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Orientador: Prof. Dr. Carlos José Soares

Banca Examinadora
Prof. Dr. Carlos José Soares
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Prof. Dr. Breno Mont'Alverne Haddade Silva

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Uberlândia, Julho, 2021

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O48
2021

Oliveira, Laís Rani Sales, 1991-
Restaurações de resina composta em dentes posteriores - Efetividade de contato proximal e efeito de associação com cimento de ionômero de vidro nas tensões residuais [recurso eletrônico] : Resin composites restorations in posterior teeth - Proximal contact effectiveness and association effect with glass ionomer cement on residual stresses / Laís Rani Sales Oliveira. - 2021.

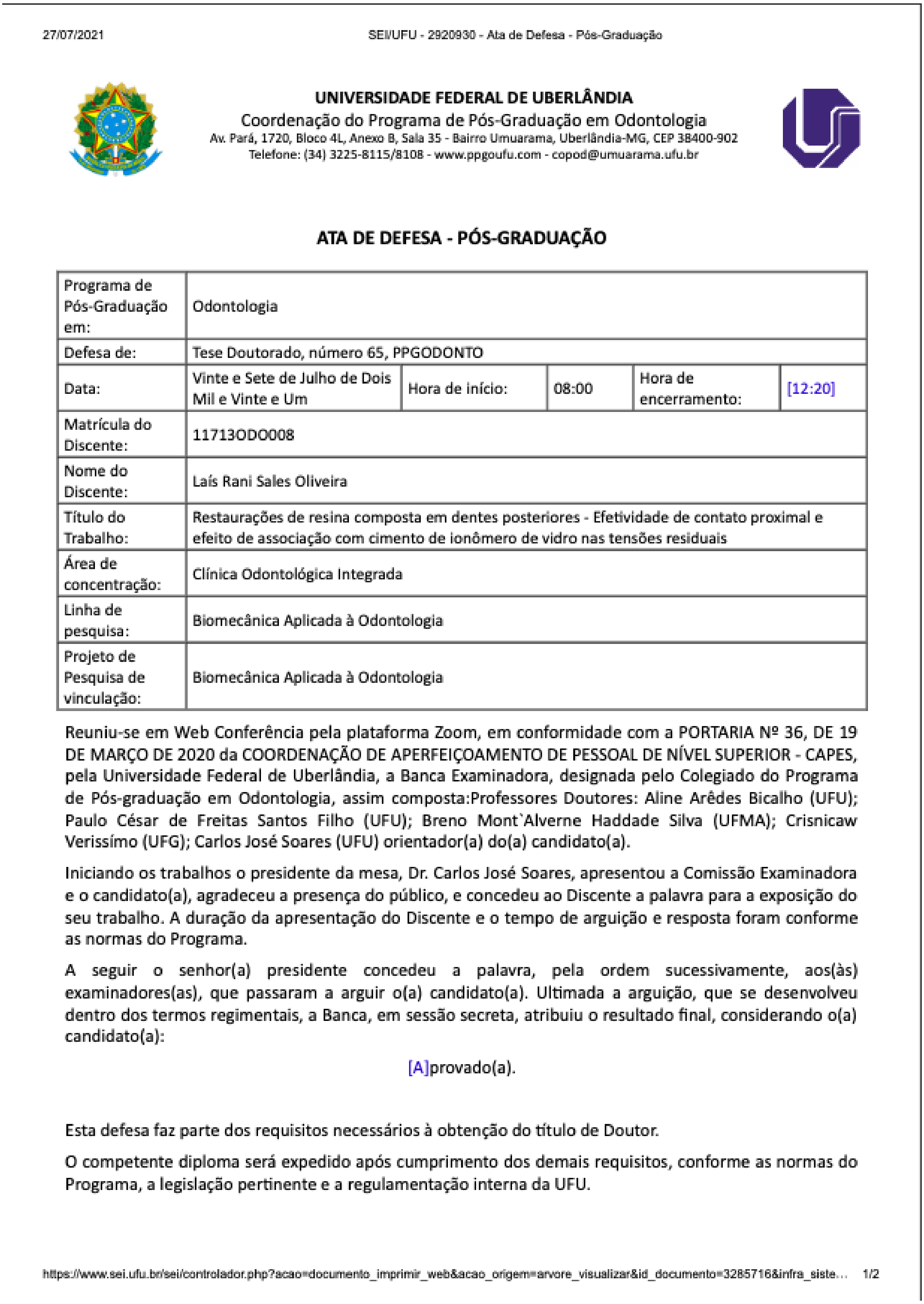
Orientador: Carlos José Soares.
Tese (Doutorado) - Universidade Federal de Uberlândia, Pós-graduação em Odontologia.
Modo de acesso: Internet.
Disponível em: http://doi.org/10.14393/ufu.te.2021.353
Inclui bibliografia.
Inclui ilustrações.

1. Odontologia. I. Soares, Carlos José ,1965-, (Orient.). II. Universidade Federal de Uberlândia. Pós-graduação em Odontologia. III. Título.

CDU: 616.314

Bibliotecários responsáveis pela estrutura de acordo com o AACR2:

Gizele Cristine Nunes do Couto - CRB6/2091



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ATA DE DEFESA - PÓS-GRADUAÇÃO

Programa de Pós-Graduação em:	Odontologia				
Defesa de:	Tese Doutorado, número 65, PPGODONTO				
Data:	Vinte e Sete de Julho de Dois Mil e Vinte e Um	Hora de início:	08:00	Hora de encerramento:	[12:20]
Matrícula do Discente:	11713ODO008				
Nome do Discente:	Laís Rani Sales Oliveira				
Título do Trabalho:	Restaurações de resina composta em dentes posteriores - Efetividade de contato proximal e efeito de associação com cimento de ionômero de vidro nas tensões residuais				
Área de concentração:	Clínica Odontológica Integrada				
Linha de pesquisa:	Biomecânica Aplicada à Odontologia				
Projeto de Pesquisa de vinculação:	Biomecânica Aplicada à Odontologia				

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A seguir o senhor(a) presidente concedeu a palavra, pela ordem sucessivamente, aos(às) examinadores(as), que passaram a arguir o(a) candidato(a). Ultimada a arguição, que se desenvolveu dentro dos termos regimentais, a Banca, em sessão secreta, atribuiu o resultado final, considerando o(a) candidato(a):

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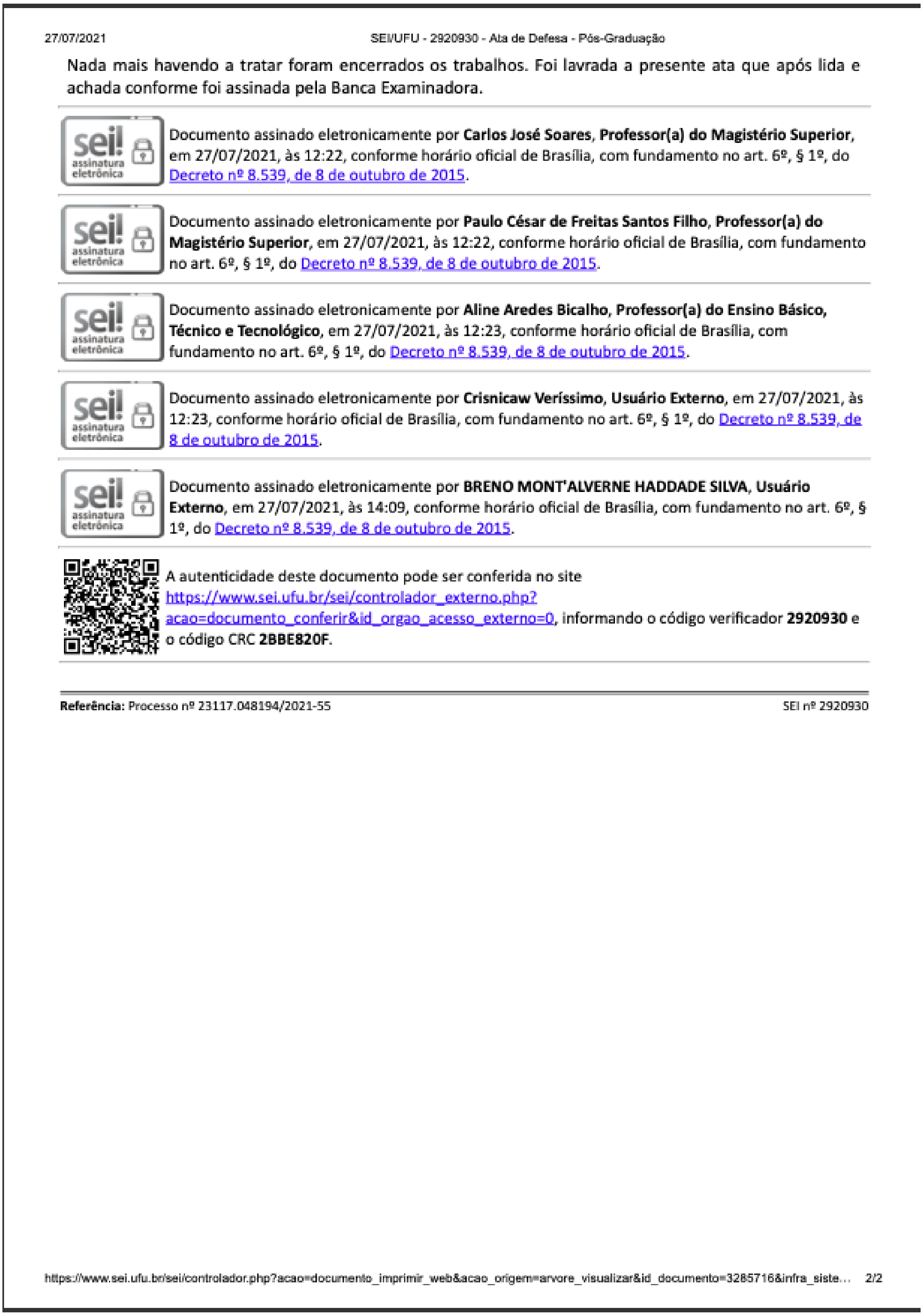

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Nada mais havendo a tratar foram encerrados os trabalhos. Foi lavrada a presente ata que após lida e achada conforme foi assinada pela Banca Examinadora.

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DEDICATÓRIA

Dedico este trabalho aos meus pais, Maria José e Luiz Carlos, por sempre acreditarem em meus objetivos de vida e me incentivarem a correr atrás deles, mesmo quando isso significava distância. Por serem apoio e porto seguro. Devo tudo a vocês! Toda conquista é vitória nossa!

AGRADECIMENTOS ESPECIAIS

À **Deus,** por guiar meus passos e abrir caminhos. Por tantas bênçãos concedidas até aqui. Por me proteger e dar a força necessária para seguir em frente todos os dias. Por colocar pessoas especiais em minha vida que me ajudaram a seguir os caminhos traçados por Ele. Gratidão por tudo!

Aos meu pais, **Maria José e Luiz Carlos**, por todo apoio à minha carreira, por acreditarem em meus objetivos de vida, por entenderem a distância. Obrigada por todo carinho, atenção, cuidado e amor que me deram durante toda vida. Obrigada pela forma que me criaram, pelos conceitos sólidos do que é certo, por serem exemplo de luta e trabalho honesto, e por me fazerem acreditar desde cedo que o estudo seria o meu bem mais precioso e me possibilitaria alcançar coisas incríveis. Continuo acreditando nisso! Não teria chegado até aqui sem o apoio incondicional de vocês. Amo vocês.

Aos meus irmãos, **Daiane Luiza, Irna, Hugo, Igor, e minha prima-irmã Fábia,** vocês fazem parte da minha saudade diária. Obrigada por tantos momentos bons vividos, pelo carinho mesmo à distância, e pelas sobrinhas lindas que vocês me deram! Gratidão pela afilhada mais linda do mundo, que tem exatamente a idade equivalente ao tempo que moro em Uberlândia, mas que você, Fábia, fez questão de cultivar o amor, respeito e carinho por mim! Como eu amo esse pequena da dinda! Como eu amo vocês.

Ao meu amor, **Frederico,** por todo amor, carinho, atenção, cuidado, paciência. Por entender minhas ausências, apoiar meus sonhos e me incentivar sempre. Por ser calmaria, me mostrar o lado bom de tudo e sempre dizer “calma, vai dar tudo certo! No fim sempre dá certo!”. Você trás leveza e alegria aos meus dias. Amo a sua bondade e esse coração gigante que você tem, e agradeço todos os dias por ter você para dividir a vida! Amo você, amo nós dois, amo nossa sintonia, amo a nossa história e a vida que estamos construindo. Nós dois sabemos tudo que já lutamos e como cada pequena conquista é valiosa. Obrigada por tanto, essa caminhada não seria a mesma sem você!

À família que ganhei de presente, **Elaine, Ademar, Isabel, Tafarel, Jeovane, Tia Beth, Dona Irondina, Vandenir, e toda a família maravilhosa do meu namorado**, e que me acolheu como filha! Me sinto em casa com todos vocês! Obrigada por tanto carinho! Vocês enchem minha vida de alegria e foram essenciais durante esses anos. Amo todos vocês!

Aos meus **amigos,** maranhenses e mineiros, por toda amizade, apoio, incentivo, e por me fazerem sentir amada e lembrada sempre. Amo vocês.

À toda a minha **família**, que, espalhada por esse Brasil, me fez crescer com a certeza de que família não precisa estar perto para se fazer presente! E que posso estar em qualquer lugar, sempre terei vocês.

AGRADECIMENTOS

Ao meu **orientador, Prof. Dr. Carlos José Soares**, por esses 6 anos de orientação, cheios de ensinamentos, crescimento e conquistas. Obrigada pela confiança na minha capacidade de desenvolver diversos trabalhos, por mostrar caminhos, por me fazer acreditar que sempre é possível ir além, e por me impulsionar a sempre buscar a excelência. Admiro seu amor pela odontologia, pela nossa Faculdade, pela pesquisa, pelo ensino e considero um verdadeiro privilégio ter sido sua orientanda e poder ver de perto essa dedicação e entrega. Você nos inspira a sermos profissionais melhores todos os dias. Obrigada pelos conselhos profissionais, que me ajudaram a traçar melhor os caminhos e ajustar a rota em direção aos meus objetivos. Serei eternamente grata por todas as oportunidades concedidas, pelo seu apoio e incentivo. Agradeço também à **professora Dra. Priscilla**, por todos os ensinamentos, ajuda e carinho de sempre, e por me receberem na casa de vocês, com essa família linda, sempre tão acolhedores e de braços abertos. Gratidão.

Ao amigo **Prof. Dr. Crisnicaw Veríssimo**, que foi fundamental no início da minha trajetória na pesquisa, que tanto me ensinou, apoiou, mostrou caminhos e incentivou. E que depois, mesmo à distância, continuou a contribuir com minha formação e crescimento. Foi responsável por gerar uma parceria de trabalho que teve como fruto, além do aprendizado e publicação, uma nova amiga querida de presente, a Laís. Sou muito grata pela nossa amizade e por ter tido a honra de aprender tanto com você.

À amiga **Profa. Dra. Aline Bicalho**, por todo carinho e atenção com que me tratou desde o primeiro dia que vim para Uberlândia. Obrigada por todo ensinamento durante o mestrado como minha co-orientadora, devo muito do que sou hoje a você. Com sua paciência, serenidade, e conhecimento gigantesco, me fez aprender tudo com muito mais leveza. Você é um ser-humano incrível e te admiro como pessoa e pela profissional brilhante que você é! Obrigada por tanto.

Ao **professor Dr. Breno Mont'Alverne**, meu orientador da graduação e amigo, que tanto me ensinou e me ajudou a traçar os caminhos e chegar até aqui. Aprendi tanto com você. Obrigada pelos ensinamentos, pela amizade, pela primeira oportunidade dada a mim para pesquisar o que amava: Dentística e materiais dentários. Obrigada por todo incentivo e me fazer acreditar que eu era capaz sim de seguir a carreira na pesquisa e na docência. Serei sempre grata.

Ao **professor Dr. Paulo César**, por toda a contribuição durante essa caminhada. Fez parte da minha banca de mestrado e me proporcionou contribuições excelentes. Hoje, colega de área, tenho aprendido tanto com você, a como ser uma professora melhor, a escutar os alunos e suas necessidades. Você é um dos meus exemplos de profissional a ser seguido, e eu admiro muito você. Muito obrigada.

À minha amiga, **Stella Braga**, que foi minha companheira inseparável, foi ombro amigo, parceira de trabalho, mas também de vida. Você foi um dos presentes que Uberlândia me deu. Obrigada pela amizade sincera, pelos conselhos, pelos momentos bons compartilhados, pelos trabalhos até tarde sem perder a alegria, por tentar apagar os incêndios comigo, literalmente, e por todas as aventuras que nos renderam o apelido de Batman e Robin. Você tem uma alma linda, que faz as pessoas ao seu redor se sentirem bem só por estarem perto de você! E eu admiro sua força, sua determinação, seu amor pelo que faz. E morro de orgulho de você e de tudo que você tem conquistado. É só o começo de uma trajetória brilhante, e eu estarei por perto, sempre aplaudindo e com coração cheio de gratidão por você fazer parte da minha vida.

Aos **amigos Rafael, Maria Tereza, Maria Cecília, Laís Carvalho, Raíssa, Gabriel, Gabriela Mesquita, Renata, Luciana, Valessa, Márcio, Tales**, **e a toda família BIAOR,** por todo apoio durante esses anos, todo auxílio nos trabalhos, pelos momentos vividos dentro e fora do laboratório, pelos cafés cheios de conversas boas. Vocês foram essenciais para tornar os dias mais leves e felizes. Sentirei saudades da convivência quase diária, mas estarei sempre aqui para o que precisarem e acompanhando as conquistas de vocês, cheia de orgulho.

Aos **amigos Andomar e Monise**, pelo auxílio no desenvolvimento do terceiro trabalho, pela paciência de me ensinarem, por todas as dúvidas tiradas. Vocês foram essenciais e maravilhosos comigo. Serei sempre grata por isso. Obrigada pela amizade de sempre, pelos conselhos, conversas animadas. Muito bom poder acompanhar as conquistas de vocês. Contem comigo sempre.

Ao meu co-orientando de iniciação científica, Calebe de Melo, por todo empenho durante a iniciação científica, que geraram contribuições essenciais para o primeiro trabalho dessa Tese. Foi uma honra ser sua co-orientadora.

Aos **alunos de iniciação científica e graduação**, que de alguma forma contribuíram com essa etapa e me fizeram aprender a ser uma professora e futura orientadora melhor.

À Universidade Federal de Uberlândia, instituição que virou minha segunda casa, que me possibilitou o acesso à pós-graduação, e agora o vínculo também como professora substituta. Serei eternamente grata e levarei com orgulho o nome da UFU comigo.

Aos professores da Faculdade de Odontologia da UFU e Programa de Pós-Graduação, muito obrigada pela contribuição à minha formação, por tantos ensinamentos valiosos, e pela convivência durante esses anos.

Aos professores da área de Dentística e Materiais Odontológicos, que hoje também são colegas de trabalho, muito obrigada pelos ensinamentos, pelas contribuições às pesquisas desenvolvidas durantes esses anos. Todos vocês contribuíram de alguma forma, em momentos diversos. Obrigada por me receberem tão bem na área, por me ajudarem, incentivarem. Aprendi e continuo aprendendo todos os dias com vocês. É uma honra poder fazer parte de um pedaço da história da área de Dentística da FOUFU.

Aos funcionários da Faculdade de Odontologia da UFU, **Graça, Laís, Brenda, Camilla, Daniela, Lilian, Bruno, Eliete, John,** por todo auxílio esses anos, pelas orientações, pela disponibilidade em ajudarem sempre, e em especial **Sr. Advaldo,** que tanto me ajudou durante esses anos, principalmente no trabalho 1 dessa tese. Gratidão.

Aos **funcionários da Universidade Federal de Uberlândia** que de alguma forma contribuíram conosco, em especial a toda equipe de vigilância da UFU, que sempre estavam prontos para atender aos chamados, pelas incontáveis madrugadas abrindo os portões do bloco, com alegria! Muito obrigada

À **CAPES**, pela bolsa concedida durante os anos de doutorado.

A todos que de alguma forma contribuíram para o desenvolvimento dessa Tese e para o caminhar na pós-graduação, minha eterna gratidão.

EPÍGRAFE

“Sempre permaneça aventureiro. Por nenhum momento se esqueça de que a
vida pertence aos que investigam.
Ela não pertence ao estático, ela pertence ao que flui.
Nunca se torne um reservatório, sempre permaneça um rio.”
(Osho)

SUMÁRIO

Resumo

RESUMO

Este estudo teve como objetivo avaliar o desempenho biomecânico de restaurações de resina composta em dentes posteriores por meio de dois objetivos gerais: análise de força do ponto de contato proximal influenciada pelo tipo de resina composta e do envelhecimento; e dos efeitos de associações de cimento de ionômero modificado como base construídas com diferentes espessuras e propriedades mecânicas nas tensões de contração. Esta tese se estrutura em três objetivos específicos: **Objetivo1:** Medir a força de contato proximal (N) de restaurações de resina composta classe II incremental e bulk-fill com dentes adjacentes sendo implante dentário de molar e com pré-molares adjacentes simulando o ligamento periodontal. **Objetivo 2:** Avaliar a contração pós-gel (Shr), resistência à compressão (CS), resistência à tração diametral (DTS), resistência à flexão (FS), módulo de elasticidade (E) e radiopacidade de cimento de ionômero de vidro modificado por resina (CIVMR) e resina composta bulk-fill usada para restaurar dentes posteriores. **Objetivo 3:** Avaliar o efeito da espessura e propriedades mecânicas de diferentes CIVMR no preenchimento da câmara pulpar na distribuição de tensões em molares jovens tratados endodonticamente e restaurados com resina composta bulk-fill, por meio do método de elementos finitos (MEF) com modelo específico de paciente. Pode-se concluir que a força de contato proximal diminuiu após 5 anos de fadiga oclusal simulada. A técnica bulk-fill mostrou força de contato proximal semelhante à técnica incremental. As diferentes composições dos CIVMRs e resinas compostas bulk-fill podem influenciar suas propriedades mecânicas e físicas. CIVMR que apresentam menor módulo de elasticidade e menor contração pós-gél quando usados como materiais de base para restaurações de resina composta bulk-fill, que apresentam maior módulo de elasticidade para suportar as cargas mastigatórias, resultam em menor geração de tensões nas estruturas dentais. A espessura de 3,0 mm do CIVMR inserido na câmara pulpar causou menores tensões na estrutura dental remanescente. O contexto geral deste estudo demonstrou que a força de contato proximal das restaurações posteriores com resina composta bulk-fill é similar à força para resinas convencionais; CIVMR e resinas compostas bulk-fill possuem propriedades mecânicas diferentes e, quando bem associadas, constituem opção viável para restaurar dentes posteriores tratados endodonticamente gerando menor tensão na estrutura dental.

Palavras-chave: força de contato proximal, resina composta bulk-fill, molar tratado endodonticamente, cimento de ionômero de vidro modificado por resina, propriedades mecânicas, análise por elementos finitos.

Abstract

ABSTRACT

This study aimed to evaluate the biomechanics performance of resin composite restorations in posterior teeth by two general objectives: analyzing the proximal contact forces influenced by resin composite type and aging; and the effects of associations with resin modified glass ionomer base under different thicknesses and mechanical properties in the shrinkage stress. This thesis is structured in three specific objectives: **Objective 1:** To measure the proximal contact force (N) of incremental and bulk fill class II resin composite restorations from proximal contact with implant molar teeth and with adjacent premolar teeth simulating the periodontal ligament. **Objective 2:** To evaluate the post-gel shrinkage (Shr), compressive strength (CS), diametral tensile strength (DTS), flexural strength (FS), elastic modulus (E), and radiopacity of resin-modified glass ionomer (RMGIC) and bulk fill resin composite (BFRC) used for restoring posterior teeth. **Objective 3:** Evaluates the effect of resin-modified glass ionomer filling the pulp chamber on stress distribution in young molar treated endodontically and restored with bulk fill resin composite, using patient-specific finite element analysis (FEA). I t can be concluded that the proximal contact force decreased after 5 years of simulated occlusal fatigue. The bulk-fill technique showed proximal contact force similar to the incremental technique. The different compositions of RMGICs and resin composites bulk-fill can influence their mechanical and physical properties. RMGIC, which have a lower elastic modulus and less post-gel shrinkage when used as base materials for resin composite bulk-fill restorations, which have a higher elastic modulus, result in less stress in the dental structures. The 3.0 mm thickness of the RMGIC inserted into the pulp chamber caused less stress on the remaining tooth structure. The general context of this study demonstrated that the proximal contact force of posterior restorations with resin composite bulk-fill is similar to the proximal contact forces of conventional resins; RMGIC and resin composite bulk-fill have different mechanical properties and, when well combined, are a viable option for restoring endodontically treated posterior teeth, generating less stress on the tooth structure.

Keywords: proximal contact force, bulk-fill resin composite, endodontically treated molar, resin-modified glass ionomer, mechanical properties, finite element analysis.

Introdução E Referencial Teórico

1. INTRODUÇÃO E REFERENCIAL TEÓRICO

Atualmente, resinas compostas têm sido usadas com sucesso para restaurar dentes posteriores, mostrando longevidade aceitável em estudos clínicos (Opdam *et al.,* 2014; Alvanforoush *et al.,* 2017)). Características como cárie secundária, resistência à fratura, retenção, adaptação marginal, descoloração e contato proximal das restaurações posteriores são fatores importantes que podem determinar o sucesso clínico destas restaurações (Gaengler *et al.,* 2001; Manhart *et al.,* 2004; Rodolpho *et al.,* 2012).

O ponto de contato proximal entre dente e restauração ocorre quando sua área de contorno na superfície distal ou mesial permanece em contato próximo com o dente adjacente (kim *et al*., 2009). Contato proximal posterior adequado entre dentes adjacentes está relacionado ao sucesso clínico das restaurações devido à manutenção e estabilização das posições dentárias nas arcadas (Nelson, 2014). Ponto de contato adequado significa que há espaço suficiente para a passagem do fio dental entre os dentes adjacentes, com pequena resistência, e sem que o fio se rasgue durante essa passagem. (Kasahara *et al.,* 2000). Um ponto de contato ligeiramente aberto pode causar acúmulo de alimentos, inflamação gengival, lesões de cárie, perda óssea em áreas proximais e migração dentária (Jerneberg, Bakdash & Keenam, 1983; Saber *et al.,* 2010; Nelson, 2014). Da mesma forma, contatos muito apertados podem causar complicações periodontais, migração dentária e dificultar a higienização com uso do fio dental para o paciente (Kasahara *et al.,* 2000). Pontos de contato inadequados (apertados ou abertos), podem estar associados à formação de cárie proximal (Dur & Ahmad, 2011).

Clinicamente, o ponto de contato é avaliado pelo dentista ao passar o fio dental, sendo caracterizado como efetivo quando apresenta leve resistência (Kim *et al.,* 2009; Byun *et al.,* 2015; Pang *et al.,* 2017). Esta é uma forma simples de avaliar a presença da resistência, mas não permite avaliar as variações da força de contato proximal utilizadas, uma vez que a força de contato proximal é considerada uma entidade fisiológica de origem multifatorial (Parakki *et al.,* 2004; Dorfer *et al.,* 2000: Kim *et al.,* 2009).

Materiais de fio de nylon e teflon testados em estudo clínico em dentes naturais, constataram que o as forças de contato variaram de 2 a 10 N (Dorfer *et al.,* 2001). Um estudo *in vitro* usando primeiros pré-molares permanentes intactos extraído mediu o ponto de contato usando fio dental de náilon encerado e descobriu que as forças de contato proximal variam de 10 a 50 N (Alali *et al.,* 2018). Forças de contato maiores foram descritas quando superfícies secas foram testadas e a magnitude da força tende a não estar relacionada com a área de angulação de contato durante o deslizamento do fio dental (Alali *et al.,* 2018). Assim, muitos estudos tentam medir a força do contato proximal usando dispositivos e metodologias desenvolvidas para este fim (Loomans *et al.,* 2006a; Loomans *et al.,* 2006b; Loomans *et al.,* 2006c; Loomans *et al.,* 2007a; Loomans *et al.,* 2007b; Wirsching *et al.,* 2011; Wolf *et al.,* 2012; El-Shamy *et al.,* 2018).

A reconstrução de contato proximal satisfatório com resina composta, com contorno anatômico correto e tensão de contato proximal adequada é essencial, mas também permanece difícil para muitos clínicos quando da confecacão de restaurações posteriores (Saber *et al.,* 2011; Akhtar *et al.,* 2015). As técnicas de resina composta e de restauração de amálgama diferem em relação à reconstrução do contato proximal principalmente pelo fato de que resina composta não pode ser "condensada" contra a matriz como o amálgama (Saber *et al.,* 2011; Akhtar *et al.,* 2015). Existem diversos tipos de matrizes disponíveis no mercado atualmente para tentar facilitar a confecção do ponto de contato satisfatório com resina composta, levando em consideração suas características de manipulação, incluindo o sistema de matrizes individuais (Wirsching *et al.,* 2011). Uma vez que uma insuficiente adaptação da matriz ao dente adjacente e da resina composta à matriz podem influenciar a reconstrução do ponto de contato (Wirsching *et al.,* 2011). Paralelo a isso, resinas compostas bulk-Fill estão ganhando popularidade entre os clínicos por simplificarem o procedimento restaurador, reduzindo o número de incrementos e, portanto, o tempo de trabalho, e mantendo propriedades mecânicas satisfarórias com desempenho semelhante às resinas compostas convencionais (Veloso *et al.,* 2019). Porém, o contato proximal, um parâmetro clínico importante, não tem sido frequentemente investigado quando se avaliam resinas compostas bulk-fill.

Um estudo clínico de restaurações de resina composta posterior já mostrou que as forças de contato nem sempre permanecem estáveis ao longo do tempo, mostrando que os contatos proximais tendem a diminuir após um período de 6 meses (Loomans *et al.,* 2007ª). A perda de contato proximal já é considerada complicação em próteses sobre implante. Estudo de acompanhamento clínico de 7 anos avaliou os efeitos negativos da perda de contato proximal entre implantes e dentes adjacentes, mostrando que o deslocamento do ligamento periodontal pode diferir para diferentes tipos de restaurações (Pang *et al.,* 2017). Dentro do conhecimento dos autores, nenhum estudo comparou a influência da ciclagem mecânica simulada na força de contato proximal de resinas compostas bulk-fill objetivando avaliar seu desempenho simulando envelhecimento, ou associando ponto de contato de resinas compostas bulk-fill com restaurações indiretas e sobre implante.

Resinas compostas bulk-fill podem ser inseridas e fotoativadas em incrementos de 4 a 5 mm e têm demonstrado desempenho mecânico similar às resinas compostas convencionais em estudos laboratoriais (Ilie *et al.,* 2014; Rosatto *et al*., 2015; Oliveira Schliebe *et al.,* 2016; Oliveira *et al*., 2018) e clínicos, como discutido acima (Cidreira Boaro *et al.,* 2019; Balkaya *et al*; 2020). O uso das resinas compostas bulk-fill vem sendo estudado também em associação com outros materiais restauradores, como o CIVMR (Pereira *et al*., 2015; Rodrigues *et al.,* 2020). Esta associação técnica das resinas compostas bulk-fill com material com módulo de elasticidade inferior, (Liu *et al.,* 2010; Nicholson *et al*., 2020; Huang *et al.,* 2021), permitiu o restabelecimento do desempenho biomecânico de forma satisfatória para restaurações de dentes tratados endodonticamente e com grande perda estrutural, demonstrando devolução do estado tensão/deformação do dente hígido (Rodrigues *et al.,* 2020). A associação é determinada pelo uso do CIVMR em áreas mais profundas, preenchendo totalmente ou parcialmente a câmara pulpar, sendo as superfícies externas restauradas usando resinas compostas bulk-fill devido às suas propriedades mecânicas superiores para suportar esforços mastigatórios (Balkaya *et al.,* 2019; Balkaya *et al.,* 2020).

O CIVMR tem demonstrado maior resistência à flexão, módulo de elasticidade, resistência à compressão e tenacidade à fratura do que os cimentos ionoméricos convencionais (Moberg *et al.,* 2019). No entanto, as diferentes composições, protocolos de manipulação, inserção e fotoativação podem influenciar diretamente suas propriedades mecânicas (Sulamain *et al.,* 2018). É difícil definir consenso sobre os valores das propriedades mecânicas dos diferentes CIVMR disponíveis no mercado (Nicholson *et al.,* 2020).

A escolha dos materiais restauradores para restaurar dentes posteriores é favorecida pelo conhecimento das propriedades dos materiais disponíveis. Estes materiais também precisam apresentar uma radiopacidade adequada que favoreça a distinção das estruturas dentais, cáries secundárias, bolhas, adaptação marginal inadequada ou fendas marginais (Dukic *et al.,* 2012; Furtos *et al.,* 2012). O CIVMR e resinas compostas bulk-fill apresentam diferentes valores de radiopacidade de acordo com as composições, espessuras de uso e características das exposições radiográficas (Yasa *et al.*, 2015; Soares *et al.,* 2017). A análise das propriedades dos materiais necessita de atualização contínua, uma vez que a evolução dos materiais é constante (Oliveira Schliebe *et al.,* 2016; Huang *et al.,* 2021). As propriedades mecânicas expressas pela resistência à flexão, módulo de elasticidade, resistência à tração e à compressão e também a radiopacidade de CIVMR e resinas compostas bulk-fill podem guiar melhor os clínicos para a seleção do material a ser utilizado e a espessura da camada interna de IVMR quando eles forem usados em combinação.

O uso de cimento ionomérico no preenchimento da câmara pulpar reduziu a deformação da cúspide, aumentou a resistência à fratura e melhorou a distribuição de tensões em molares restaurados com resina composta (Pereira *et al.,* 2015). O CIVMR tem menor módulo de elasticidade que a resina composta e geram redução nas tensões residuais também devido a redução do volume de resina composta necessária para preencher a cavidade (Bonifácio *et al.,* 2009; Sulaiman *et al.,* 2018; Nicholson *et al.,* 2020; Huang *et al.,* 2021). CIVMRs preenchendo a câmara pulpar associado à resina composta vêm sendo usado para restaurar molares severamente destruídos em pacientes jovens (Rodrigues *et al.,* 2020). A literatura ainda carece de informações se a espessura do CIVMR utilizado para selar a câmara pulpar pode influenciar na distribuição de tensões de resina composta bulk-fill. A associação de metodologias laboratoriais com análises computacionais como o método de elementos finitos constitue estratégia eficiente que gera respostas complementares, sendo essencial para levantar discussões com base científica e iniciar questionamentos e tomadas de decisões clínicas.

Objetivos

2. OBJETIVOS

2.1 Objetivo Geral

Avaliar o desempenho biomecânico de restaurações de resina composta em dentes posteriores por meio de dois objetivos gerais: Avaliar o efeito da força do ponto de contato proximal influenciada pelo tipo de resina composta e do envelhecimento; avaliar o efeito das propriedades mecânicas e da espessura do material de base em restaurações diretas em resina composta em dentes posteriores, por meio de objetivos específicos que integram testes laboratoriais e análise de elementos finitos.

2.2 Objetivos Específicos

Objetivo específico 1

Capítulo 1 - *Effects of adjacent tooth type and occlusal fatigue on proximal contact force of posterior bulk-fill and incremental resin composite restoration.*

Medir a força de contato proximal (N) de restaurações de resina composta classe II incremental e bulk-fill a partir do contato proximal com implante dentário de molar e com dentes pré-molares adjacentes simulando o ligamento periodontal.

Objetivo específico 2

Capítulo 2 - *Mechanical and physical properties of resin modified glass ionomer cements and bulk-fill resin composites used for restoring posterior teeth.*

Avaliar a contração pós-gel (Shr), resistência à compressão (CS), resistência à tração diametral (DTS), resistência à flexão (FS), módulo de elasticidade (E) e radiopacidade do ionômero de vidro modificado por resina (RMGIC) e resina composta bulk-fill (BFRC) usada para restaurar dentes posteriores.

Objetivo específico 3

Capítulo 3 - *Effect of glass ionomer thickness on endodontically treated molar restorative protocol - patient-specific finite element analysis.*

Avaliar o efeito da espessura ionômero de vidro modificado por resina no preenchimento da câmara pulpar na distribuição de tensões em molares jovens tratados endodonticamente e restaurados com resina composta bulk-fill, usando análise de elementos finitos com modelo específico de paciente (FEA).

Capítulos

Capítulos

3.1 CAPÍTULO 1

Effects of adjacent tooth type and occlusal fatigue on proximal contact force of posterior bulk-fill and incremental resin composite restoration.

Artigo submetido e aceito para publicação no periódico **Operative Dentistry**

Effects of adjacent tooth type and occlusal fatigue on proximal contact force of posterior bulk fill and incremental resin composite restoration.

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Short title: Proximal contact of and conventional resin composites.

Keywords: resin composite, bulk-fill, incremental technique, proximal contact force, dental implants, class II composite resin restorations.

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Effects of adjacent tooth type and occlusal fatigue on proximal contact force of posterior bulk fill and incremental resin composite restoration.

ABSTRACT

Objectives: To measure the proximal contact force (N) of incremental and bulk fill class II resin composite restorations from proximal contact with implant molar teeth and with adjacent premolar teeth simulating the periodontal ligament.

Methods: The model was created with a typodont first molar tooth with two bilateral occlusal-proximal class II cavities, an adjacent tooth simulating an implanted molar tooth (Titamax CM, Neodent) and a premolar simulating the periodontal ligament. Two resin composite restorative techniques were used: Inc-Z350XT, (Filtek Z350, 3M Oral Care) inserted incrementally; Bulk-OPUS, (Opus Bulk Fill APS, FGM) high viscosity bulk fill resin composite (n=10). As a control, a group without cavity preparation and without restoration was used. After the restorative procedure, each specimen was radiographed using a digital system (DürrDentall). The proximal contact force (N) was measured using dental floss with a microtensile machine (Microtensile ODEME, Luzerna, SC, Brazil). The specimens were then subjected to mechanical fatigue cycling to simulate 5 years of aging. All the parameters were measured after the aging simulation. The X-rays were blindly qualitatively analyzed by two operators to identify the loss of proximal contact. The proximal contact force data were analyzed using two-way ANOVA in a split-plot arrangement followed by Tukey's test (α=0.05). The X-ray proximal contact analyses were described by the frequency.

Results: The proximal contact force with the molar was significantly higher than that with the premolar, irrespective of the resin composite or occlusal fatigue effect. The bulk fill technique showed a contact force similar to the incremental filling technique. Fatigue resulted in a significant reduction in the proximal contact force ($P < 0.001$), irrespective of the region analyzed or restorative material used. The digital X-rays detected no alteration in the proximal contact after occlusal fatigue.

Conclusions: The proximal contact force decreased with 5 years of simulated occlusal fatigue. The bulk fill technique showed a proximal contact force similar to that of the incremental filling technique.

Clinical relevance: *The proximal contact effectiveness tends to decrease with aging. This aspect is not easy to verify clinically using radiography. The bulk fill and incremental filling techniques have similar proximal contact forces.*

INTRODUCTION

Currently, resin composites have been very successfully used for restoring posterior teeth, showing acceptable longevity in clinical studies.[1] More than 500 million direct dental restorations are carried out each year around the world, including approximately 261 million direct resin composite restorations.[1,2] Characteristics such as secondary caries, fracture resistance, retention, marginal adaptation and discoloration and proximal contact of posterior restorations are the most important factors determining the clinical success of posterior restorations.[3,4]

The proximal contact point between tooth or restoration occurs when its contour area on the distal or mesial surface remains in close contact with the adjacent tooth.[5] An adequate posterior proximal contact between adjacent teeth is related to the clinical success of the restorations due the maintenance and stabilization of the dental positions in the arches.[6] Adequate proximal contact point means that there is a space for the passage of dental floss between adjacent teeth with little resistance. This dental floss does not to pass without resistance, but also, doe not so tight enough to prevent the passage of the wire or tear it up.[7]A contact point slightly opened may cause food accumulation, gingival inflammation, carious lesions, bone loss in proximal areas and tooth migration.[6,8,9] Likewise, too tight contact may cause periodontal complications, tooth migration and to making it difficult for the patient to floss.[7] Inadequate contact points (tight, open or loose), can be associated with proximal caries formation.[10] Clinically, this satisfactory contact point is assessed by the dentist by passing the wire with a slight resistance.[5,11,12] It is a simple method but does not allow to evaluate the proximal contact force variations used once proximal contact force is considered a physiological entity of multifactorial origin.[5,13,14] Nylon and Teflon floss materials tested in clinical study in natural teeth, found that the contact forces ranged from 2 to 10 N.[15] An in vitro study using intact extracted permanent first premolar measured the contact point using waxed nylon dental floss found that the proximal contact forces range from 10 to 50 N.[16] Greater contact forces has been described when tested dry surfaces and the magnitude of the force tend to be not related with the contact angulation area during sliding of dental floss.[16] Thus, many studies try to measure the strength of the proximal contact using devices and methodologies developed for this purpose.[17-24]

The reconstruction of a satisfactory resin composite proximal contact, with correct anatomical contour and appropriate proximal contact tightness is essential but also remains difficult when placing direct posterior restorations.[25,26] Resin composite and amalgam restoration techniques differ from proximal contact reconstruction based on several potential mechanisms, including resin composites that cannot be "condensed".[27,28] Bulk-fill resin composites are gaining popularity among clinicians because these materials simplify the restorative procedure by reducing the number of layers and thus the curing time.[1] Bulk-fill and conventional resin composites inserted incrementally in posterior teeth have shown similar clinical performance.[29] Proximal contact is an important clinical parameter that has not been frequently investigated for bulk fill resin composites. Also, proximal contact in natural dentition and implant restorations should be better understood to facilitate faithful reproduction of this parameter in posterior proximal resin composite restorations.[8]

Insufficient adaptation of the matrix to the adjacent tooth, shrinkage of material polymerization, and position of the tooth can influence the initial proximal contact.[30,31] A clinical study of posterior resin composite restorations has already shown that contact forces do not always remain stable over time, showing that proximal contacts tend to diminish after a period of 6 months.[20] Proximal contact loss is already considered to be a complication in implant prostheses, and a 7-

year clinical follow-up study evaluated the negative effects of proximal contact loss with implants and adjacent teeth, showing that periodontal ligament displacement can differ when performing resin composite restorations.[11]

To the best of our knowledge, no study has compared the influence of simulated mechanical cycling on the proximal contact force of bulk fill resin composites. Therefore, the purpose of this *in vitro* study was to analyze the proximal contact force(N) in incremental and bulk fill class II resin composite restorations with implant molar teeth and premolars simulating periodontal ligaments. The null hypotheses were as follows: 1) restoration generated by two different resin composites does not influence the proximal contact force; and 2) occlusal fatigue does not reduce the proximal contact force between resin composite restorations and the implant molar tooth or premolar simulating the periodontal ligament.

METHODS AND MATERIALS

Study design

Twenty models were made using the artificial tooth Tech Pro (IM do Brazil Ltda., São Paulo, Brazil) (protected and registered with the National Institute of Intellectual Property under no. P11001631-7) using it as a basis for making the replica specimens, with bilateral class II occlusal-proximal (OM, occlusal-medial; and OD, occlusal-distal) standardized cavity preparations. As a control, a group without cavity preparation and without restoration was used. The specimens were restored with 2 protocols, bulk filling and incremental filling techniques. The number of specimens was based on the coefficient of variability and the sample calculation. The power of the test was 80%, with a minimum detectable difference of 20%. There was a residual standard deviation of 15% and a significance level of 0.05, resulting in 10 specimens per group. The compositions of the resin composites provided by the manufacturers are listed in Table 1. The proximal contact openings of the specimens were determined by digital radiographic examination, and the proximal contact force (N) was measured by microtensile tests.

Model development

A model with proximal metallic teeth was designed for testing the proximal contact of posterior restorations (Figure 1). The mandibular posterior arcade of a mannequin (MOM, Manequins Odontológicos Marília, Marília, SP, Brazil), covering the 2nd molar, 1st molar and 2nd premolar, was used. The alveolus was adapted to the root of the first molar, and the second premolar was sculpted with Vipflash® acrylic resin (VIP, Pirassununga, SP, Brazil). A Morse taper 3.5 mm x 7.0 mm dental implant (Neodent, Curitiba, PR, Brazil) was placed as a substitute for the second molar. The matrix model was then duplicated using silicone rubber (Redelease, Barueri, SP, Brazil), and 20 models made of polystyrene resin (Cristal, Piracicaba, SP, Brazil) were replicated. A polystyrene resin cylindrical base 2.5 mm in diameter was added to the base of all the models to fit the cycling machine and then the microtensile test machine. Metal crowns were replicated from an individual waxing pattern applied to the reference model and adapted for each model from a standard silicone matrix. Premolars were replicated in wax from an artificial tooth rubber silicone mold and cast completely with nickel chrome alloy (Kromalit, Knebel Produtos Dentários, Porto Alegre, RS, Brazil) to ensure that wear only occurred on the specimen of interest. The implant crowns were cemented using dual cure resin cement (Allcem Core, FGM, Joinville, SC, Brazil) light cured for 40s on each surface using a VALO Cordless LED light curing unit (Ultradent, Salt Lake City, USA) with an irradiance of 1400 mW/cm², which was verified using a MARC Resin Calibrator (BlueLight, Halifax, NS, Canada). The typodont first molar and the second metallic premolars were included in the alveoli with the polyether impression material (Impregum, 3M Oral Care, St Paul, MN, USA) simulating the periodontal ligament.[32]

Specimen development and preparation:

One artificial first molar tooth (TechPro) received two proximal standard occlusal proximal cavity preparations (MO and OD) using a preparation machine.[33]A trained operator used a high-speed diamond bur (N.3198 bur, KG Sorensen, Barueri, SP, Brazil) under constant irrigation to prepare two proximal class II cavities 4 mm mesial/distal, 4 mm deep in the occlusal surface and 5.0 mm in the gingival box. This single tooth was duplicated after cavity preparation to create twenty replica teeth of polystyrene resin pigmented (Cristal, Piracicaba, SP, Brazil) with standardized preparations. For the control group, the replica of the artificial typodont tooth was used without cavity preparation, simulating the intact tooth and standardizing the position of the adjacent teeth.

Restorative procedure

The cavities in the specimens were then cleaned with 0.12% chlorhexidine, the well was dried, and the adhesive system Âmbar APS (FGM, Joinville, SC, Brazil) was applied. The adhesive system was photoactivated for10s. The partial preshaped metal matrix (Unimatrix, TDV Dental, Pomerode, SC, Brazil) was inserted and burnished to better define the proximal contact, and wood wedges (Cunhas anatômicas, TDV Dental) were inserted. The specimens were randomized (random.org.) and divided into 2 groups (n = 10) according to the restorative techniques used (since the control group did not receive restorative intervention): In the Inc-Z350XT group, the proximal boxes were restored in two increments using nanofilled resin composite, Filtek Z350 XT (3M Oral Care).[34] The Bulk-OPUS group was restored with a single increment of a bulk fill high viscosity resin composite, Opus Bulk Fill APS (FGM). The resin composites were photoactivated for 40s. All the restorative procedures were performed by the same operator. The finishing was performed using diamond burs (2135F and 2135FF, KG Sorensen, Barueri, SP, Brazil) to remove the excess with intermittent water spray. The polishing was performed using Sof-Lex Pop-On discs (3M Oral Care).

Proximal contact force calculation - Initial

The specimens were tested in a microtensile test machine (Microtensile ODEME, Luzerna, SC, Brazil) using a 1 mm/min crosshead speed to calculate the proximal contact force of the molar and premolar teeth. For the test, two metallic accessories were created for the microtensile machine, one for positioning the model during the tests and the other for stabilizing the dental floss during the tensile tests (Figure 2). Waxed texturized nylon dental floss with 0.09 mm diameter (Hillo, Aperibé, RJ, Brazil),[16] was inserted below the proximal contact area and was attached to the accessory stem fixed on the microtensile machine. The initial proximal contact tensile force values were measured 6 times for each specimen in newtons (N), with 3 measurements at each proximal contact, and the average of the maximum tensile force was calculated for each proximal contact surface. The dental floss used was changed after each test, eliminating possible influence of the dental floss wear on the measured proximal contact forces.[16]

Digital radiographic examination- initial

Digital phosphor plate sensor radiography (DürrDentall, Bietigheim-Bissingen, Germany) was obtained within 20 cm of the source of the Timex 70 E X-ray machine (Gnatus, Ribeirão Preto, SP, Brazil). Interproximal radiography was performed, and the images were transferred from the phosphor plate to the computer by means of a scanner (VistaScan Mini View, Durr Dental AG). When the specimens did not present contact between the adjacent teeth in the initial radiographic analysis, i.e., when they presented visible gaps between adjacent teeth, these restored specimens were replaced, because it was necessary and mandatory to start from the existing contact point to assess the contact force.[15]

Mechanical cycling tests

The specimens restored were submitted to occlusal mechanical fatigue simulating 5 years of oral aging. The specimens were submerged in water at approximately 37°C simulating chewing and mouth temperature and cycled 1,200,000 times from 0 to 50 N axial compressive loading with 8.0 mm diameter stainless steel spheres on the occlusal cusps with a 2 Hz frequency (Biocycle, Biopdi, São Paulo, SP, Brazil).[35,36]

Post mechanical fatigue tests

After mechanical aging, the proximal contact tensile force values in Newtons (N) were measured 3 times for each specimen, and the average of the maximum tensile force was calculated as described before. The difference between the proximal contact forces was calculated: Δ PCforce = Final PCforce – Initial PCforce.

Final digital radiographic examination

Final X-ray images were taken of all the specimens following the initial method. The initial and final X-ray images were displayed in PowerPoint (Microsoft office power point, Microsoft, Washington, EUA) on a screen without any manipulation or adjustment of the images. The X-ray images were blindly evaluated by two experienced and calibrated professionals, and the professionals analyzed the proximal contact using the following scores: (1) perfect proximal contact –no visible gap between restoration and adjacent tooth; (2) acceptable proximal contact - minimal areas of gapping that do not compromise the contact with the adjacent tooth; (3), unacceptable proximal contact - visible gapping between restoration and adjacent tooth that compromises the function of proximal contact (Figure 3).

Statistical analysis

The contact force data were tested for normal distribution (Shapiro-Wilk test) and equality of variances (Levene test), followed by parametric statistical tests. Two-way ANOVA was performed in a split-plot arrangement, with the plots represented by the restorative material and contact region and the subplot represented by the moment of the cavity. Multiple comparisons were made using Tukey's test. All the tests used $\alpha = 0.05$ as the significance level, and all the analyses were carried out with the statistical package Sigma Plot version 13.1 (Systat Software Inc, San Jose, CA, USA). The X-ray analyses were described by the frequency.

RESULTS

Microtensile

The proximal contact forces (N) between the restored molars using incremental and bulk fill filling techniques and adjacent molars and premolars measured by microtensile tests before and after the aging process are shown in

Table 2. Two-way repeated ANOVA revealed that the contact region had a significant influence ($P < 0.001$); however, no significant influence was observed for the resin composite type ($P = 0.102$) or for the interaction between the contact region and restorative material ($P = 0.622$). The incremental filling technique always showed a contact force similar to that of the bulk fill resin composite technique. Fatigue resulted in a significant reduction in the proximal contact force ($P < 0.001$), irrespective of the region analyzed or restorative material tested.

Proximal contours - Digital Radiographic Examination

The results of the digital radiographic examination analysis are shown in Table 3. Perfect proximal contact (score 1) was predominant for the proximal contour after the fatigue mechanical cycling tests, regardless of the region analyzed (molar or premolar) or resin composite tested. The Inc-Z350XT group had 3 molar specimens and 4 premolar specimens with a score of 2, and no specimen had unacceptable proximal contact. The Bulk-OPUS group had 4 molar specimens and 3 premolar specimens with a score of 2 and 1 molar specimen and 1 premolar specimen with a proximal contact score of 3.

DISCUSSION

The posterior restorations created using the incremental and bulk fill techniques had similar proximal contact forces; therefore, the first null hypothesis was accepted. However, occlusal fatigue simulating 5 years of aging significantly decreased the proximal contact force irrespective of the region of contact with the metal implant or tooth with periodontal ligament simulation; therefore, the second null hypothesis was rejected.

Assessing proximal contact force in in vitro studies has the advantage of possibly standardizing the conditions to be tested. Among the studies addressing the proximal contact that report wear or strength, many use pre-fabricated mannequin models or prepared typodonts but lack a simulation of the periodontal ligament for tests.[8,18-20,37] For this reason, a model was developed to approximate the characteristics tested in an *in vitro* study of the oral physiological conditions using a simulation of the periodontal ligament using polyether impression material.[32] The model of this study showed that proximal contact wear tends to occur only on the resin composite because both the crown on the implant and the simulation of the natural tooth were made of metal.[8,37] To evaluate the influence of the absence of flexibility on proximal contact with adjacent teeth, the implant was added to the model, simulating a frequent clinical condition currently observed.

In the literature, only the initial pre-restoration and post-restoration forces were measured without further clinical follow-up in a clinical study.[22] A 7-year clinical follow-up observed the natural tooth wear associated with the dental implant but with no quantification the proximal contact force.[11] In this study, the use of a specimen replica of the intact artificial tooth, without preparation or restoration, attempted to simulate the pre-restoration condition. In a similar way, the use of identical replicas of a single prepared tooth, restored in position in the fabricated models, allowed us to standardize and simulate clinical conditions. It was possible to compare the proximal contact forces on different materials before and after mechanical cycling.[18] Differently from *in vivo* studies, the great variability of the anatomical characteristics of the contact points between individuals only allows for evaluation between the states before and after the restorative procedure.[14,19]

The proximal contact force was measured using a device constructed at the University of Technology Delft in the Netherlands or similar devices. A 0.05 mm thick metal strip is connected to the device, which is inserted interdentally from the occlusal surface, quantifying the proximal contact tightness (N) as the maximum frictional force as the strip is slowly removed in the occlusal direction.[19,21-24] The proximal contact force measurement using a metallic matrix was modified in the present study.[14,17,18,20,24] Dental floss was used in this study to eliminate the influence of the matrix on adjacent teeth without changing the physiological conditions.[14] Additionally, the method with dental floss used in this study is similar to a method that has been used in other clinical studies.[12,15] The use of dental floss approximates the *in vitro* tests in clinical situations, and the force used by the patient to floss without pre-pressure can be easily translated to clinical recommendations and professional orientation.

A clinical study using nylon and Teflon floss materials in natural teeth, conclude the contact forces ranged from 2 to 10 N.[15] The contact point force values found in this study measured with waxed nylon dental floss corroborate the previous findings, despite the existing methodological differences, since they remained between 4.1 and 8.9 N, including control group. *In vivo* studies have shown that the loss of proximal contact structure tends to be greater in the mesial due to mesial displacement of natural teeth by the anterior component of the occlusal force.[11] Using a model that simulates the positioning of samples according to the natural position of teeth *in vivo*, the application of occlusal loads during the mechanical fatigue tests led to a reproduction of these forces, which corroborated the findings of lower force on the premolar contacts. The displacement was accentuated at the mesial since the distal contact simulated the absence of the periodontal ligament.

Occlusal fatigue resulted in a significant reduction in proximal contact force, irrespective of region analyzed or restorative material tested. The reduction in the proximal contact force can be attributed to wear resulting from the restored molar intrusion process during occlusal fatigue. The tooth moved up and down, generating friction with the adjacent metallic teeth, resulting in resin composite wear. The standardization of the load application is important to isolate the effect generated from additional factors, leading to the possible reproducibility of this methodology. The load applied only to restored tooth can be considered as a limitation of this study, and should be considered as worst scenario of the proximal contact restoration. Future studies analyzing the proximal wear caused by occlusal loading in all posterior teeth are necessary to complement the results of this study. This finding can be correlated with the observations extracted in clinical studies, since to the best of the author’s knowledge, no *in vitro* studies have evaluated the wear of the contact point after years of aging simulation. Clinical studies have shown that proximal contact loss occurs over time, from short follow-ups of 3 months to longer couplings of 5 years, under different clinical conditions.[11,12,21,38]

The incremental filling technique using Inc-Z350XT always presented a contact force similar to that of the bulk filling technique using Bulk-OPUS. These results occurred because Opus Bulk FillAPS and Filtek Z350XT have similar compositions for both the organic and the inorganic matrix and thus similar mechanical properties and wear resistance.[39,40] Although a resin composite is conventionally inserted in oblique increments of up to 2 mm and bulk fill is inserted in a single increment, both have high viscosity and similar inorganic filler content (Table 1). The wear of resin composite is widely dependent on the size, volume and quantity of charge particles.[41] A previous study demonstrated that high-viscosity bulk fill resin composites had KHN values similar to those of conventional resin composites.[42]

The results of the present study corroborate those of another study that stated that proximal contact force is related to the consistency of the restorative material and the restorative technique used[17], reaffirming that high viscosity resins produce strong proximal contact.[8] Previous studies affirmed that conventional resin composite inserted in bulk filling did not improve proximal contact force values.[17,43,44] The X-ray image analysis showed differences before and after cycling, but similar behavior was maintained between the two groups tested, reinforcing the contact point strength findings. The use of only one bulk resin composite should be considered as another limitation of this study. Different materials that present different filler content and mechanical properties can be performed differently. [34,37,43]

Food impaction caused by the lack of proximal contact between adjacent teeth can lead to problems such as tooth movement and biofilm formation, increasing the risk of secondary caries and periodontal disease.[8,45] In contrast, very tight contact points can cause patient discomfort, make it difficult to floss and cause periodontal injuries because the teeth are probably invading the interdental papilla space.[9] Clinical studies have shown that contact loss occurs over time at different intensities for restorations.[11,12,21,38] An annual failure rate of 2.8% was observed for resin composite restorations, in which one factor evaluated was the lack of contact points and overhang.[46] For this reason, the generation of a proximal contact with adequate form and function respecting the physiological characteristics is essential for the longevity of resin composite restorations, as expected for natural teeth,[20] and implant prostheses.[11,12] The use of bulk-fill resin composite provided good performance regarding this characteristic; however, future clinical studies should be performed.

As observed in the new methodology tested, occlusal fatigue was supported only by the central tooth, and the effect of fatigue may have been influenced by the adjacent tooth type, influencing the results. Future studies varying the viscosity of resin composites, using a larger number and different composition of bulk fill resin composites; and using specimens with greater resistance to the effects of cycling are needed to complement the current findings, leading to *in vitro* analysis of contact point strength closer to clinical conditions.

CONCLUSIONS

Within the limitations of this *in vitro* study, the following conclusions can be drawn:

- Occlusal fatigue simulating an aging process of 5 years decreased the proximal contact force between the implant and adjacent teeth with simulated periodontal ligaments, for high viscosity resin composites.
- Bulk filling using high viscosity resin composite and the incremental filling technique showed similar proximal contact forces before and after occlusal fatigue, in relation of two materials used.

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Tables

Table 1. Resin Composites used in this study

Material	**Code**	**Resin Composite Type**	**Organic Matrix***	**Filler***	**Filler% Wt/Vol***	**Manufacturer**	**Number**
Filtek Z350XT	Inc-Z350XT	Nanofilled	Bis-GMA, Bis-EMA, UDMA, TEGDMA	Silica and zirconia nanofillers, agglomerated zirconia silica nanoclusters	79/63	3M Oral Care (St Paul, MN, USA)	N652583
OPUS Bulk Fill APS	Bulk-OPUS	High-viscosity bulk fill	TEGDM, Bis-EMA, UDMA	Silica with urethane dimethacrylate, salinized silica dioxide, salinized barium glass, YbF3	68	FGM (Joinville, Brazil)	N251017

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

Table 2. Means and standard deviation of proximal contact force (N) measured using microtensile test.

Restorative Material	Region			
	initial		Post-Fatigue	
	Molar	Premolar	Molar	Premolar
Incremental – Filtek Z350XT	7.7 ± 1.9 Aa	5.8 ± 2.5 Ba	5.7 ± 2.4 Aa	4.1 ± 1.8 Ba
Bulk fill – Opus Bulk Fill APS	8.9 ± 2.3 Aa	6.1 ± 2.2 Ba	7.3 ± 1.9 Aa	4.5 ± 2.1 Ba
Pooled average	7.4 ± 2.2*		5.3 ± 2.0**	

Different letters indicate a significant difference calculated using two-way RM ANOVA (*P*< 0.05).; upper caser letters were used for comparing location at contact point (molar or premolar); and lower caser letters were used for comparing restorative material (Z350XT or OPUS); *indicate difference significant for sub-plot fatigue effect (pre and post-fatigue).

Table 3*.* Proximal contour score analysis with digital radiography examination after fatigue mechanical cycling.

Restorative Material	Number of teeth with each criterion evaluated					
	Molar (D)			Premolar (M)		
	1	**2**	**3**	**1**	**2**	**3**
Incremental – Filtek Z350XT	7	3	0	6	4	0
Bulk fill – Opus Bulk Fill APS	5	4	1	6	3	1

* 1- perfect proximal contact; 2- proximal contact acceptable; 3- unacceptable proximal contact; M, mesial; D, Distal.

Figures

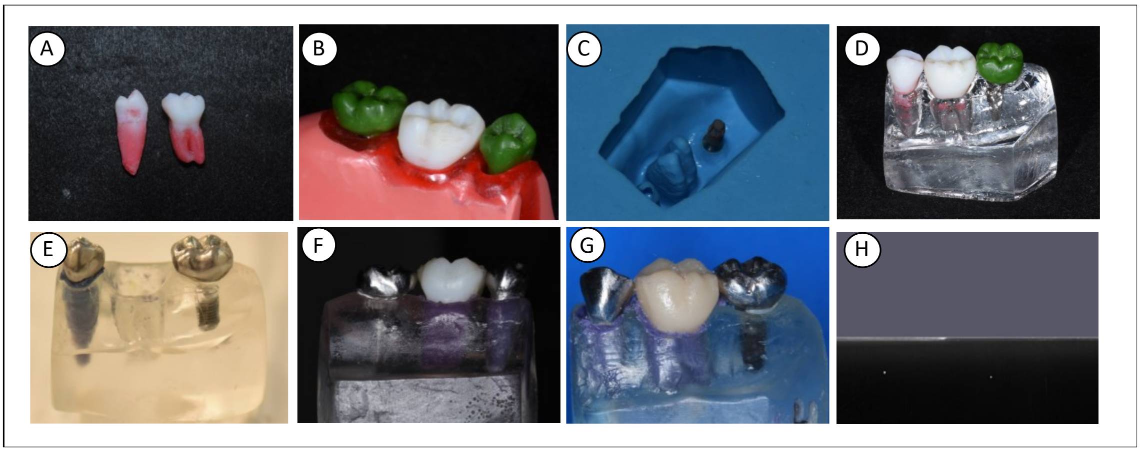

Figure 1. Device developed for proximal contact test: A, artificial teeth with the periodontal ligament simulation; B, artificial teeth fitted in the base model after alveoli relined with red acrylic resin shaping the roots of artificial teeth with periodontal ligament simulation; C, mold base with rubber silicone and implant positioned; D, checking the fitting of the artificial teeth and wax crown over implant; E, aspect of the model with metal teeth and metal crown in position; and F, final aspect of the model with specimen before the restorations; G, final aspect of control group specimens without cavity preparation; and, H, Control group specimen radiographic image showing satisfactory proximal contact.

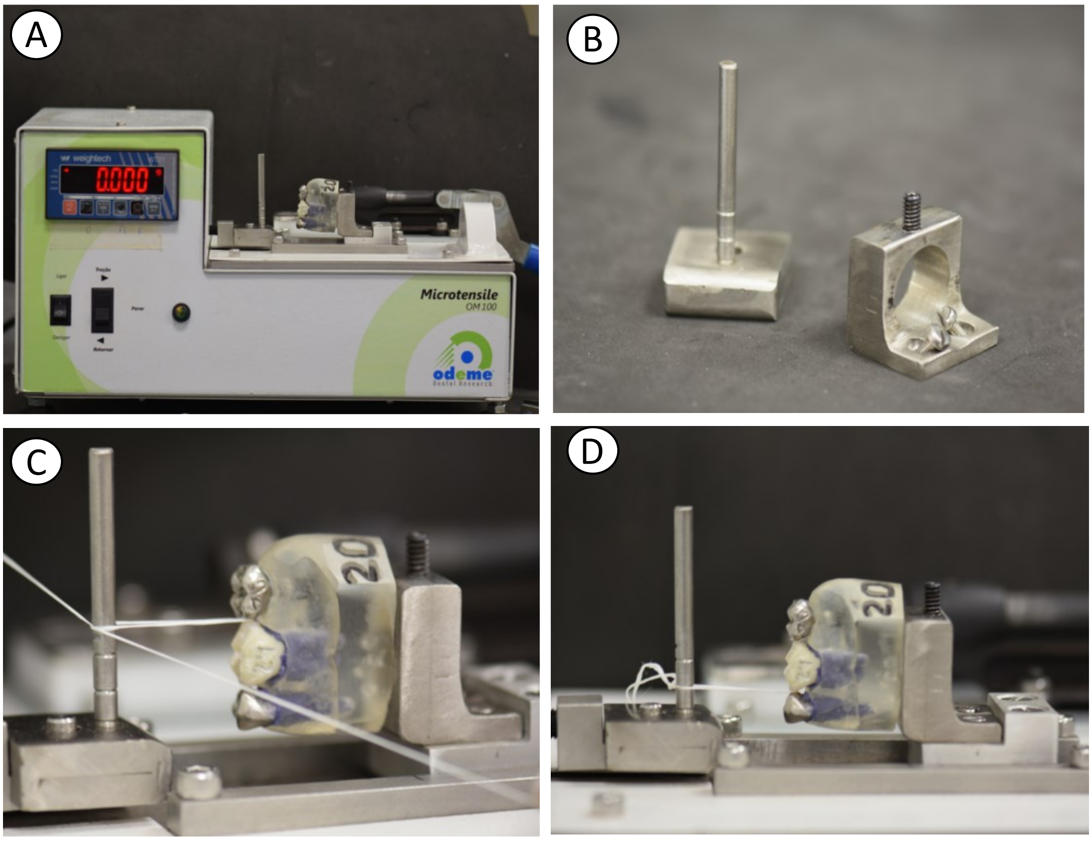

Figure 2. Microtensile method used for contact force measurement: A, microtensile machine with specimen and devices positioned the traction for measurements; B, devices developed to standardize the specimen position during test; C, clinical dental floss passed parallel around the contact point and pulled by the equipment in molar contact; and D, dental floss passed in premolar contact.

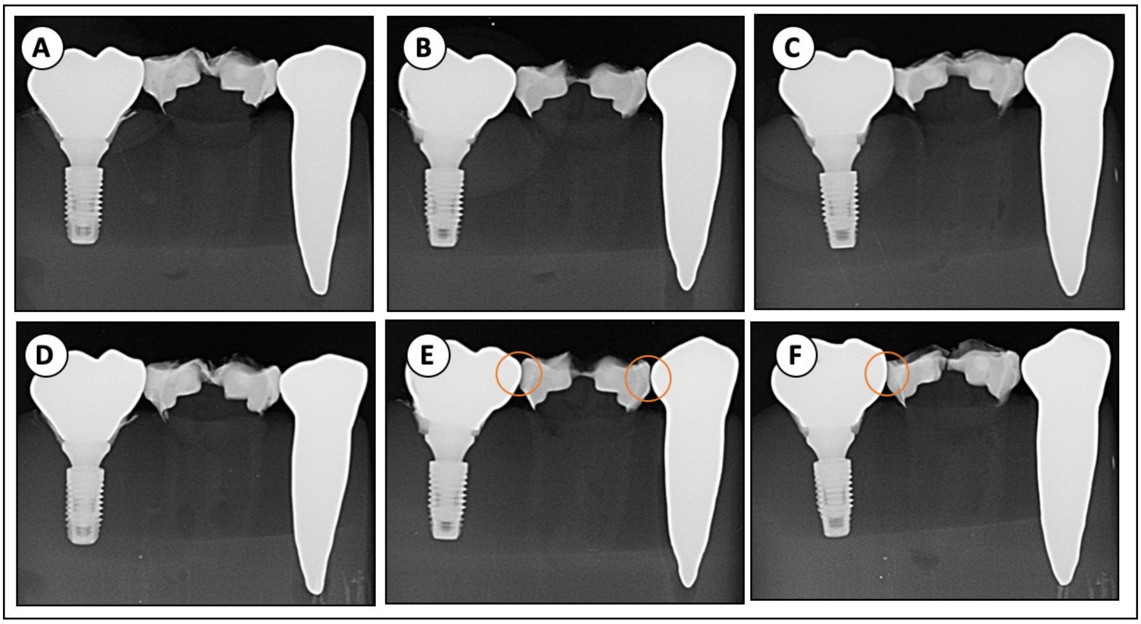

Figure 3. Digital radiography examination: A and D, Bulk-OPUS specimen score 0, with no difference at both proximal contact points comparing pre and post-fatigue; B and E, Inc-Z350XT specimen score 1, difference without continuity in both proximal contact points; C and F, Bulk-OPUS specimen score 2 at the mesial and score 0 at distal, representing no difference.

3.2 CAPÍTULO 2

Mechanical and physical properties of resin modified glass ionomer cements and bulk fill resin composites used for restoring posterior teeth.

Artigo a ser submetido para publicação no periódico **Operative Dentistry**

Mechanical and physical properties of resin modified glass ionomer cements and bulk fill resin composites used for restoring posterior teeth.

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Short title: Properties of Resin modified glass ionomer cements and bulk fill resin composites.

Keywords: resin-modified glass ionomer cement, bulk-fill resin composite, shrinkage stress, radiopacity.

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Mechanical and physical properties of resin modified glass ionomer cements and bulk fill resin composites used for restoring posterior teeth

ABSTRACT

Objective: To evaluate the post-gel shrinkage (Shr), compressive strength (CS), diametral tensile strength (DTS), flexural strength (FS), elastic modulus (E), and radiopacity of resin-modified glass ionomer (RMGIC) and bulk-fill resin composites (BFRC) used for restoring posterior teeth.

Materials and methods: Four RMGIC Ionoseal (ION, Ionoseal, Voco GmbH; VIT, Vitremer, 3M-ESPE; FUJI, GC Fuji lining lc, GC America Corporation; RLC, Riva light cure, SDI) and two regular viscosity BFRC (TN-Cer, Tetric N-Ceram Bulk Fill, Ivoclar Vivadent; FOBF, Filtek One Bulk Fill, 3M Oral Care) were tested. Shr was calculated using strain-gauge test. CS, DTS (MPa) were calculated at 0.5mm/min. FS and E were calculated by 3-bending flexural test. Radiodensity was calculated and compared with the aluminum step wedge. Data analyzed using one-way analysis of variance (ANOVA) followed by Tukey's test ($\alpha = 0.05$) was performed for each mechanical property for RMGIC. *T*-Student test was used for each mechanical property for BFRC ($\alpha = 0.05$).

Results: RLC group had the highest values for post-gel shrinkage, and ION group had the lowest. The ION group had the highest values for compressive, diametral tensile, and flexural strengths, and RLC had the lowest values. VIT had the highest values of elastic modulus. For radiopacity, RLC had the highest radiopacity values and other RMGIC had similar values ($P < 0.001$). TN-Cer presented the higher value of post-gel shrinkage, compressive strength, elastic modulus and radiopacity. FOBF presents low pos-gel shrinkage and higher diametral tensile and flexural strengths ($P< 0.001$).

Conclusion: The RMGIC and BFRC have different compositions, which can influence their mechanical and physical properties. According to the ideal material choices for restoring posterior teeth, which needs a balance of a low post-gel shrinkage value and elastic modulus for generated good resistance when in association, the ION and FOBF had a highlight, for a base and cover material, respectively.

CLINICAL RELEVANCE: *The lower elastic modulus and post-gel shrinkage values of RMGIC support their use as base materials for posterior restorations and may be covered by BFRC due to higher elastic modulus, flexural, tensile and compressive strength for restoring posterior teeth.*

INTRODUCTION

Clinical applications of resin-modified glass ionomer cements (RMGICs) are similar of conventional glass ionomer cements (CGI).[1,2] Both can be used for restoring posterior primary teeth, cervical lesions, or as a materials base of final resin composite restorations.[3-9] The incorporation of resin components, as 2-hydroxyethyl methacrylate (HEMA) and the photoinitiator camphorquinone, improve their mechanical properties and increased working time of RMGIC.[10,11] The use of CGI and RMGI are not the principal indication for areas of extreme occlusal forces.[1]

The HEMA monomers addition to the material adds the polymerization reaction to the conventional acid-base reaction, leading to the need for a balance between the two reactions.[12] The photoactivation time after manipulation influences the proportion between the two reactions, demonstrating the importance of carrying out photoactivation for reach the ideal mechanical properties.[13-15]

The RMGIC have been demonstrated higher flexural strength, flexural toughness, compressive strength, and fracture toughness than of CGI materials.[1] However, the different compositions, manipulation, insertion and photoactivation protocols, can directly influence the mechanical properties of RMGIC.[16] Is difficult to define consensus on the values of the mechanical properties of RMGIC.[17]

Large posterior cavities in vital and endodontic permanent teeth required more than RMGIC for providing longevity of direct restorations of molars and premolars.[7,9,18,19] Clinical studies with RMGIC have been demonstrate suitable performance similar to a resin composites in primary molars, despite more pronounced occlusal wear.[4,5,18] This similar clinical performance doesn't occur only for secondary carious lesions, in this case RMGIC presents superior clinical performance.[5] However, the requirements for materials restoring primary molars are different from permanent teeth.[18] For improve better biomechanical principles of posterior teeth, the use of resin composites has been prioritized.[18] Clinical studies have reported more successful clinical performance for bulk fill and conventional resin composites in class II restorations.[20,21] The use of BFRC can decrease the clinical time of the restorative procedure and minimizing the clinical effects of polymerization shrinkage stresses.[22,23] BFRC can be inserted, and light cured, in 4 to 5 mm increments, and have demonstrated mechanical performance like conventional resin composites in laboratory studies.[22-25] Clinical studies demonstrate good clinical behavior for BFRC in direct restorations of posterior teeth.[21,26]

The BFRC has optimized characteristics and are being increasingly used, even in association with other restorative materials such as RMGIC.[7,9] This technical association of BFRC with a material with lower elastic modulus, has enabled the reestablish the biomechanical performance satisfactorily.[9,17,27,28] The association is determined by the use of RMGIC in deeper areas, where the mechanical properties are not main requirement and the external surfaces restored using BFRC due their higher mechanical properties.[20,21]

The materials used for restoring posterior teeth needs also to present an adequate radiopacity favoring to distinguish the tooth structures, secondary caries, voids, inadequate marginal adaptation or gaps.[29,30] RMGIC and BFRC present different radiopacity values according to the compositions, thickness and expositions.[31,32]

Restorative material choices to restore posterior teeth is favored by knowledge of the materials properties available. For this reason, the analyze of material properties needs continuous update, once the materials evolution its constant.[23,28] The mechanical properties expressed by flexural strength, flexural modulus, tensile and compressive strength and also the radiopacity of different RMGICs and BFRCs can better guide the clinicians for material selection and the thickness of the inner RMGIC layer when they are used in combination. This study aimed to evaluate the mechanical properties expressed by post-gel shrinkage, compressive strength, diametral tensile strength, elastic modulus, flexural strength, and radiopacity of RGMICs and BFRCs used for restoring posterior teeth. The null hypothesis was that different the composition of RMGIC and BFRC would not influence their mechanical and physical properties.

METHODS AND MATERIALS

Study design

Four RMGICs materials: ION, Ionoseal (Voco GmbH, Cuxhaven, Germany), VIT, Vitremer (3M Oral Care, St. Paul, USA); FUJI, GC Fuji Lining LC (GC America Corporation, Tokyo, Japan); and RLC, Riva light cure (SDI, Victoria, Australia); and two regular viscosity BFRCs: TN-Cer, Tetric N-Ceram Bulk Fill (Ivoclar Vivadent, Schaan, Germany) and FOBF, Filtek One Bulk Fill (3M Oral Care, St. Paul, USA) were tested in this study. All materials were light activated using a multi-peak light curing unit (VALO Cordless; Ultradent, South Jordan, UT, USA), with irradiance of 1200 mW/cm^2, checked using MARC Resin Calibrator (BlueLight Analytics, Halifax, Canada). Post-gel shrinkage (Shr) was calculated using strain-gauge test. Compressive strength (CS) and diametral tensile strength (DTS) were calculated. Flexural strength (FS, MPa) and elastic modulus (E, MPa) were calculated by 3-bending flexural test. Radiodensity was calculated and compared with the aluminum step wedge. The compositions and information of tested materials are listed in Table 1.

Post-gel shrinkage (Shr, %)

Post-gel linear shrinkage was determined using the strain gauge method.[33] Five specimens were tested for each group (n = 5). The materials were shaped into a hemisphere (1mm thick and 2mm x 2mm) on top of a biaxial strain gauge (CEA-

06-032WT-120, Excel Sensores, Taboão da Serra, SP, Brazil), that measured shrinkage strains in two perpendicular directions. A strain conditioner (ADS0500IP, Lynx, São Paulo, SP, Brazil) converted electrical resistance changes in the strain gauge to voltage changes through a quarter-bridge circuit with an internal reference resistance (120 Ω). The strain values measured along the two axes were averaged since the material properties were homogeneous and isotropic on a macro scale. All materials were manipulated and inserted by the same operator. The RMGIC were manipulation of handmix and inserted using a syringe (Centrix, Shelton, CT, USA), excepted ION group, that does not require manipulation and was inserted with the needle tip. All materials were light activated using the VALO Cordless positioned with a device developed for the standardization with the light tip held at 1 mm distance from the surface of the specimen, for the time recommended by the manufacturer (table 1).[14,15] All tests were performed in a dark room with yellow light. The strain values were collected for five 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%.[34]

Compressive (CS) and diametral Tensile strength (DTS)

The RMGIC were manipulation of handmix and inserted using Centrix syringe and ION group was inserted with the needle tip. The materials were placed into a cylindrical Teflon mold for the compressive strength test (6 mm height, 3 mm diameter) or the diametral tensile strength test (2 mm height, 4 mm diameter).[22] The specimens for the compressive test made with BFRC were polymerized with 4.0 mm for the first increment and 2.0 mm for second increment. The specimens for the compressive test made with resin-modified glass ionomers were polymerized with three increments of 2.0 mm each. Afterwards, the specimens were stored in distilled water for 24 h at 37 ^{o}C. The specimens were submitted to compressive strength and diametral tensile testing in a universal testing machine (DL2000, EMIC, São José dos Pinhais, PR, Brazil) at a crosshead speed of 0.5 mm/min until failure occurred. Compressive strength values (MPa) were calculated by dividing the fracture load (F) by the cross-sectional area and converted into MPa. Diametral tensile strength values (MPa) were calculated using the equation:

$DTS = 2F/¶dt$,

where d is the specimen diameter, and t is the height of the specimen.

Flexural strength and elastic modulus (E)

The flexural strength of all groups was determined by a three-bending flexural test performed in accordance with ISO 4049 Standard.[35] Five specimens made for each group and were tested after being stored for 24h in a dry oven at 37°C. The specimens (n = 5) were prepared in stainless steel molds (25 x 2 x 2 mm) in a dark room with yellow light. To minimize the presence of bubbles and obtain a smooth surface, the mold was placed on a glass plate and a polyester strip was positioned between the glass plate and the mold. The RMGIC were manipulation of handmix and inserted using Centrix syringe, excepted ION group, that does not require manipulation and was inserted with the needle tip. The BFRC were inserted into the mold using a condenser for better adapt to the material, then another polyester strip was placed, and a second glass plate was used to press the material to force the excess resin composite out. The specimens were light activated for 20 seconds with 3 light expositions covering the entire specimen extension whit a multi-peak LCU (VALO Cordless). The test was performed using the 3-point bending set-up using a universal testing machine (Instron ElectroPuls TM E3000, Instron, High Wycombe, UK) and assembled using the software (Bluehill Universal, Instron Training Center, Norwood, MA, USA) with a crosshead speed of 0.5 mm / min. Flexural strength was determined according to the following formula:

$\alpha = 3FL/2wt$;

where F is the maximum force applied (N); L is the distance between the support beams (mm); *w* is the width of the specimen (mm); and *t* is the thickness of the specimen (mm). The modulus of elasticity (MPa) was determined using flexural deflectometer (W-E401- J, E-Series Deflectometer, Instron, Norwood, MA, USA).

The deflectometer tip was positioned at the center of specimen base during the test to measure the deflexion during loading application. The modulus of elasticity (MPa) was determined to the following formula:

$$E = FL^3/ 4BH^3d$$

where F is the maximum load (N); L is the length of the specimen (mm); B is the width of the specimen (mm); H is the height of the specimen (mm) and d is the deflection (mm) corresponding to the load F.[36]

Radiopacity

After measuring Flexural strength, the specimens from each group were used for analysis radiopacity. Five specimens of RMGIC and resin composites were positioned over a phosphor plate (n = 5) (Figure 1). The aluminium step was also placed on phosphor plate and the set was positioned inside a device developed for the standardization for in vitro studies.[31] The radiographic exposure was performed using Timex 70 E (Gnatus, Ribeirão Preto, Brazil) with exposure of 0.35s at 70kV and 7.0 mA. The phosphor plate was placed 20 centimeters away from radiographic cylinder. Three radiographic exposures were performed for each group. The radiographs were transferred from the phosphor plate to a computer using a Vistascan 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 specimen 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 material. The final value of each group was obtained from the mean of the three radiodensity values obtained of each radiograph.[32]

Statistical analysis

The Shr, CS, DTS, FS, E and radiopacity data were tested for normal distribution (Shapiro Wilk test) and equality of variances (Levene test), followed by parametric statistical analysis. One-way analysis of variance (ANOVA) was performed for each mechanical property for RMGIC. Multiple comparisons were made using Tukey's test. Test-t was used for each mechanical property for BFRC. All tests employed α = 0.05 significance level and all analyses were carried out with the statistical package (Sigma Plot version 13.1, Systat Software Inc, San Jose, CA, USA).

RESULTS

Post-gel shrinkage (Shr, %)

The Shr mean and standard deviation values of RMGIC and BFRC are shown in Figure 2A, and the Shr curves are shown in Figure 2B. One-way ANOVA showed significant difference between the RMGIC Shr (*P* < 0.001). Tukey's test showed that the RLC group had the highest Shr values (*P* <0.001) and ION had the lowest Shr values (*P* < 0.001). TN-Cer had higher Shr values than FOBF (*P* < 0.001).

Compressive (CS) and diametral Tensile strength (DTS)

The CS mean and standard deviation values of RMGIC and BFRC are shown in Table 2 and Table 3, respectively. One-way ANOVA showed significant differences between the RMGIC (*P* < 0.001). Tukey's test showed that the ION group had the highest and RLC and FUJI had the lowest CS values (*P* < 0.001). The *t*-Student test showed that TN-Cer had the higher CS values than FOBF (*P* = 0.034).

The DTS mean and standard deviation values of RMGIC and BFRC are shown in Table 2 and table 3, respectively. One-way ANOVA also showed significant differences between the RMGIC (*P* < 0.001). Tukey's test showed that the ION group had the highest and RLC had the lowest DTS values. The *t*-Student test showed FOBF had higher DTS values than TN-Cer (*P* < 0.001).

Flexural strength and elastic modulus (E)

The flexural strength means and standard deviation values of RMGIC and BFRC are shown in Table 2 and Table 3, respectively. One-way ANOVA showed significant difference between RMGIC (*P* < 0.001). Tukey's test showed that ION had the highest FS values (*P* < 0.001). The test-t showed significant difference between BFRC (*P* <0.001). The FOBF had the highest FS (*P* = 0.023).

The elastic modulus means and standard deviation values of RMGIC and BFRC are shown in Table 2 and Table 3, respectively. One-way ANOVA showed significant difference among the RMGICs (*P* < 0.001). Tukey's test showed that VIT and FUJ had the highest E values (*P* <0.001) and RLC and ION presents the lowest, but also its not significant different of FUJ. The test-t showed significant difference between BFRC (*P* < 0.001). The TN-Cer had the highest E values (*P* < 0.001).

Radiopacity

The radiopacity mean and standard deviation values are shown in Figure 3. One ANOVA showed significant difference between the RMGIC (*P* < 0.001). Tukey's test showed that the RLC had the highest radiopacity values, and ION, FUJI, and VIT had similar and lower values (*P* < 0.001). RMGIC demonstrated radiopacity level similar or higher than 4mm of aluminum step-wedge, with RLC demonstrated similar radiopacity with 5mm of aluminum step-wedge. The *t*-Student test that TN-Cer had higher radiopacity values (similar to 8mm of aluminum step-wedge) than FOBF (similar to 6mm of aluminum step-wedge); *P* < 0.001).

DISCUSSION

This study evaluated the mechanical properties of RMGIC and regular viscosity BFRC. The RMGIC and the BFRC type demonstrated significant effect on Shr, CS, DTS, FS, E, and radiopacity values; therefore, the null hypothesis was rejected.

Restorative procedures aim to return the condition of form and function to the teeth, as close as possible to the properties of natural tooth.[37] The use of restorative materials that have mechanical properties similar to the tooth structure contributes to a greater predictability of clinical success and longevity.[16,17] The

BFRC and RMGIC have as a common and positive point the ease of clinical insertion and faster execution of the technique, when compared to conventional resins and GIC, respectively.[17,23] This is one of the reasons these two materials are increasingly used to directly restore posterior teeth.[20,21]

The interaction of materials and restorative techniques has shown good biomechanical results in laboratory and clinical studies, in vital posterior teeth and endodontically treated.[7,9,19-21] High shrinkage stress is a serious concern, and harmful for the integrity of the bonded interface of resin composite restorations, being one of the main reasons for adhesive failures.[38-41] Materials with high post-gel shrinkage tend to generate stress at the interface and can cause cusp deformation,[23,42] leading to cracks in the enamel and in the future, which can lead to restoration failure, thus, one of the properties that must be taken into account when choosing the restorative material, but not the only.[7,23,38,42]

In this study, RLC had the highest value of Shr while ION and VIT had the lowest values. The composition of the material is one of the factors related to the development of post-gel shrinkage, such as inorganic concentration and monomeric content.[43] The high values of Shr of the RLC can be explained by the presence of the monomer HEMA in its organic matrix, and the absence of the monomer Bis-GMA, responsible for increasing the viscosity and, when not in excess, providing a decrease in the Shr.[38,43,44] The FOBF had lower Shr than TN-Cer, despite both having similar amount of charge particles by weight. Materials with different proportions of monomers and similar filler content demonstrate clearly relationship when they have more than 50% filler by weight,43 such as FOBF and TN-Cer. The lower values of Shr for VIT presented in this study corroborates with a previous study that also found low values of Shr for VIT and related to lower stress generation in the dental structure.[7]

The combination of high post-gel shrinkage with high elastic modulus can generate high polymerization shrinkage stresses in the tooth structure and at the interfaces.[7] To minimize the stresses generated at the bonded interfaces, techniques with a combination of resin composite and lower elastic modulus have been proposed.[7,18,19] The E demonstrates the relative stiffness of the material which helps in predicting how occlusal forces might be supported by a given material.[45] In this study, the BFRC presents high E values, with the TN-Cer the highest, with Bis-GMA in their matrix and silanized filler.

The ideal material must have an E compatible with the dental substrate, to minimize the effect of the deformation, under the action of masticatory forces and resist wear.[41,45] Therefore, would be expect that a material that will serve as a base, inserted into dentin region, should have an E similar to the dentin substrate.[45] In the present study, all RMGIC had lower E than resin composites, proving to be a possible choice for be base in this technique. RLC and ION had the lowest E values, and VIT had the highest value. As E is related to Shr, the low E values of the RMGICs also can be explained by their compositions, such as the type of filler and their matrix composition, and the absence of signaling of the glass particles constitutes a weak binding of the monomeric components.[38,43,46]

Compressive strength may be used as a measure of the ability of a material to resist a masticatory force.[47] Another factor that interferes with the mechanical properties of the RMGIC is manipulation.[16] In this study, the RLC, FUJI, and VIT are hand mixed from a powder-liquid formulation. Despite being handled according to the manufacturer's recommendations, by the same calibrated operator, they differ from the ION group, which is presented in a syringe and does not require manual handling, being inserted with the tip of the material itself. Material handling has been related to CS values, which are higher for RMGIC auto mix.[16] In this study, ION presents higher CS values, and RLC and FUJI had the lowest and similar values. Besides, the ION was the unique RMGIC used that presents Bis-GMA in its composition. For the DTS, ION also presented higher values, and RLC also was the lowest DTS values.

For BFRC, the Tn-Cer presents higher values of CS, and FOBF presents higher DTS values. As well as ION, TN-Cer presents Bis-GMA in your composition.[43,44,46] The filler particle type, size and weight percentage have directly influence in these properties. The small filler particle size and nanoparticles improved compressive and flexural strengths.[43,48] However, the result of BFRC for CS contradict the claims of a prior study which relates high CS values for BFRC with Zr nanohybrid filler.[49]

The 3-bending test is considered a representative condition test that corresponding the occlusal forces exerted by the cusp of an antagonistic tooth, involving tensile, compression, and shear stress, simulating the clinical conditions.[47,50] Flexural strength values can be associated with the prediction of long-term material wear and with CS values.[46,51,52] In this study, the ION group presents highest values for FS and CS; likewise, RLC presented the lowest of FS and CS values. According to ISO, RMGIC should have a minimum FS value of 20 MPa for clinical use.[16,52] All RMGIC tested in this study presents highest values than minimal required. In a previous study, FS for RMGIC ranged from 49-76 MPa, with this difference being attributed to the presence of light activated resin components, which increases the material's load bending performance.[1] For BFRC, FOBF presents the highest values of FS, since FS and CS are related, and both are related to charge particle size, this FOBF value may be related to its charge size characteristic, filler cluster, and composition with zirconia which is very stable and adds excellent mechanical properties to the material, as shown in a previous study.[48,49]

Different values have been reported for ideal radiopacity level of materials and an ideal material for correct diagnosis must have good radiopacity.[31,53] This study used the aluminum wedge step for evaluate the radiopacity of materials and was used because your similarities with same dentin thickness, and for have twice radiopacity value when compared of enamel.[31,35,52] All materials tested have sufficient radiopacity for facilitated secondary caries detection, voids, and marginal defects, as previous studies published.[31,32] The radiopacity of materials is related with chemical composition and to filler content and size.[31] The addition of elements with a high atomic number, such as zirconium, silicon, barium, aluminum, for example, increases the radiopacity of these materials because it increases their capacity to absorb x-rays.[29] RLC presents the highest values for RMGIC. The ION, FUJ and VIT groups had similar values. These differences may be caused by filler volume, as the type of particles of the powder has basically the same (glass ionomer powder with fluor aluminosilicate glass), but the quantities of these particles are not clearly provided by the manufacturers. TN-Cer presents the highest values for BFRC. In this material, the following elements related to radiodensity were found: Silanated barium glass filler (high atomic number). For FOBF, the elements are silica and zirconia, radiopaque fillers, but have silica cluster filler, which modify their size and structure in relation to Tn-Cer and may the cause of the differences, although both contain a similar amount of filler.[29,31]

For restoring permanent teeth, the choice of RMGIC with good mechanical properties, with lower E values than BFRC, however that fill the required FS values is recommended. When both materials present lower Shr values, a satisfactory strategy is reached for restoring molars and premolars.

Considering all the variables related to the RMGIC and BFRC, the choice of restorative material is enriched by information on composition and mechanical properties. However, other mechanical and chemical properties need to be considered to determine the material and associated restorative technique suitable for clinical use.[17] It is necessary to emphasize that laboratory studies alone are not enough to extrapolate results to clinical practice, but they are essential to raise scientifically based discussions and initiate questions. This can be considered one of limitation of the work, and further studies are needed to accompany the new materials and techniques that are continually launched and developed. Also, further studies are needed to establish a relationship of these materials, your mechanical properties and their implications on dental structure, and stress generated when a RMGIC will used in combination with BFRC for restoring teeth in different cavities configurations, vital or not vital.

CONCLUSIONS

Within the limitations of this laboratorial study, the following conclusions can be drawn:

1. ION group presented the lowest value of pos-gel shrinkage and higher values of most properties. VIT presented the highest elastic modulus value. FUJI demonstrated median behavior and closer to VIT in most of tests. RLC presented the highest value for post-gel shrinkage and radiopacity, and lowest values for other properties.
2. TN-Cer presented the higher value of post-gel shrinkage, compressive strength, elastic modulus and radiopacity. FOBF presents low pos-gel shrinkage and higher diametral tensile and flexural strengths.
3. According to the ideal material choices for restoring posterior teeth, which needs a balance of a low post-gel shrinkage and good resistance when in association, the ION and FOBF had a highlight, for a base and cover material, respectively.

Conflict of interest

The authors have no conflict of interest.

Acknowledgement

This project was supported by CNPq and granted from FAPEMIG. The authors thank 3M-ESPE to provide the resin composites.

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Tables

Table 1. Materials Tested information's.

Material	Code	LOT	Material type	Shade	Increment size and light activation time	Organic Matrix	Filler	Filler% (wt)	Manufacturer
Tetric N-Ceram Bulk Fill	TN-Cer	U22999 Z00y36	Bulk-fill paste resin composite	IVW	4.0 mm – 10 s	Bis-EMA, Bis-GMA, UDMA	Silanated barium glass filler	75-77	Ivoclar Vivadent (Schaan, Liechtenstein, Germany)
Filtek One Bulk Fill	FOBF	NA223 65	Bulk-fill paste resin composite	A2-S	4.0 mm 20 s - >1000 mW/cm^2 40 s - <1000 mW/cm^2	AUDMA, diurethane-DMA, 1,12-dodecane-DMA	Silica filler, Zirconia filler, Ziirconia/ silica cluster filler	76.5	3M-ESPE (St. Paul, MN, USA)
Ionoseal	ION	1845144	Resin-modified glass ionomer	----	2.0 mm – 20 s	Bis-GMA, diurethanedimethacrylate, BHT and glass ionomer powder.			VOCO GmbH (Cuxhaven, LS, Germany)
Vitremer	VIT	NA211 49	Resin-modified glass ionomer	A3	2.0 mm – 40 s	Poly (acrylic-itaconic acid) with pendent methacrylate, H2O	Fluoroaluminosilicate glass, microencapsulated	90 - 99.9	3M-ESPE (St. Paul, MN, USA)
GC FUJI LINING LC	FUJ	1801061	Resin-modified glass ionomer	----	1.6 mm – 30 s	Liquid: Polyacrylic acid 20–22% 2-Hydroxyethyl methacrylate (HEMA) 35–40% Proprietary Ingredient 5–15% 2,2,4, Trimethyl hexamethylene dicarbonate 5–7% Triethylene glycol dimethacrylate 4–6% Powder: Alumino-fluoro-silicate glass (amorphous) 100%			Gc America Corporation (Bunkyo-ku, Tokyo, Japan)
Riva light cure	RLC	11450301	Resin-modified glass ionomer	A3	2.0 mm – 20 s	Hydroxyethyl Methacrylate, Acrylic acid homopolymer, Dimenthacrylate Cross-linker, Acidic Monomer, Tartaric acid, Glass powder			SDI (Victoria, Australia)

Abbreviations: Bis-GMA, bisphenol-A glycol dimethacrylate; AUDMA, aromatic dimethacrylate; DMA, dimethacrylate; FAS, fluoroaluminosilicate.

Table 2. Experimentally determined mean (standard deviation) of volumetric post-gel shrinkage, compressive strength, diametral tensile strength, elastic modulus, and flexural strength*, and the ratio of compressive and tensile strength for RMCIC.

Material	**Volumetric post-gel shrinkage (%)**	**Compressive strength (MPa)**	**Diametral tensile strength (Mpa)**	**Elastic modulus (MPa)**	**Flexural strength (MPa)**
ION	0.08 (0.01) ^{DC}	192.8 (26.4) ^{A}	45.9 (2.8) ^{A}	5652.4 (2186.4) ^{B}	119.9 (19.6) ^{A}
FUJ	0.1 (0.02) ^{B}	117.2 (12.0) ^{C}	28.8 (5.4) ^{BC}	8744.6 (5771.9) ^{AB}	74.2 (15.3) ^{BC}
RLC	0.7(0.20) ^{A}	116.6 (10.0) ^{C}	22.4 (3.2) ^{D}	3955.2 (1420.5) ^{B}	63.4 (3.9) ^{C}
Vitremer	0.09 (0.01) ^{CB}	141.7 (6.4) ^{B}	33.0 (2.6) ^{B}	14574.9 (3854.1) ^{A}	82.9 (8.3) ^{B}

Different uppercase letters indicate significant difference between the RMGIC (*P* <0.001).

Table 3. Experimentally determined mean (standard deviation) of volumetric post-gel shrinkage, compressive strength, diametral tensile strength, elastic modulus, and flexural strength*, and the ratio of compressive and tensile strength for BFRC.

Material	**Volumetric post-gel shrinkage (%)**	**Compressive strength (MPa)**	**Diametral tensile strength (Mpa)**	**Elastic modulus (MPa)**	**Flexural strength (MPa)**
Tetric N Ceram Bulk Fill	0.43 (0.02) ^{a}	283.84 (16.2) ^{a}	48.70 (2.4) ^{b}	15232.3 (1964.1) ^{a}	115.5 (7.8) ^{b}
Filtek Bulk Fill One	0.31 (0.02) ^{b}	256.1 (18.2) ^{b}	65.82 (1.8) ^{a}	11430.0 (2073.2) ^{b}	150.6 (26.6) ^{a}

Different lowercase letters indicate significant difference between the BFRC (*P* < 0.001).

Figures

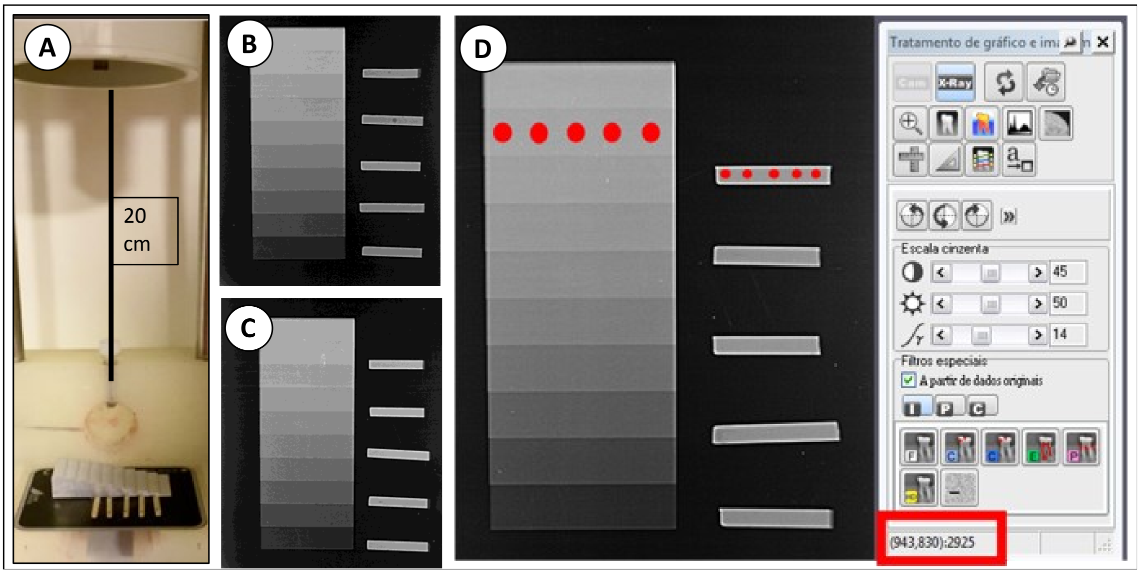

Figure 1. A. Group positioned for radiograph. with 20cm distance from collimator. B and C. Examples of radiographs for RLC and TN-Cer, respectively. E. Demonstration of five points selections in each specimen and value collected.

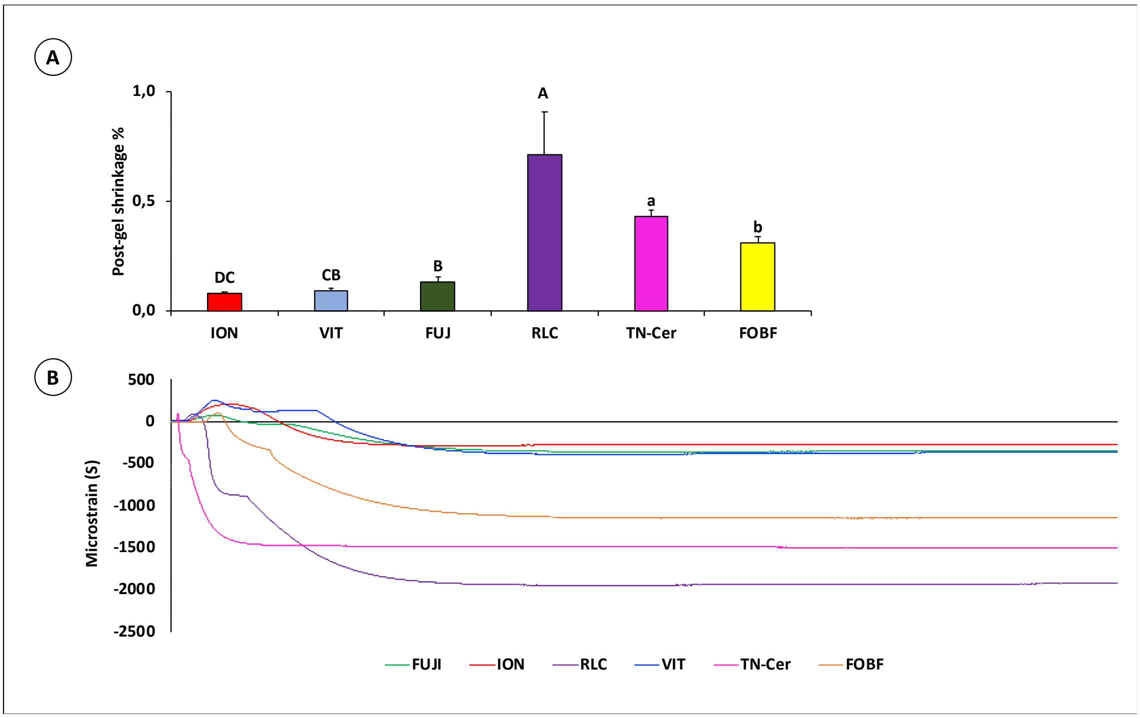

Figure 2. A. Experimentally determined mean (standard deviation) of volumetric post-gel shrinkage; B. Post-gel shrinkage curves measured for 5 minutes after light activation.

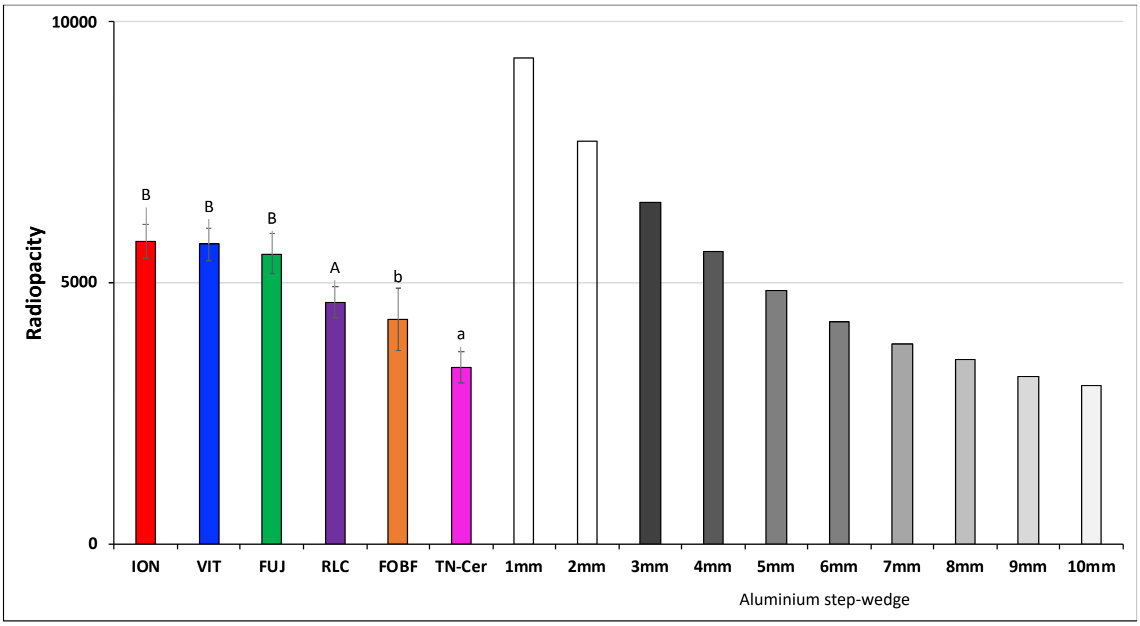

Figure 3. Experimentally determined mean (standard deviation) of RMGIC, and BFRC radiopacity compared with aluminum step-wedge

Capítulos

3.3 CAPÍTULO 3

Effect of glass ionomer thickness on endodontically treated molar restorative protocol - patient-specific finite element analysis.

Artigo a ser submetido para publicação no periódico **Operative Dentistry**

Effect of glass ionomer thickness on endodontically treated molar restorative protocol - patient-specific finite element analysis.

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Short title: Glass ionomer thickness on endodontically treated molar restoration.

Keywords: endodontically treated molar, resin-modified glass ionomer, Finite element analysis. Patient specific modeling.

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Effect of glass ionomer thickness on endodontically treated molar restorative protocol - patient-specific finite element analysis.

ABSTRACT

Objective: This study evaluated the effect of the thickness of resin-modified glass ionomer (RMGIC) filling the pulp chamber on stress distribution in molar endodontically treated restored with bulk-fill resin composites, using patient-specific finite element analysis (FEA).

Methods: Shrinkage stresses and the residual during occlusal loading were evaluated using a 3D patient specific FEA of a young molar tooth endodontically treated and restored with bulk-fill resin composites. The RMGIC thickness filling pulp chamber varied in two thicknesses: 1.0 mm and 3.0 mm. Four RMGIC (ION, Ionoseal, Voco GmbH; VIT, Vitremer, 3M-ESPE; FUJI, GC Fuji lining lc, GC America Corporation; RLC, Riva light cure, SDI) and two regular viscosity bulk-fill resin composites (TN-Cer, Tetric N-Ceram Bulk Fill, Ivoclar Vivadent; FOBF, Filtek One Bulk Fill, 3M Oral Care) were used for created 16 FEA models with different materials associations. All materials and structure were considered isotropic, homogeneous, and linear, and the mechanical properties previously calculated was applied. To evaluate the stress distribution in the structures in relation to the different restoring materials during the polymerization process, shrinkage values were applied. The modified von Mises stresses were analyzed qualitatively.

RESULTS: The RMGIC filling the 1.0-mm thickness in pulp chamber associated with bulk-fill resin composites generated higher shrinkage stress and residual stress than 3.0-mm RMGIC thickness, for most associations. The association of ION, VIT or FUJI with FOBF demonstrated lower and similar shrinkage and residual stress, for both thicknesses. The RLC with TN-Cer presented the higher shrinkage and residual stress, for both RMGIC thickness. For all thickness and associations, the lingual cusps present the highest shrinkage and residual stress.

CONCLUSION: The 3.0-mm thickness of RMGIC on pulp chamber caused lower stresses in the remaining tooth structure. The material type and composition influence the stresses in the tooth structure and the association of ION, VIT or FUJI in the pulp chamber with FOBF presents lower shrinkage and residual stress, independent of RMGIC thickness.

CLINICAL RELEVANCE: *The use of resin modified glass ionomer in the pulp chamber, with a thickness of 3.0 mm, associated with bulk-fill resin composites showed a lower stress in the remaining tooth structure.*

INTRODUCTION

Restoring endodontically treated teeth due to extensive structural damage caused by caries and cavity preparations remains a challenge.[1] This loss of structure and changes in the mechanical properties of dentin after endodontic treatment, can make them more prone to future failure.[2,3]

Direct restorations have been increasingly used as a restorative option in young endodontically treated molars with extensive loss of tooth structures,[4] once direct resin composite does not require extra removal of tooth structure and have a lower cost when compared to indirect restorations.[5] Despite these advantages, resin composite still has characteristics inherent to the materials, such as polymerization shrinkage, which if high can generate residual stresses concentrated in the structure.[6] The evolution of restorative materials, such bulk-fill resin composites,[7] and the restorative techniques with combination of different materials,[8,9] enable the recovering of form and function with satisfactory mechanical properties of posterior teeth, and reduce the negative effects of residual stress generated.[4,7]

The bulk-fill resin composites is a material with a higher fracture resistance, lower post-gel shrinkage and cusp strain when compared with conventional resin composite and can decrease the clinical time of restorative procedure once can be inserted, and light cured, in increments with 4-5 mm size,[10,11] and have demonstrated good and promisor clinical behavior in direct restorations of posterior teeth in clinical studies.[12,13] The RMGIC have been demonstrated higher flexural strength, flexural toughness, compressive strength, and fracture toughness than of conventional glass ionomer materials, and work time increased and facilitated for the resin components incorporation on your composition.[14,15]

The use of RMGIC in filling the pulp chamber reduced cusp deformation, increases fracture resistance, and improved stress distribution in molars restored with resin composite.[9] The RMGIC has lower modulus of elasticity than resin composite.[14,16-18] They can lead to a reduction in residual shrinkage stresses, for this lower elastic modulus, and also by reducing the volume of resin composite needed to fill the cavity.[19] RMGIC used for filling the pulp chamber associated with resin composite has been used to restore severely destroyed molars in young patients. [4]

The literature is still lacking information whether on the thickness of the RMGIC used to seal the pulp chamber it can influence the mechanical properties of the direct restoration. This study aimed to evaluate the effect of different thickness, 1.0mm or 3.0mm, and different RMGIC filling the pulp chamber on stress distribution in young molar treated endodontically restored with two different bulk-fill resin composites, using patient-specific finite element analysis (FEA). The null hypothesis evaluated is that different thickness of glass ionomer filling the pulp chamber do not influence the stress distribution in young molar treated endodontically when restored with bulk-fill resin composite. The second null hypothesis is the different restorative materials would have no effect on shrinkage stresses and the residual during occlusal loading.

METHODS AND MATERIALS

Study design

Shrinkage stresses and the residual stresses caused by occlusal loading were evaluated using 3D patient-specific FEA of a young molar tooth endodontically treated and restored with bulk-fill resin composite. Sixteen models were generated by combination of: 2 RMGIC thickness: 1.0 or 3.0 mm used for cover the entrance root canal into the pulp chamber; 4 RMGIC materials: ION, Ionoseal (Voco GmbH, Cuxhaven, Germany), VIT, Vitremer (3M Oral Care, St. Paul, USA); FUJI, GC Fuji Lining LC (GC America Corporation, Tokyo, Japan); and RLC, Riva light cure (SDI Bayswater, Victoria, Australia); and 2 regular paste bulk-fill resin composites: TN-Cer, Tetric N-Ceram Bulk Fill (Ivoclar Vivadent, Schaan, Germany) and FOBF, Filtek One Bulk Fill (3M Oral Care, St. Paul, USA). All mechanical properties were calculated in a previous study and are shown in table 2.

Three-Dimensional patient specific Finite Element Analysis (3D-FEA)

A three-dimensional (3D) patient specific FEA was carried out for restoration of an endodontically-treated molar as described by Rodrigues et al. 2020.[4] This study was approved by the ethics committee (1.776.692). The Cone-beam image acquisition of one patient was selected (14 years old, which will be referred to as adolescent) with a first lower permanent molar affected by caries with pulpal involvement resulting in dental pain requiring endodontic treatment. The patient received endodontic treatment followed by direct restoration in resin composite (Figure 1). The bite force was collected after restorative treatment and used in the present study to simulate the applied load. After the endodontic treatment and restorative procedure, the teeth and surrounding support structures were imaged using cone-beam computed tomographic scanning (i-CAT GXCB-500; Imaging Sciences International, Hatfield, Pennsylvania) with the median sagittal plane perpendicular to the horizontal plane and the occlusal plane parallel to the horizontal plane. Voxel dimensions were 0.125 mm. In total, 704 slices were obtained with 6 seconds of acquisition and exposure parameters of 120 kV and 5.0 mA. The projection data were exported using Digital Imaging and Communication in Medicine (Dicom) file format.

A 3D reconstruction was created based on the cone-beam tomography images (i-CAT GXCB-500™ Imaging Sciences International, Hatfield, Pennsylvania). The images were exported in Digital Imaging and Communication in Medicine (DICOM) file format and imported into an interactive medical imaging software (Mimics 18.0, Materialise Dental, Leuven, Belgium), image processing and geometric model reconstruction software that converts two-dimensional images into three-dimensional models.[20] The segmentation of the tooth structures and restorative materials was accomplished using image density thresholding.[21,22] Two segmentations were performed to generate the RMGIC thickness. The gutta-percha was not modeled because of the very low elastic modulus, that would not impair on the stress distributions. Periodontal ligament layers (0.2 mm thick) were imposed on tooth roots by Boolean operations. After segmentation, the 3D triangle-based surface of tooth structure was exported in Stereo Lithography (STL) format (Figure 1). An advanced STL design and mesh software (3- Matic 14.0, Materialize) was used to prepare the tooth sample as an STL file. After processing, the different parts were merged into a single STL file called an assembly. The final assembly was then redone using the 3-matic REMESH option. The STL surface models were imported and meshed in MSC.Patran® 2010 (MSC.Software, Santa Ana, CA, USA) with tetrahedral elements, which is element number 134 (Figure 1). The created volumetric element mesh was imported in a FEA software package (MSC.Marc/Mentat; MSC.Software) to perform the structural analysis (Figure 1). All materials were considered linear-elastic, isotropic, and homogeneous. The properties applied to dental structures, such as the values of the elastic modulus, the Poisson's ratio, compressive strength and tensile strength, were taken from the literature (Table 1).[23-27] The properties applied to materials were calculated in previous study (Table 2). The Poisson’s ratio was chosen to be the same for all resin composites at 0.24; for all ionomers was 0.35.[9]

Interfaces between model components were prescribed as bonded contacts, preventing relative motion along model interfaces. Nodes on the mesial and distal sectioned surfaces of the bone structure were rigidly fixed in all directions. The individual mean bite force values (N) determined clinically after endodontic and restorative procedures were used as biting loading. The bite load for patient was applied by placing a vertical load (parallel to the tooth axis) and was distributed in three nodes selected points, representing antagonist contact, while the vertical load was distributed in three nodes on the occlusal edge of the molar. The bite force value was determined in the intraoral bite force test – 100N. Stress distributions were analyzed using modified von Mises (MVM) stresses. To evaluate the stress distribution in the structures in relation to the different restoring materials during the polymerization process, shrinkage values calculated experimentally in previous study (Table 2) were applied.

RESULTS

The shrinkage stresses for different RMGIC and bulk-fill resin composites associations for 1.0mm and 3.0mm thickness, during incremental filling, using a linear color scale, with blue indicating low stress values and yellow being high values, was showed in figure 2 for buccal side, and in figure 3 for lingual side.

RMGIC filling pulp chamber associated with bulk-fill resin composites, the 1.0mm thickness in pulp chamber generated higher shrinkage stress in crown region than 3.0mm, mostly for lingual cusps. The ION, VIT, and FUJI different associations demonstrated similar behavior, with relatively lower shrinkage stress when associated with FOBF. The exception occurs for RLC+TN-Cer 3mm, once presented the highest shrinkage stresses generated in tooth structure, followed by RLC-FOBF 3mm thickness.

Shrinkage stress for different RMGIC and bulk-fill resin composites associations for 1.0mm and 3.0mm thickness in axial section with 2d internal view, using a linear color scale, was showed in figure 4. The higher shrinkage stress was demonstrated for TN-Cer BFRC, in all associations. The RLC showed the highest shrinkage stress, most visible in 3.0mm thickness, confirmed which showed in others views. The ION, FUJI, and FUJI associations with FOBF demonstrated lowest and similar shrinkage stress.

The residual stresses for different RMGIC and bulk-fill resin composites associations for 1.0mm and 3.0mm thickness, during 100N load, using a linear color scale, was showed in figure 5 for buccal side, and in figure 6 for lingual side. For residual stress, the RMGIC associated with bulk-fill resin composites, the 1.0mm thickness presented the higher stress than 3.0mm, mostly for lingual cusps. The ION, VIT, and FUJI different associations demonstrated similar behavior, and for RLC+TN-Cer association, the 3.0mm thickness caused the higher residual stress than all, followed by RLC-FOBF 3mm.

DISCUSSION

The results of this study confirmed that the different thickness of RMGIC, 1.0mm and 3.0mm, used in the pulp chamber influenced the stress distribution in young molar treated endodontically when restored with bulk-fill resin composites. Besides, the restorative material type and composition, different RMGIC or bulk-fill resin composites also influenced mechanical behavior stress distribution. Therefore, the first and second null hypothesis of this study was rejected.

High shrinkage stress still presents a concern for restorations and their bonded interfaces, once is directly related with adhesive failures.[28-31] When high shrinkage stress occurs, the stress generated in bonded interface can cause cusp deformation, cracks in the enamel and possible restoration failure.[9,11,32] This several factors related with negative effects of high shrinkage stress are most significant when restored endodontic treated teeth.[1] Endodontically treated teeth are compromised by the loss of healthy structure and need to be rebuilt to regain strength and stress-strain state close to the original.[2,33] The choice of restorative material and the restorative technique used are fundamental to bring restoration closer to the mechanical performance of a healthy tooth.[5,7,34-36] Several studies have been proposed the use of RMGIC as a base of bulk-fill resin composites restorations for restoring these endodontically treated teeth and have been reported good mechanical performance,[4,8,9] associated of the lower elastic modulus of RMGIC, and has enabled the reestablish the biomechanical performance satisfactorily.[12,13,17,18]

In this study, was proposed of different thickness of glass ionomer filling the pulp chamber to predict stress distribution in young molar endodontically treated when restored with bulk-fill resin composites. The different RMGIC thickness evaluated in this study bring contributions for this discussion questions. The use of RMGIC in 1.0mm in association bulk-fill resin composites demonstrated higher shrinkage stress than 3.0mm. This can be attributed to the fact of the most volume of bulk-fill resin composites presence in the cavity for 1.0mm RMGIC thickness.[19] The greater the volume of composite resin, the greater the polymerization shrinkage generated, and more photoactivation are needed, which also contributes for more stress.[32,37] Even if bulk-fill resin composites was used, which can be light cured with an increment of up to 4-5 mm,[10] in a cavity of an endodontically treated tooth measuring 8.0 mm, it will be necessary more than one increment of bulk-fill resin composites to respect the maximum size indicated increment and obtain the appropriate mechanical properties.[11] Besides, the combination of high post-gel shrinkage and high elastic modulus can generate high polymerization stress.[9,28] This is also observed in this study, once the RLC+Tn-Cer association presents the high shrinkage stress of all associations. The TN-Cer BFRC presents high post-gel shrinkage and elastic modulus than FOBF, and RLC presents the higher post-gel shrinkage then all other RMGIC tested, like demonstrate in previous study.

When a load is applied to a structure, both its interior and its interfaces generate stresses and strains. When these stresses are excessive and exceed the strength limit of the tooth structure, structural failure can occur.[5,9] To obtain information about the internal behavior of dental structures under different restorative conditions and techniques, FEA can be used for more precisely answers and helps in the prediction of future problems associated with the materials and techniques used in these structures.[20,21,29,36,38,39] The use of a patient-specific finite element model generated from the computed tomography of an endodontically treated tooth with great structural loss allowed obtaining information and analyzing the generation of stresses in the internal structures in a way that would not be possible in a clinical study.[4,40,41] However, the data and information obtained should be interpreted with caution when extrapolating to different clinical conditions. As previous study reported, computed tomographic scanned promoted a correct and efficient generation of a three-dimensional model in this study.[4,40,41]

The RMGIC has lower modulus of elasticity than resin composite.[14,16-18] They can lead to a reduction in residual shrinkage stresses, for this lower elastic modulus.[19] For the ION, VIT and FUJI associations, this behavior was proved, once they presented similar and lower shrinkage stress in most associations, but principal for FOBF association. For this reason, the use of more volume of RMGIC, like 3.0mm in association a one bulk-fill resin composites with balanced values of elastic modulus and shrinkage stress demonstrate satisfactory results, in accordance with previous study which evaluation only the RMGIC and bulk-fill resin composites associations.[9] The lower stress generation in the dental structure for VIT corroborates with a previous study that also found low values of shrinkage and stress generation on dental structure for VIT in pulp chamber of endodontic treated teeth.[9]

For residual stress, the 1.0-mm thickness in pulp chamber generates higher stress, once the RMGIC thickness for absorb and dissipates the loads is low and major proportion of restoration is the bulk-fill resin composites, which have high values of post gel-shrinkage as demonstrated in part 1.[19] This isn't applicable only for the RLC 3.0-mm groups. Since the post-gel shrinkage of RLC is higher of all RMGIC tested in this study, increase their thickness leads an increase of residual stress generated in tooth structure, most when associated with TN-Cer, which had higher values of shear compared with FOBF.

The similar residual stress of VIT-FOBF in relation FUJI and ION, despite FUJI presents the second highest values of post-gel shrinkage, is related the higher elastic modulus of VIT. The balance between post-gel shrinkage and elastic modulus its necessary since elastic modulus is a material property with relationship stress and strain, and high elastic modulus leads a lower value deformation of materials and a higher shrinkage stress.[9,28,37,42]

For all thickness and associations, the most affected for shrinkage and residual stress was the lingual cusp. This can attribute the smaller structural proportion and amount of dentin lost during access from this cusp in relation to the vestibular cusp, and this result corroborates with previous laboratory and computational studies which demonstrates major cusp deformation in lingual cusp on direct restorations with conventional and bulk-fill resin composites.[9,11,32,37]

To select the materials base for sealing pulp chamber when restoring endodontically treated teeth, clinicians should try to combine lower elastic modulus for RMGIC, should have an elastic modulus similar to the dentin substrate[43] with low post-gel shrinkage and bulk-fill resin composites with this equal balance. The use of bulk-fill resin composites for covering the RMGIC is supported by the higher elastic modulus, reducing the wear caused by occlusal loads.[28,43] Besides, the RMGIC should be used in pulp chamber with 3.0-mm thickness for promote the endodontic obturation sealing and reducing the shrinkage and residual stress, and stress-strain. Future studies with the application of laboratory tests of cusp deformation and fracture resistance, in addition to clinical studies, using the association of RMGIC and bulk-fill resin composites materials with the demonstrated thickness, may provide important and necessary complementary information.

CONCLUSIONS

Within the limitations of this study, and according to the conditions of the 3D patient specific FEA, it is possible to appreciate that:

1. The 3.0mm thickness of RMGIC used for sealing the pulp chamber caused lower stresses in the remaining tooth structure, except for RLC.
2. The 1.0mm thickness shrinkage and residual stress was higher for lingual cusps, for all associations.
3. The RMGIC ION, FUJI and VIT presented lower and similar shrinkage and residual stress when associated with FOBF.
4. The association of RLC-TN-Cer 3.0mm showed the highest values of shrinkage and residual stress.
5. The different types of RMGIC and bulk-fill resin composites had effects on shrinkage and residual stress.

Conflict of interest

The authors have no conflict of interest.

Acknowledgement

This project was supported by CNPq and granted from FAPEMIG.

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Tables

Table 1. Tissue properties from literature.

Structures	Elastic Modulus (MPa)	Poisson's ratio	Tensile Strength (MPa)	Compressive Strength (MPa)	References
Dentin	18600	0.31	98.7	297.0	Sano *et al*., 1994[24]
Enamel	84100	0.30	10.3	384.0	Zarone *et al*., 2006[26]
Periodontal Ligament	50	0.45	-	-	Rees & Jacobsen 1997[25]
Cortical Bone	13700	0.30	-	-	Carter & Hayes, 1992[23]
Cancellous Bone	1370	0.30	-	-	Carter & Hayes, 1992[23]

Table 2. Materials properties calculated and described on previous study.

Material	Volumetric post-gel shrinkage (%)	Elastic modulus (MPa)	Tensile strength (Mpa)	Compressive strength (MPa)	Compressive/tensile strenght
ION	0.08 (0.01)	5652.4 (2186.4)	45.9 (2.8)	192.7 (26.4)	4.2
FUJ	0.10 (0.2)	8744.5 (5771.9)	28.8 (5.4)	117.1 (12.0)	4.0
RLC	0.70 (0.2)	3955.2 (1420.5)	22.4 (3.2)	116.6 (10.0)	5.2
VIT	0.09 (0.01)	14574.8 (3854.1)	33.0 (2.6)	141.7 (6.4)	4.2
TN-Cer	0.43 (0.02)	15232.2 (1964.1)	48.7 (2.4)	283.8 (16.2)	5.8
FOBF	0.31 (0.0)	11430.0 (2073.2)	65.8 (1.8)	256.1 (18.2)	3.8

Figures

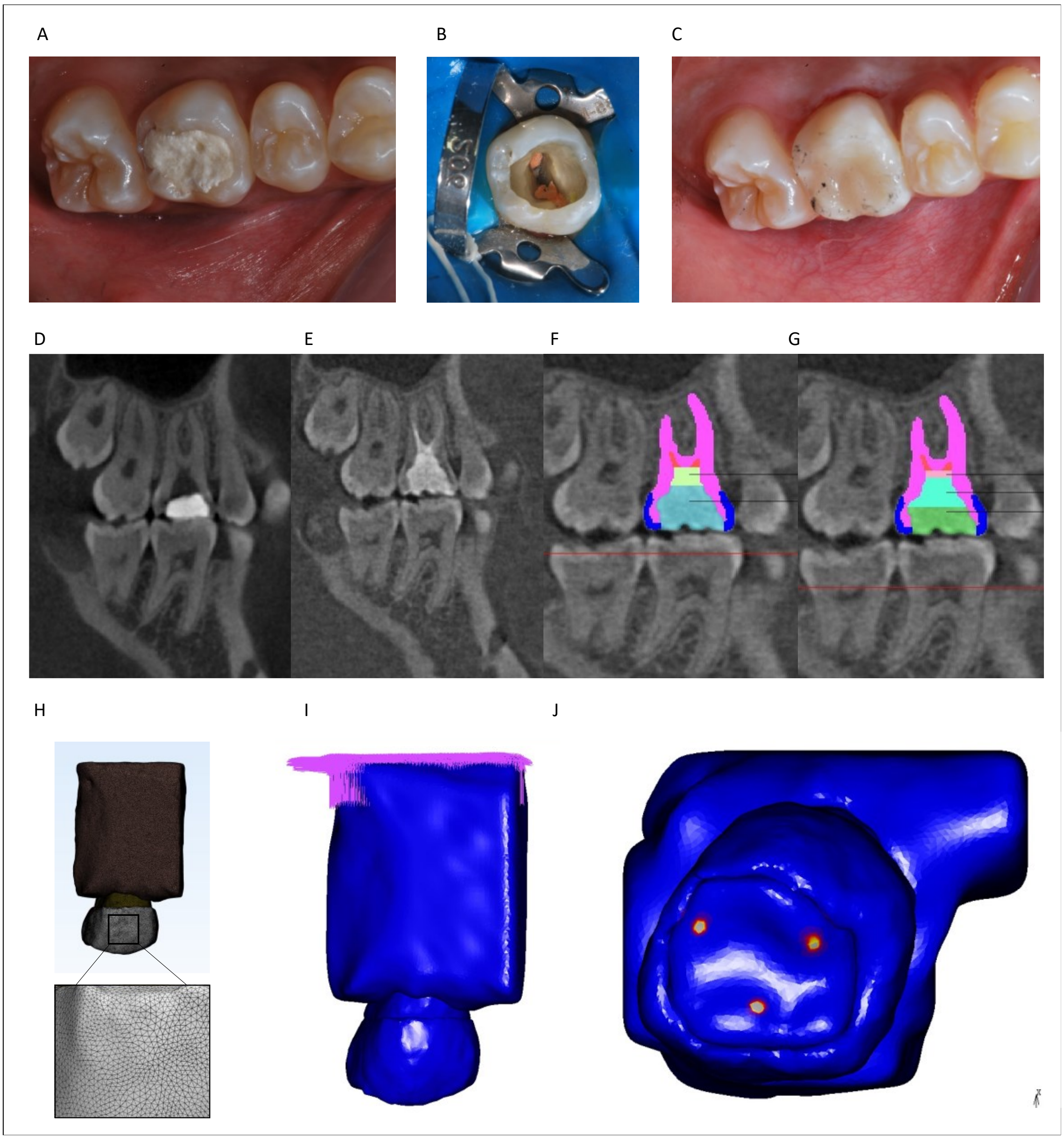

Figure 1. Clinical pictures and cone-beam computed tomographic image corresponding patient-specific finite element models, and schematic showing the approach for developing a patient-specific finite element model: A: initial condition; B: after endodontic treatment; C: After restoration; D: the initial condition of severe tooth structure loss; E: after endodontic treatment and direct resin composite restoration; F: segmentation using Mimics software with 1mm of RMGIC in pulp chamber; G: segmentation using Mimics software with 3mm of RMGIC in pulp chamber. H: final mesh of the 3D model using 3-Matic software. I: boundary condition showing the fixation at the top maxillary bone. J: Nodal load application points.

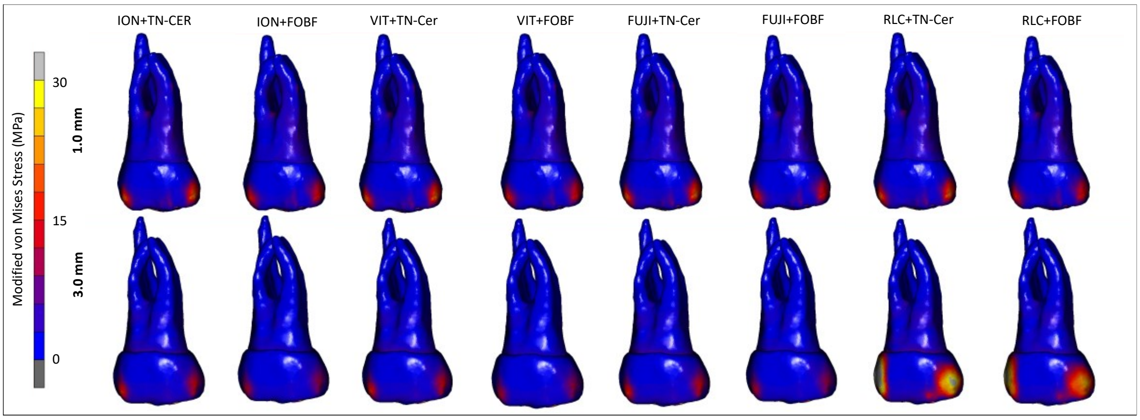

Figure 2. Modified von Mises shrinkage stresses for different RMGIC and bulk-fill resin composites associations using a linear color scale, with blue indicating low stress values and yellow being high values: buccal side during incremental filling, for 1.0mm and 3.0mm thickness.

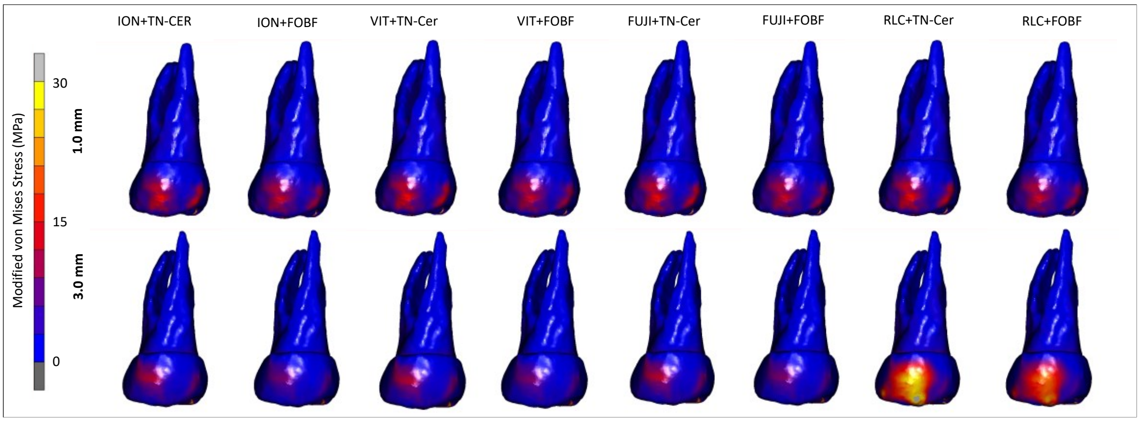

Figure 3. Modified von Mises shrinkage stresses for different RMGIC and bulk-fill resin composites associations using a linear color scale, with blue indicating low stress values and yellow being high values: lingual side during incremental filling, for 1.0mm and 3.0mm thickness.

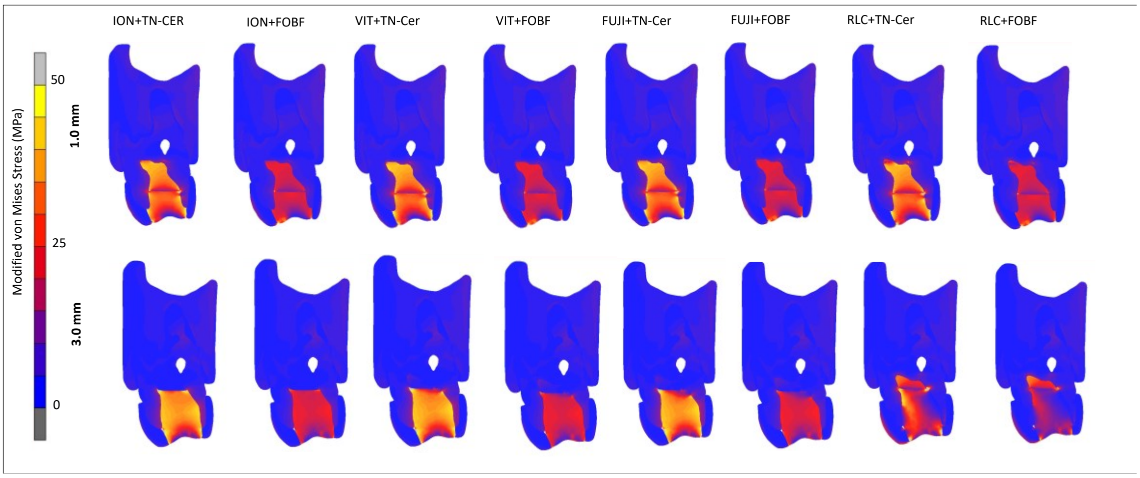

Figure 4. Shrinkage stress for Different RMGIC and bulk-fill resin composites associations for 1.0mm and 3.0mm thickness using a linear color scale, with blue indicating low stress values and yellow being high values: axial section with 2d internal view.

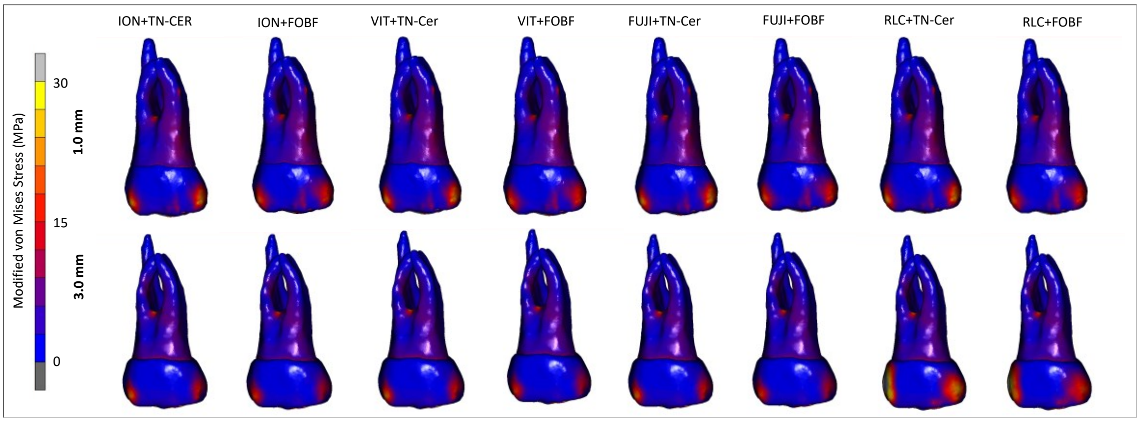

Figure 5. Modified von misses residual stress for different RMGIC and bulk-fill resin composites associations using a linear color scale, with blue indicating low stress values and yellow being high values: buccal side with 100 N load application, for 1.0mm and 3.0mm thickness.

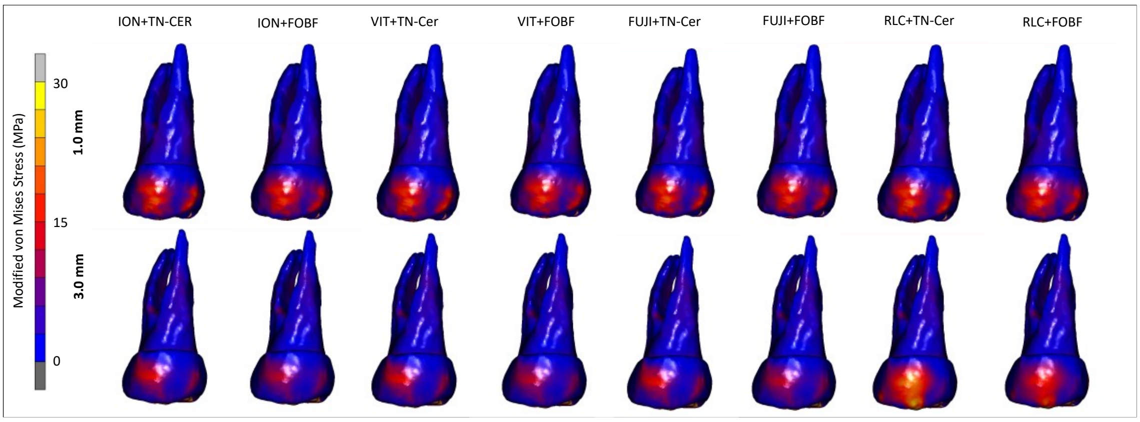

Figure 6. Modified von misses residual stress for different RMGIC and bulk-fill resin composites associations using a linear color scale, with blue indicating low stress values and yellow being high values: lingual side with 100 N load application, for 1.0mm and 3.0mm thickness.

Considerações Finais

4. CONSIDERAÇÕES FINAIS

A eficácia do contato proximal tende a diminuir com o envelhecimento. Esse aspecto não é fácil de verificar clinicamente pela radiografia. As técnicas de restauração direta com resina composta bulk-fill e incremental demonstraram gerar forças de contato proximal semelhantes. O processo de envelhecimento reduz a efeitividade de ponto de contato, e isso mostra que o clínico deve estar atento a testar esse aspecto em retornos posteriores quando da avaliação de resinas compostas posteriores. Contatos com dentes ou implantes tendem apresentar a mesma efetiviadade.

O menor módulo de elasticidade e menores valores de contração pós-gel da maioria dos CIVMR suportam seu uso como materiais de base para restaurações posteriores. As propriedades mecânicas dos CIVMR e resinas bulk-fill são materiais dependentes, sendo que o clínico deve estar atento a essas características para selecionar o material para uso clínico. CIVMR devem ser associados com cobertura por resinas compostas que podem ser do tipo bulk-fill, devido o maior módulo de elasticidade, resistência à flexão, tração e compressão dessas resinas compostas em comparação aos CIVMR para suportar forças mastigatórias ao restaurar dentes posteriores.

O tipo de ionômero de vidro modificado por resina composta na câmara pulpar, com espessura de 3,0 mm, associado a resinas compostas bulk-fill, apresentou menor geração de tensão na estrutura dentária remanescente.

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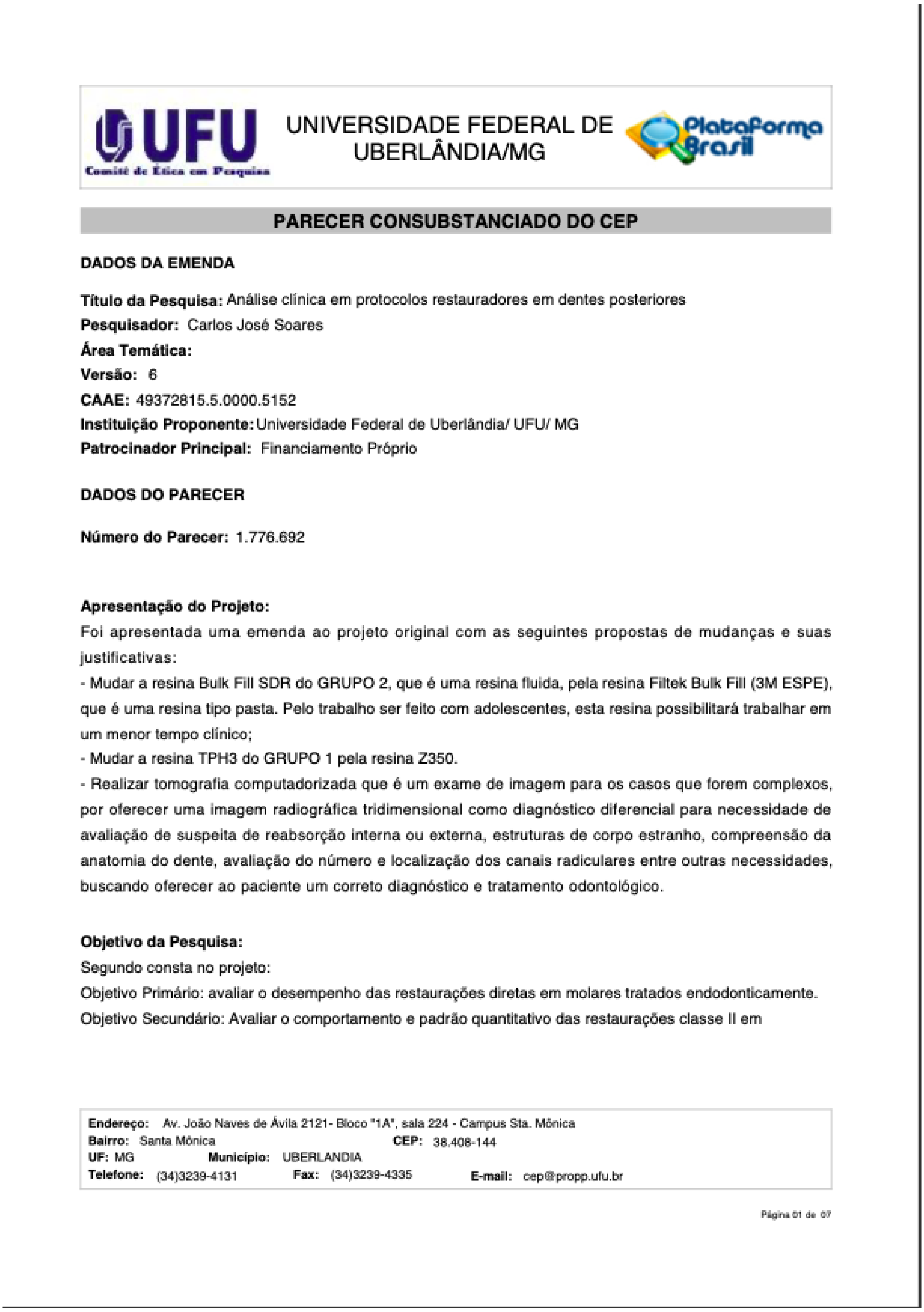
Anexos

6.1 Pareceres do Comitê de ética



UFU
Comitê de Ética em Pesquisa

UNIVERSIDADE FEDERAL DE
UBERLÂNDIA/MG

Plataforma Brasil

PARECER CONSUBSTANCIADO DO CEP

DADOS DA EMENDA

Título da Pesquisa: Análise clínica em protocolos restauradores em dentes posteriores
Pesquisador: Carlos José Soares
Área Temática:
Versão: 6
CAAE: 49372815.5.0000.5152
Instituição Proponente: Universidade Federal de Uberlândia/ UFU/ MG
Patrocinador Principal: Financiamento Próprio

DADOS DO PARECER

Número do Parecer: 1.776.692

Apresentação do Projeto:

Foi apresentada uma emenda ao projeto original com as seguintes propostas de mudanças e suas justificativas:

- Mudar a resina Bulk Fill SDR do GRUPO 2, que é uma resina fluida, pela resina Filtek Bulk Fill (3M ESPE), que é uma resina tipo pasta. Pelo trabalho ser feito com adolescentes, esta resina possibilitará trabalhar em um menor tempo clínico;
- Mudar a resina TPH3 do GRUPO 1 pela resina Z350.
- Realizar tomografia computadorizada que é um exame de imagem para os casos que forem complexos, por oferecer uma imagem radiográfica tridimensional como diagnóstico diferencial para necessidade de avaliação de suspeita de reabsorção interna ou externa, estruturas de corpo estranho, compreensão da anatomia do dente, avaliação do número e localização dos canais radiculares entre outras necessidades, buscando oferecer ao paciente um correto diagnóstico e tratamento odontológico.

Objetivo da Pesquisa:

Segundo consta no projeto:
Objetivo Primário: avaliar o desempenho das restaurações diretas em molares tratados endodonticamente.
Objetivo Secundário: Avaliar o comportamento e padrão quantitativo das restaurações classe II em

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6.2 Normas dos periódicos

1. Operative Dentistry (artigos capítulos 1, 2 e 3)

https://jopdent.com/author-review-for-journal/instructions-to-authors/technical-specifications-for-submission/