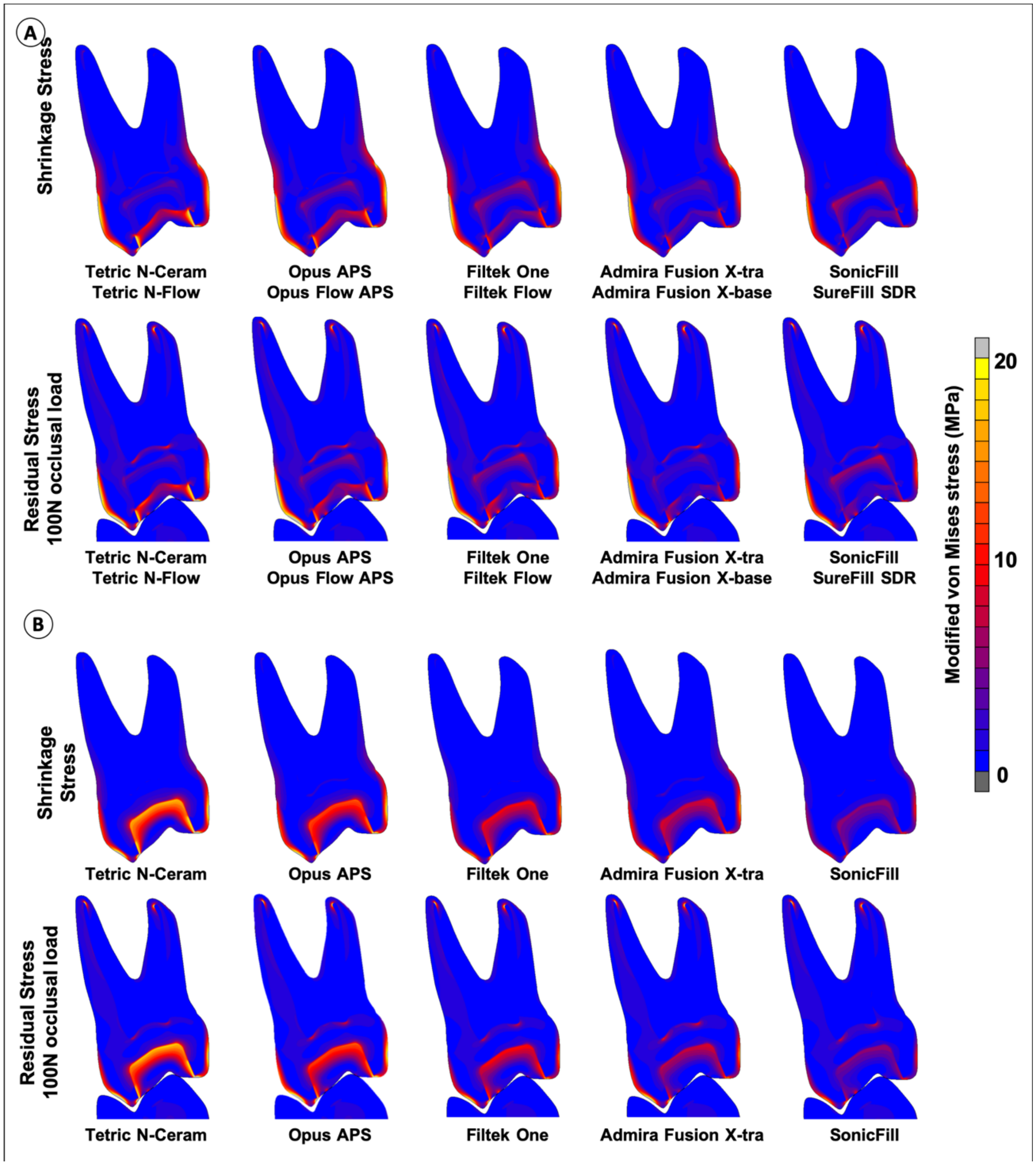

Figure 2. A. Modified von Mises stress distribution at shrinkage and occlusal contact final movement on finite element models restored flowable/high viscosity bulk fill resin composites light cured with 1200mW/cm^2 for the time recommended for manufacturer of each resin composite. **B.** Modified von Mises stress distribution at shrinkage and occlusal contact final movement on finite element models restored with only high viscosity bulk fill resin composites light cured with 1200mW/cm^2 for the time recommended for manufacturer of each resin composite.

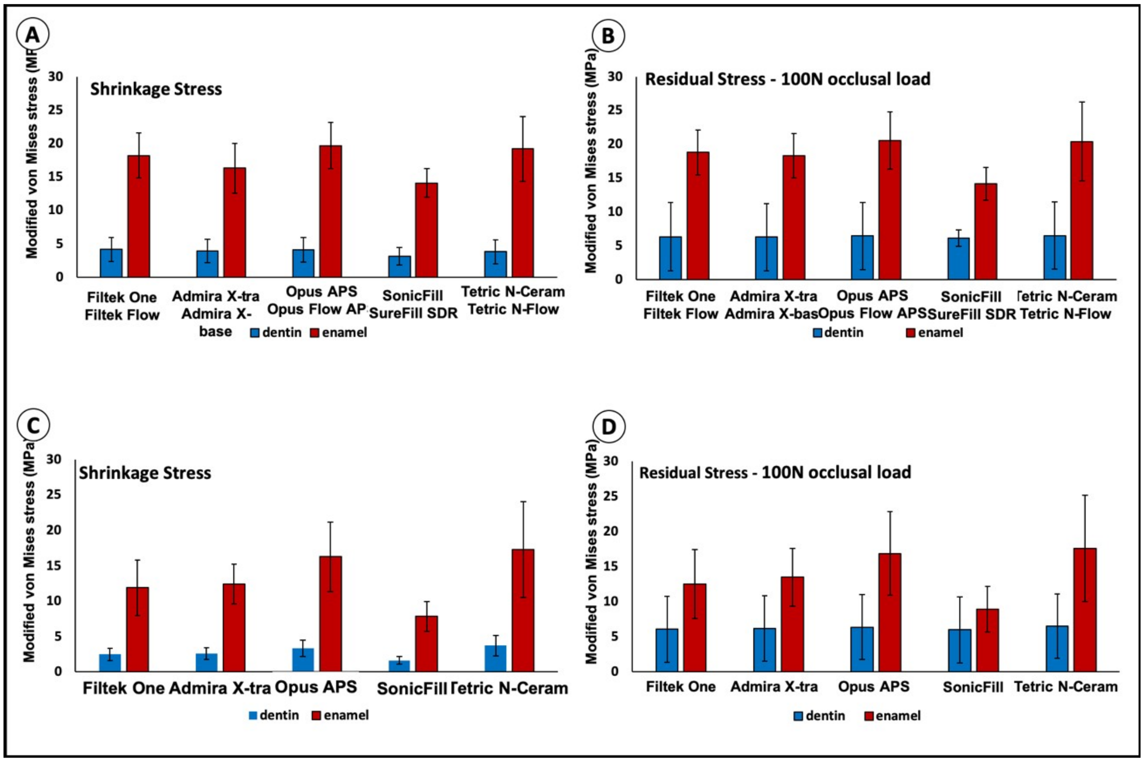

Figure 3. Mean values of the 10% highest stresses concentrated in the enamel and dentin when was simulated resin composite light cured with 1200 mW/cm^2 for the time recommended for manufacturer of each resin composite extracted for the FEA models: **A.** Shrinkage stresses for restored flowable/high viscosity bulk fill resin composites; **B.** Residual occlusal stresses restored flowable/high viscosity bulk fill resin composites; **C.** Shrinkage stresses for models restored with only high viscosity bulk fill resin composites; **D.** Residual occlusal stresses models restored with only high viscosity bulk fill resin composites.

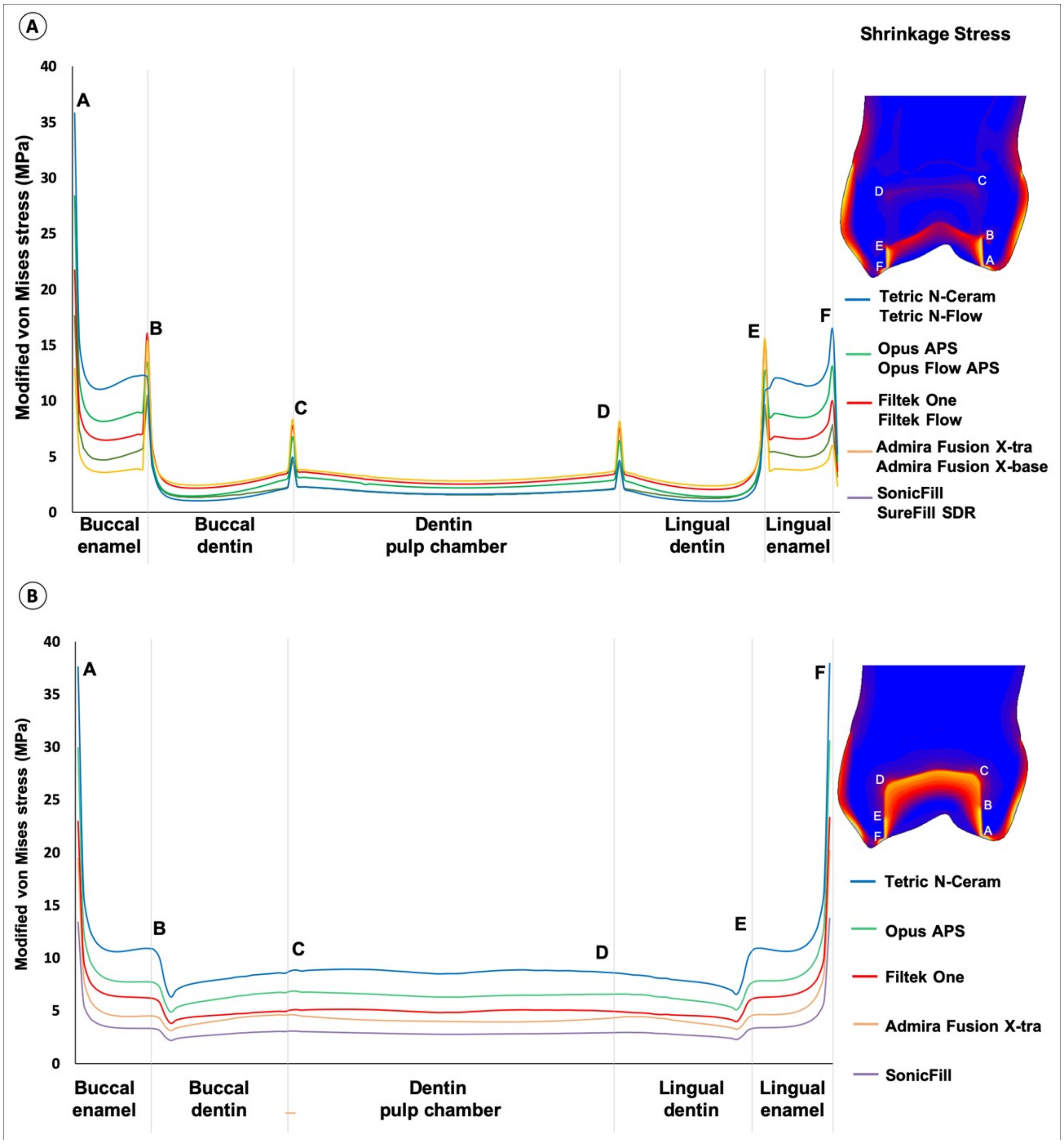

Figure 4. A. Modified von Mises stress distribution along the interface tooth/restoration at shrinkage on finite element models restored flowable/high viscosity bulk fill resin composites light cured with 1200mW/cm^2 for the time recommended for manufacturer of each resin composite. **B.** Modified von Mises stress distribution along the interface tooth/restoration at shrinkage on finite element models restored with only high viscosity bulk fill resin composites light cured with 1200mW/cm^2 for the time recommended for manufacturer of each resin composite.

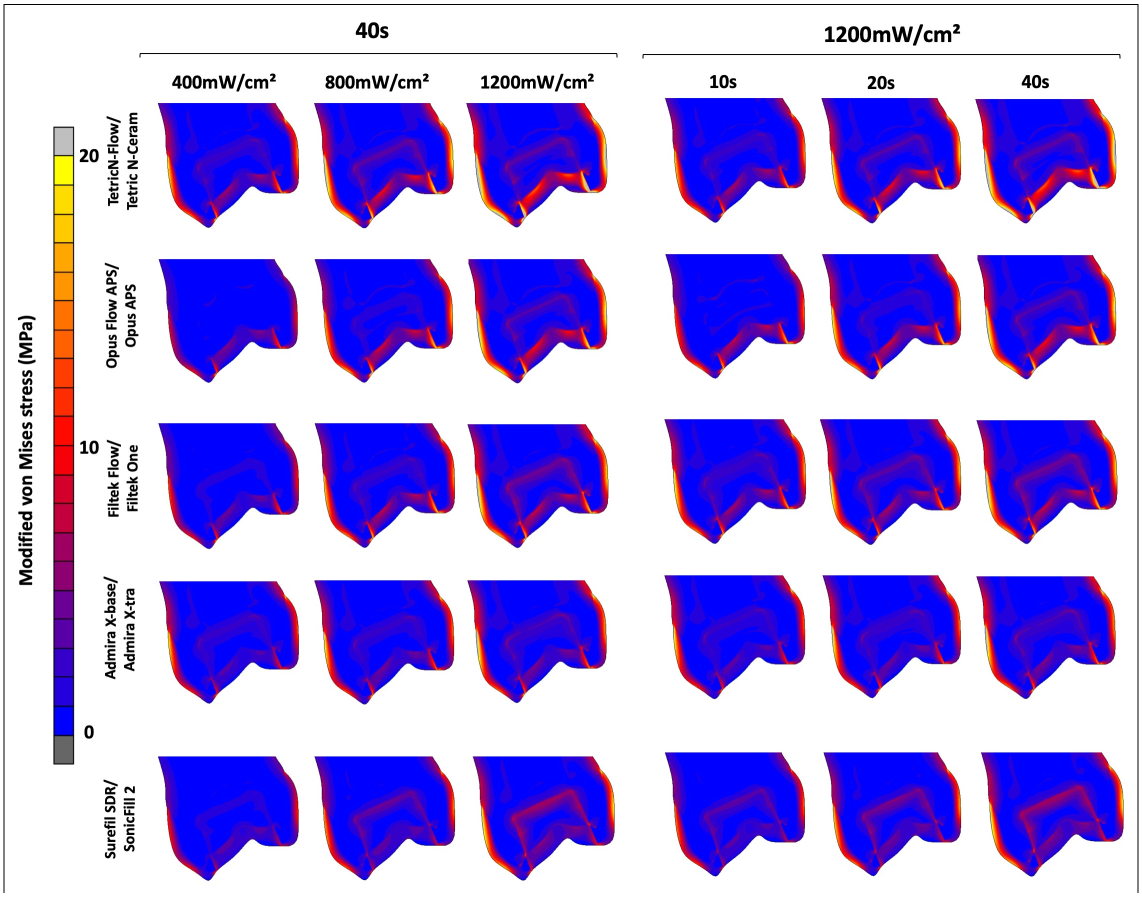

Figure 5. Modified von Mises shrinkage stress distribution in finite element models restored flowable/high viscosity light cured with irradiance 400, 800 and 1200mW/cm^2 for 40s, and light cured for 10, 20 and 40s with the irradiance of 1200mW/cm^2.

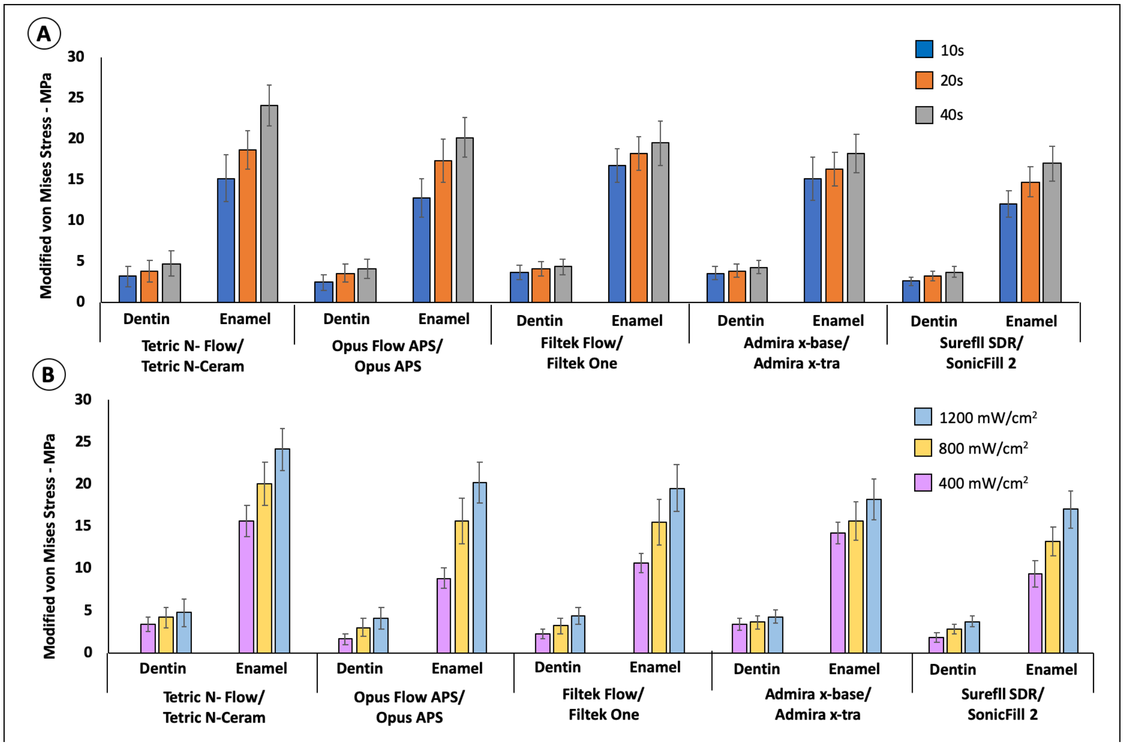

Figure 6. A. Mean values of the 10% highest stresses concentrated in the enamel and dentin in finite element models restored flowable/high viscosity light cured for 10, 20 and 40s with the irradiance of 1200mW/cm^2; **B.** Mean values of the 10% highest stresses concentrated in the enamel and dentin in finite element models restored flowable/high viscosity light cured with irradiance 400, 800 and 1200mW/cm^2 for 40s.

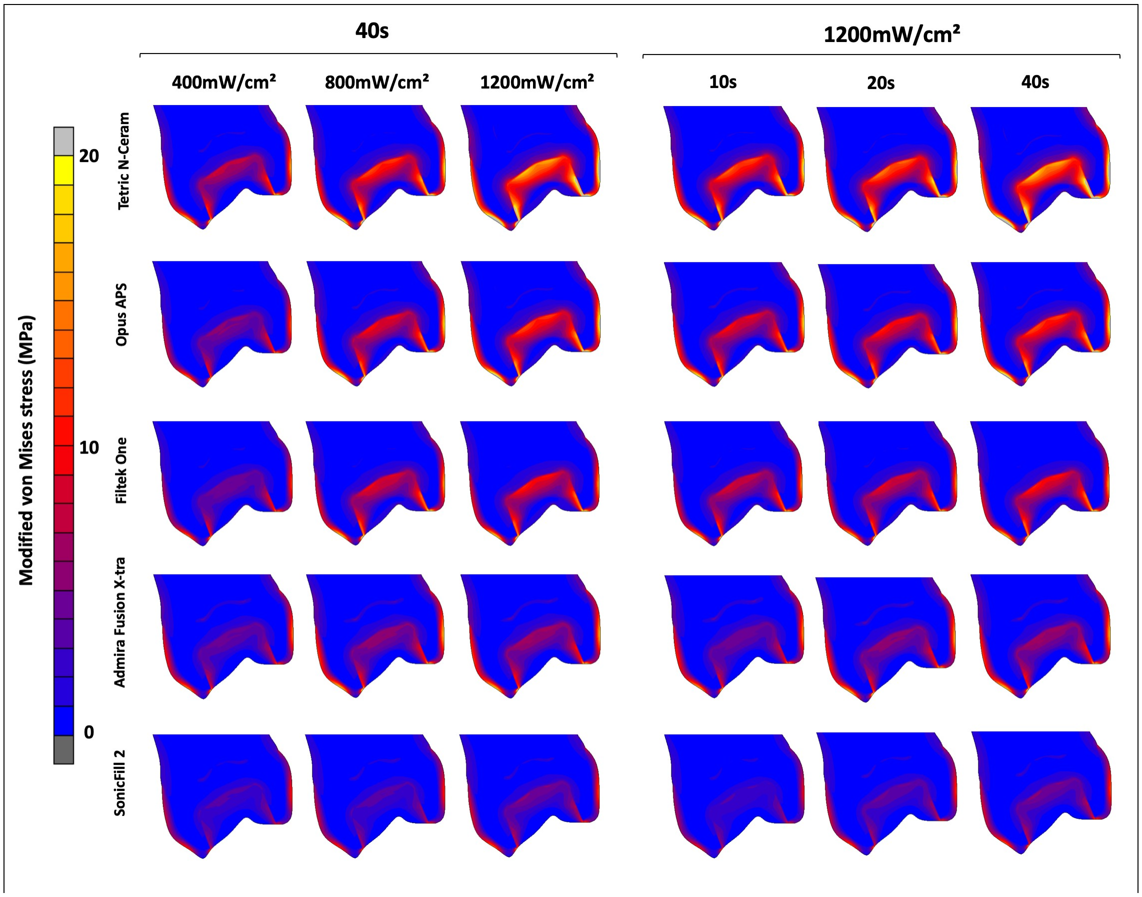

Figure 7. Modified von Mises shrinkage stress distribution in finite element models restored with only high viscosity bulk fill resin composites light cured with irradiance 400, 800 and 1200mW/cm^2 for 40s, and light cured for 10, 20 and 40s with the irradiance of 1200mW/cm^2.

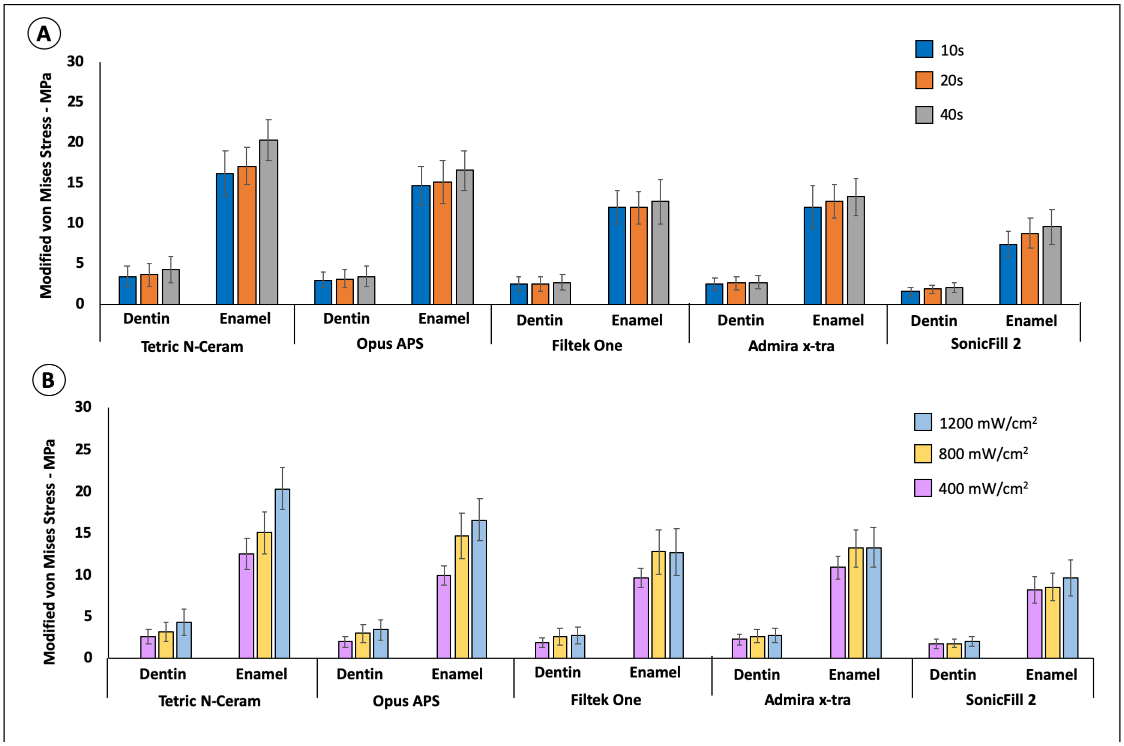

Figure 8. A. Mean values of the 10% highest stresses concentrated in the enamel and dentin in finite element models restored with only high viscosity bulk fill resin composites light cured for 10, 20 and 40s with the irradiance of 1200mW/cm^2; **B.** Mean values of the 10% highest stresses concentrated in the enamel and dentin in finite element models restored with only high viscosity bulk fill resin composites light cured with irradiance 400, 800 and 1200mW/cm^2 for 40s.

4. CAPÍTULO 3

ARTIGO 3

Light activation time and irradiance on flowable and high viscosity bulk fill resin composites - Part 3: effect on the light transmission

***Artigo a ser enviado para o periódico Operative Dentistry**

Light activation time and irradiance on flowable and high viscosity bulk fill resin composites - Part 3: effect on the light transmission

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Running title: Light transmission of bulk fill resin composites

Keywords: bulk fill resin composite, irradiance, light transmission, translucency, beam profile

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Light activation time and irradiance on flowable and high viscosity bulk fill resin composites - Part 3: effect on the light transmission

ABSTRACT

Objectives. To evaluate the effect of the exposure time and the irradiance of a mult-peak light curing unit (LCU) on the light transmission of bulk-fill resin composites.

Methods. Five flowable bulk fill resin composites (Tetric N-Flow Bulk Fill, Ivoclar Vivadent; Filtek Bulk Fill Flow, 3M Oral Care; Opus Bulk Fill Flow APS, FGM; Admira Fusion x-base, VOCO; SureFil SDR Flow, Dentsply) and five viscosity bulk fill resin composites (Tetric N-Ceram Bulk Fill, Ivoclar Vivadent; Filtek One Bulk Fill, 3M Oral Care; Opus Bulk Fill APS, FGM; Admira Fusion x-tra, VOCO; SonicFill 2, Kerr) were light cured for 40 seconds, using VALO Cordless, varying the irradiances of 1200, 800 and 400 mW/cm^2, according to distances of 1, 5 and 13 mm, respectively. The light beam profile of light transmitted was measured using a laser beam profiler camera both during real time polymerization and after polymerization. Images were collected using BeamGage Professional 6.14.0.355 software.

Results. All bulk-fill resin composites decreased the light transmission as the irradiance decreased. SF showed the lowest light transmission at all different LCU irradiances. Tetric N-Ceram and Admira Fusion x-tra showed the highest light transmission among all bulk-fill resin composites at 1200 mW/cm^2. None of them was similar to the VALO images through the 60-degree screen. As the polymerization process occurs, there is a progressive decrease of light transmission through the material, regardless of bulk-fill resin composites

Conclusion. The irradiance level affected the light transmission of bulk-fill resin composites; flowable and high viscosity bulk fill resin composite had different light transmission after cured. Moreover, as the polymerization process occurs, there is a progressive decrease of light transmission through the material for all resin composites tested, except for Opus Bulk Fill APS.

Clinical Significance. *LCUs with low irradiance (400 mW/cm^2) affect significantly the light transmission though the material, and it can decrease the mechanical properties of flowable and high viscosity bulk-fill resin composites. So, it is recommended to use higher irradiance level to results in a proper polymerization process.*

INTRODUCTION

The light transmission into resin composite restorations depends on several factors, such as the composition of the restorative material and characteristics of the light curing unit (LCU).[1] If the light does not reach adequately on the bottom of restorations, the material polymerization may be impaired.[2] Lower energy delivered into deep areas, can result in resin composites insufficiently polymerized, compromising the mechanical properties.[3]

Different LCUs present vary as on internal tip diameter, light beam profile, emission spectrum, radiant exposure and irradiance, which may result in different outcomes in the polymerization of resin composites.[4] Radiant exposure is related to the amount of light emitted by the LCU, and it is important for the generation of free radicals that start the polymerization reaction.[5] Resin composite restorations need to be light cured properly so that the mechanical properties intended by manufacturer are achieved, ensuring long-term clinical success.[9] Resin composite that receives lower irradiance can have the polymerization impaired at the surface and mainly in deep areas of the restorations.[6,7] This aspect gained more relevance nowadays due the increasing use of bulk fill resin composites. The correct choice of LCU is essential for making adequate polymerized bulk fill resin composite restorations.[8]

LCU is an essential factor in the resin composite light curing process, as the material must receive sufficient energy for effective polymerization.[4] It is important to measure irradiance and power of the LCUs to know how much light reaches the surface of resin composites; the irradiance value is obtained from the total power emitted by the LCU that affects the surface of known dimensions, while the light output is evaluated from power radiant and diameter of LCU tip.[4] The emission spectrum can also influence the transmission of light emitted by LCUs into resin composite restorations.[10] Light with long wavelength as 460 nm (blue) has greater penetration through the resin composite than a short wavelength as 400 nm (violet).[11] Some manufacturers have inserted new photoinitiators in bulk fill resin composites to ensure polymerization in great depths.[12] Ivocerin, is a photoinitiator more reactive compared to camphorquinone, usually used in conventional and bulk fill resin composites.[13] The absorption spectrum of this photoinitiator is not emitted by high monowave LCUs and also the violet light wavelengths has lower capacity of the penetration.[10,14] The APS system is a combination of different photoinitiators in which camphorquinone is the main photoinitiator, this system are also presented in conventional and bulk fill resin composites. The interaction of the camphorquinone with other compounds enhances the light curing ability of the monowave LCUs to polymerize these materials.

Bulk fill resin composites have greater translucency than conventional resin composites.[15] Higher translucency results in greater light transmission essential to promote the polymerization on the bottom surface.[15] However, the correlation of the light transmitted through the bulk fill resin composite measured using beam profiling mapping with the calculated properties can clarify this statement.[10] Flowable bulk fill resin composites have a higher translucency compared to bulk fill materials with high viscosity because of their smaller amount of filler particles.[16] However, the consequence of this modification is a lower wear resistance of the material.[17] The capacity of the light transmission can also modify during the polymerization process increasing or decreasing the translucency of the resin composite.[18] Optical properties such as color, translucency and fluorescence are important characteristics of bulk fill resin composites for mimic color of natural teeth.[19] Increased translucency of bulk fill resin composite can compromise the capacity of the masking the color pigmentation of the dentin substrate when stained by amalgam or sclerotic dentin.[19] The expected behavior is the resin composites permit the more light transmission as possible, and after polymerization process the bulk fill resin composite should gain more opacity, increasing the capacity of the masking the color of the substrate. Therefore, this study aimed to evaluate the effect of the different irradiance and the real time light translucency on the light transmission of flowable and high viscosity bulk fill resin composites. The null hypotheses were: 1) the irradiance and the real time light translucency would not affect the light transmission of the bulk fill resin composite; 2) flowable and high viscosity bulk fill resin composite will present similar light transmission after cured.

METHODS AND MATERIALS

Five flowable bulk fill resin composites (Tetric N-Flow Bulk Fill, Ivoclar Vivadent; Filtek Bulk Fill Flow, 3M-ESPE; Opus Bulk Fill Flow APS, FGM; Admira Fusion x-base, VOCO; SureFil SDR Flow, Dentsply) and five high viscosity bulk fill resin composites (Tetric N-Ceram Bulk Fill, Ivoclar Vivadent; Filtek One Bulk Fill, 3M-ESPE; Opus Bulk Fill APS, FGM; Admira Fusion x-tra, VOCO; SF- Sonic*Fill 2*, Kerr Corporation) were tested in this study.

The light beam profile of light transmitted through 4.0 mm bulk fill resin thickness was measured using a laser beam profiler camera both during real time polymerization and after polymerization. The samples were prepared as described in the part I of this study. The LCU guide tip was placed on one side of the resin mold, and the transmitted light beam was examined from the other side using a profile camera with a 50 mm focal length lens (SP928, Ophir-Spiricon, Logan, UT, USA) with two blue filters (HOYA UV-VIS colored glass bandpass filter, Edmund Industrial Optics, Barrington, NJ, USA) and two neutral density filters (1.0 and 3.0, Edmund Optics). They were used to flatten the spectral response of the CCD camera. All materials were light cured using a multi-peak LCU (VALO Cordless; Ultradent, South Jordan, UT, USA) varying the distances of 1, 5 and 13 mm correlated to the irradiances of 1200, 800 and 400 mW/cm^2, respectively. The distances between the LCU and the sample top surface were measured to be equivalent to each irradiance checking using a MARC resin calibrator (BlueLight Analytics Inc, Halifax, NS, Canada). In order to capture the images during the 40 seconds of light curing, the number of frames and exposure time were calculated to each bulk fill resin composite on its scale. After that, the beam profile camera took an image of each bulk fill resin composite after polymerization in the same scale compared to the VALO Cordless image characterized using a holographic diffuser (60° holographic diffuser screen, Edmund Optics). Images were collected using Beam Gage Professional 6.14.0.355 software (Ophir-Spiricon, North Logan, UT, USA).

RESULTS

The three-dimensional representations of the beam profile captured at the irradiance of 1200 mW/cm^2 during the light curing through 4.0 mm thickness of flowable and capacity of the masking the color pigmentation of the dentin substrate when stained by amalgam or sclerotic dentin bulk fill resin composites are shown in Figure 1. Tetric N-Ceram kept the same light transmission during the different periods of times of 5, 10, 20 and 40 seconds. The other flowable bulk fill resin composites increased the light transmission through the exposure time of 40 seconds. Opus Bulk Fill APS had an opposite behavior, was observed the decreasing of the light transmission through the material during the exposure time from 5s to 40s. Admira Fusion x-base and Admira Fusion x-tra showed the highest differences between 5 seconds and 40s. Figure 2 illustrates the three-dimensional representations of the beam profile captured at different irradiances at 40s of the light curing of resin composites. All bulk fill resin composites decreased the light transmission as the irradiance level decreased.

The two-dimensional beam profile images after polymerization captured at different LCU irradiances through flowable and high bulk fill resin composites compared to the VALO beam profile images through the 60-degree screen are shown in Figure 3. The light beam profile of light transmitted through 4.0 mm bulk fill resin thickness is higher for Admira Fusion x-base and SDR than other bulk fill resin composites at 800 mW/cm^2. Tetric N-Ceram and Admira Fusion x-tra showed the highest light transmission among all bulk fill resin composites at 1200 mW/cm^2. At 400 mW/cm^2, lower light transmission is showed through all bulk fill resin composites. SonicFill 2 showed the lowest light transmission at all different LCU irradiances. None of them was similar to the VALO images through the 60-degree screen.

DISCUSSION

The irradiance of the VALO LCU affected the light transmission of bulk fill resin composite; flowable and high viscosity bulk fill resin composite presented different light transmission behavior during the curing process, most of the resin composite increase the capacity of light transmission after cured. Additionally, flowable bulk fill resin composites had higher light transmission capacity than high viscosity bulk fill resin composites. Therefore, both null hypotheses were rejected.

Part I study shows that low irradiance level affects the quality of mechanical properties of bulk fill resin composites; all materials tested results low values of degree of conversion, elastic modulus and Knoop hardness when light cured with 400 mW/cm^2. According to the results of this study, resin composites light cured with low irradiance level (400 mW/cm^2) had light transmission substantially impaired. Therefore, materials that do not receive sufficient energy at the bottom of cavity shown inferior mechanical properties.

The beam profile images of this study showed that flowable bulk fill resin composites allow a greater light transmission regarding high viscosity bulk fill resin composites, regardless of irradiance level. In general, flowable bulk fill resin composites have a lower filler concentration than high viscosity bulk fill resin composites. A larger amount of filler can result in greater light scattering; the light scatters through the filler particles, and it is absorbed by the photoinitiator molecules.[20] It means that as light passes through the resin composite, its intensity is attenuated, resulting in decreased irradiance and polymerization effectiveness.[20] SDR presented also larger filler particles that permits higher light transmission though the resin composite depth.[15] Although, Sonic Fill 2 and Admira Fusion x-tra have a high filler concentration (approximately 84%), beam profile images showed that Admira Fusion x-tra allows for greater light transmission than SF at any irradiance level. According to the manufacturer, Admira Fusion x-tra is a restorative material based on ceramics (silicates), ensuring greater translucency to the composite; SonicFill 2 has larger and irhigh filler particles, which decreases their translucency.[21] SonicFill 2 shows translucency comparable to conventional resin composites,[16] showing the worst light transmission results for all irradiance levels when compared to others bulk fill resin composites tested.

Light is a type of electromagnetic radiation with wavelengths ranging from 400 to 700 nm. When an electromagnetic wave collides with particles in its path, it undergoes the absorption, reflection and refraction processes, inducing a progressive drop in intensity as it advances in depth into the material.[22] Beam profile images of all bulk fill resin composites tested confirm this fact; as the polymerization process occurs, there is a progressive decrease of light transmission through the material, except for Opus APS. The light transmission also depends on the amount and type of monomers, the size and quantity of filler particles, the presence of pigments and the differences in the refractive index.[23]

High light transmission is expected optical properties of bulk fill resin composite for resulting in properly polymerization in the entire depth of the restoration resulting in higher mechanical properties. However, higher light transmission is in the optical perspective accompanied by lower capacity of the opacification the tooth substrates. The posterior cavities that were restored with amalgam for long term and cause tooth structure staining or cavities with darker dentin caused by obliteration and mineralization of the bellow the caries cannot be blocked. The combination of the adequate light transmission and opacity gained after curing process can be the nest balance for achieving the properly mechanical and esthetic properties of bulk fill resin composite.

CONCLUSION

All bulk fill resin composites decreased the light transmission as the irradiance decreased; flowable and high viscosity bulk fill resin composite did not present similar light transmission after cured. Moreover, as the polymerization process occurs, there is a progressive decrease of light transmission through the material for all tested resin composites, except for Opus APS.

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Conflict of Interest

The authors of this manuscript certify that they have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in this article.

Nota à banca de defesa de mestrado: o artigo intitulado *Light activation time and irradiance on flowable and high viscosity bulk fill resin composites - Part 3: effect on the light transmission* está em desenvolvimento. Serão inseridos dados de potência provenientes da esfera integradora, a qual encontra-se em calibração na empresa fabricante. Com essas mesmas amostras geradas com a passagem da luz, será mensurada a opacidade de todas as resinas polimerizadas em todas as condições utilizando o espectrofotômetro (Ci6X Spectrophotometer, X-rite) para correlacionar com a capacidade de bloquear a alteração de cor de substrato. Em sequência, as análises de irradiância serão feitas a partir destes resultados e em conjunto com as imagens exportadas do software BeamGage. Portanto, este arquivo consta apenas os resultados parciais e análises qualitativas. Os autores se comprometem a concluir este trabalho após a defesa, momento este, em que o equipamento terá retornado ao laboratório de pesquisa.

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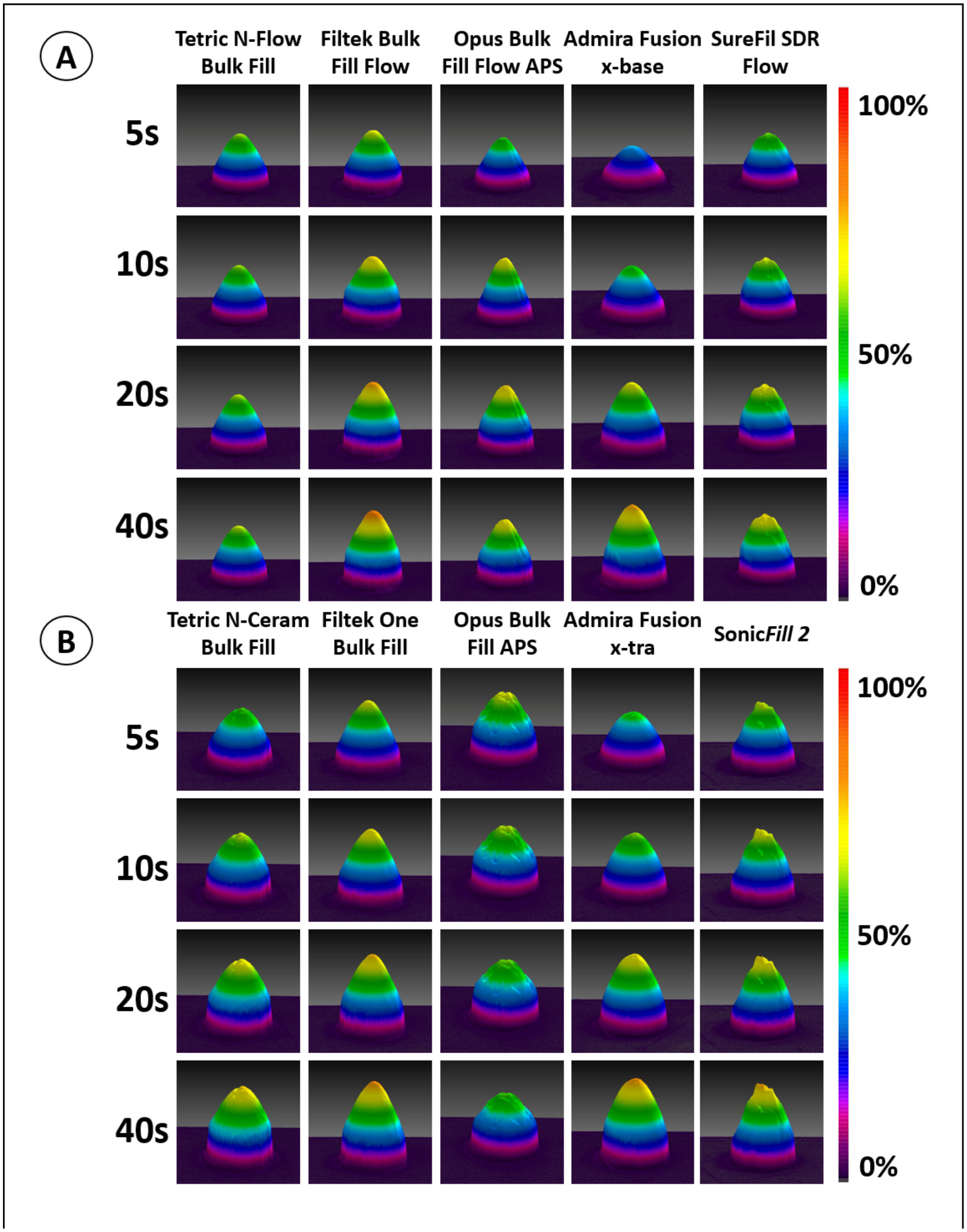

Figure 1. Three-dimensional representations of the beam profile captured at the irradiance of 1200 mW/cm^2 during the light curing through flowable and high composite resins. Each material is showed in its own maximum scale. **A.** Flowable bulk-fill resin composite beam profile images, and **B.** High viscosity bulk- fill resin composite beam profile images.

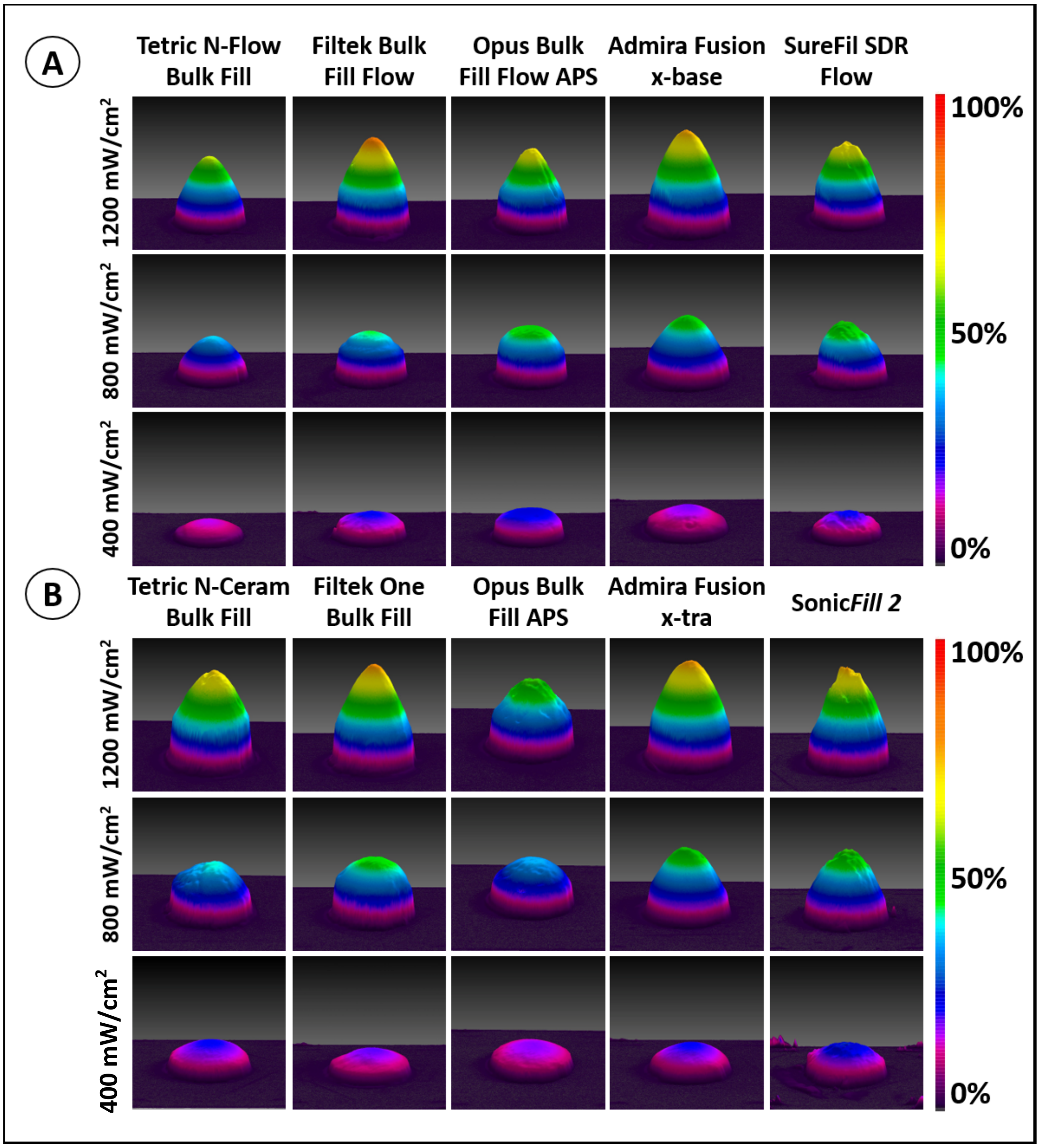

Figure 2. Three-dimensional representations of the beam profile captured at different irradiances at 40 seconds of the light curing of resin composites. Each material is showed in its own maximum scale. **A.** Flowable bulk-fill resin composite beam profile images, and **B.** High bulk- fill resin composite beam profile images.

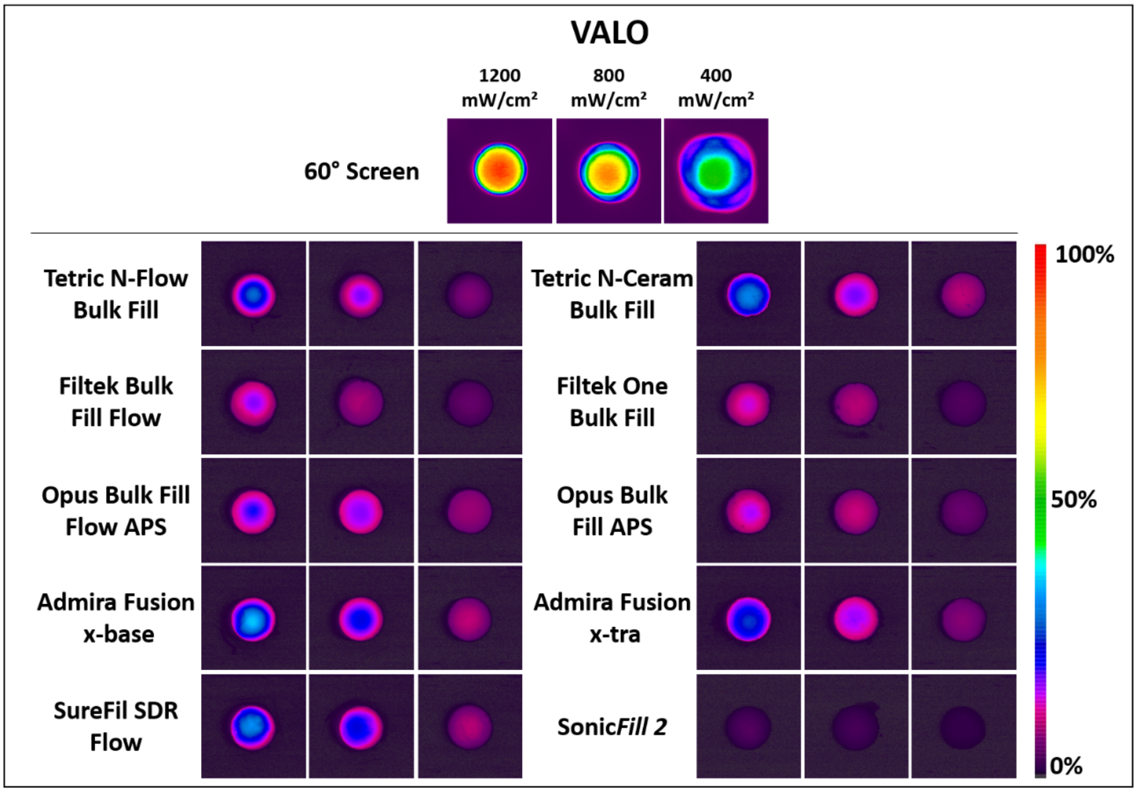

Figure 3. Two-dimensional beam profile images captured at different LCU irradiances through flowable and high bulk-fill resin composites. All materials are showed in the same scale compared to the VALO beam profile image through the 60-degree screen.

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Anexos

Normas do periódico *Operative Dentistry*

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EXAMPLES OF REFERENCE STYLE

- Journal article: two authors
  Evans DB & Neme AM (1999) Shear bond strength of composite resin and amalgam adhesive systems to dentin *American Journal of Dentistry* **12(1)** 19-25.

- Journal article: multiple authors
  Eick JD, Gwinnett AJ, Pashley DH & Robinson SJ (1997) Current concepts on adhesion to dentin *Critical Review of Oral and Biological Medicine* **8(3)** 306-335.

- Journal article: special issue/supplement
  Van Meerbeek B, Vargas M, Inoue S, Yoshida Y, Peumans M, Lambrechts P & Vanherle G (2001) Adhesives and cements to promote preservation dentistry *Operative Dentistry* **(Supplement 6)** 119-144.

- Abstract:
  Yoshida Y, Van Meerbeek B, Okazaki M, Shintani H & Suzuki K (2003) Comparative study on adhesive performance of functional monomers *Journal of Dental Research* **82(Special Issue B)** Abstract #0051 p B-19.

- Corporate publication:
  ISO-Standards (1997) ISO 4287 Geometrical Product Specifications Surface texture: Profile method – Terms, definitions and surface texture parameters *Geneve: International Organization for Standardization* **1st edition** 1-25.

- Book: single author
  Mount GJ (1990) *An Atlas of Glass-ionomer Cements* Martin Duntz Ltd, London.

- Book: two authors
  Nakabayashi N & Pashley DH (1998) *Hybridization of Dental Hard Tissues* Quintessence Publishing, Tokyo.

- Book: chapter
  Hilton TJ (1996) Direct posterior composite restorations In: Schwarts RS, Summitt JB, Robbins JW (eds) *Fundamentals of Operative Dentistry* Quintessence, Chicago 207-228.

- Website: single author
  Carlson L (2003) Web site evolution; Retrieved online July 23, 2003 from: http://www.d.umn.edu/~lcarlson/cms/evolution.html

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  National Association of Social Workers (2000) NASW Practice research survey 2000. NASW Practice Research Network, 1. 3. Retrieved online September 8, 2003 from: http://www.socialworkers.org/naswprn/default

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