SERVIÇO PÚBLICO FEDERAL
MINISTÉRIO DA EDUCAÇÃO
UNIVERSIDADE FEDERAL DE UBERLÂNDIA
FACULDADE DE ODONTOLOGIA
PROGRAMA DE PÓS GRADUAÇÃO

ALINE AREDES BICALHO

Efeito da Contração de Polimerização em Restaurações Diretas em Resinas Compostas em Dentes Posteriores

Tese apresentada à Faculdade de Odontologia da Universidade Federal de Uberlândia, como requisito para obtenção do Título de Doutor em Odontologia na Área de Concentração de Clínica Odontológica Integrada

Uberlândia, 2014

ALINE AREDES BICALHO

Efeito da Contração de Polimerização em Restaurações Diretas em Resinas Compostas em Dentes Posteriores

Tese apresentada à Faculdade de Odontologia da Universidade Federal de Uberlândia, para obtenção do Título de Doutor em Odontologia na Área de concentração de Clínica Odontológica Integrada

Orientador: Prof. Dr. Carlos José Soares
Banca Examinadora:
Prof. Dr. Alfredo Júlio Fernandes Neto
Prof. Dr. Paulo Sérgio Quagliatto
Prof. Dr. Alessandro Dourado Loguercio
Prof. Dr. Rafael Ratto de Moraes

Uberlândia, 2014

DEDICATÓRIA

Dedico este trabalho a Deus e à minha família.

AGRADECIMENTOS

A Deus, que se mostrou criador e foi criativo. Seu fôlego de vida em mim foi sustento e deu-me coragem para questionar realidades e propor sempre um novo mundo de possibilidades;

Ao meu marido Maiolino, que foi o primeiro a visualizar e acreditar no caminho da Academia, o primeiro a me incentivar e sempre o último a desistir, companheiro e parceiro de todas as horas. Obrigada por ser meu melhor porto seguro;

Aos meus pais Ivan e Aurora que me deram a vida e me ensinou a vivê-la com dignidade. Obrigada por não medirem esforços em me ver feliz, e por estarem sempre felizes com as minhas conquistas, obrigada pela generosidade em me dividir com o mundo e proporcionar em mim coragem de voar;

Ao meu irmão Angelo, minha cunhada Lisa, Bianca e Eduardo por todo apoio mesmo que distante, por me dar o prazer e a honra de ser a minha família;

Aos meus sogros Mariuza e José Geraldo, e cunhados Bernard, Gi e Gabi que torceram muito pela minha vitória;

Ao meu orientador Prof. Carlos José Soares por ter oportunizado tanto aprendizado e possibilidades mesmo sem me conhecer. Aprendi com o senhor que a arte de pensar é o tesouro dos sábios e que pensar antes de reagir é essencial. Obrigada por ter permitido que eu vivesse o seu conhecimento tão gratuitamente;

À Priscilla B. F. Soares por toda compreensão, generosidade e serenidade, exemplo de força e luta, obrigada por fazer parte disso tudo;

Ao professor Anthony Versluis e Darannee Tantbirojn, co-orientadores especiais, sempre prontos a ajudar e sem medir esforços para fazer dar certo. Quanto conhecimento me foi passado, serei grata todo o sempre.

À Faculdade de Engenharia Mecânica e ao LTAD representado pelo prof. Sinésio Domingues Franco.

Aos amigos de Doutorado: Andrea Dolores C. M. Valdívia, Crisnicaw Veríssimo, Felipe Eduardo Baires Campos, Flaviana Soares Rocha, Karla Zancopé, Luiz Fernando Barbosa de Paulo, Maria Antonieta V. C. De Oliveira, Roberta Rezende Rosa, Vanessa Álvares de Castro Rocha, pelo companheirismo durante todo o Doutorado;

À alguns amigos em especial, Rodrigo Dantas Pereira (Jaíba), Luiz Fernando, Thiago Carneiro, João Paulo Servatto, Andrea Dolores, Camila Rosatto, Renata Afonso, Ana Luiza, Luiza e Fabiane Maria. Obrigada por todos os momentos de descontração e apoio que cada um teve da sua maneira, que nos momentos difíceis foram essenciais;

À todos os alunos de iniciação científica que tive oportunidade de conviver, em especial Silas, Júlia e Mariana, todos vocês foram muito especiais pra mim, obrigada pelos anos de convivência, pela paciência com meu aprendizado em orientar e pela amizade que podemos construir.

Obrigada a todos os alunos do mestrado pelos momentos compartilhados nesta instituição.

A todos os professores da Universidade e do programa, em especial: Adérito Soares da Mota, Alfredo Júlio Fernandes-Neto, Darceny Zanetta-Barbosa, Paulo Vinícius Soares, Paulo Cesar Freitas Santos-Filho, Paulo Cézar Simamoto Júnior, Paulo Sérgio Quagliatto, Sérgio Vitorino Cardoso, Veridiana Resende de Novaes, Giselle Rodrigues, Murilo Menezes, por todos os ensinamentos;

Um agradecimento especial a um casal que fez e sempre fará toda a diferença, André e Iara, obrigada por terem doado tanto tempo e amizade que foram essenciais nestes últimos anos;

À Faculdade de Odontologia da Universidade Federal de Uberlândia e ao Programa de Pós Graduação pelo apoio e oportunidade.

A CAPES pela bolsa de Doutorado e FAPEMIG por apoio financeiro em fomento aos nossos trabalhos.

A todos os funcionários da Faculdade de Odontologia da Faculdade Federal de Uberlândia, por toda a ajuda; em especial Daniela, Graça, Brenda, Wilton, Seu Advaldo, Eliete, John Douglas, que sempre ajudaram muito, tornando-se bons amigos.

À banca examinadora composta pelos professores Alessandro Dourado Loguércio, Rafael Ratto de Moraes, Paulo Sérgio Quagliatto, Alfredo Júlio Fernandes Neto e Carlos José Soares. Agradecer também aos membros suplentes representados pela professora Giselle Rodrigues dos Reis e professor André Figueiredo Reis.

E a todas as pessoas que, de alguma forma, contribuíram para que essa etapa fosse vencida!

EPÍGRAFE

“Mas é preciso ter manha
É preciso ter graça
É preciso ter sonho sempre
Quem traz na pele essa marca
Possui a estranha mania
De ter fé na vida”

Milton Nascimento

SUMÁRIO

RESUMO

RESUMO

As resinas compostas tem sido amplamente utilizadas ao longo dos anos nas restaurações de dentes posteriores. No entanto, os materiais resinosos apresentam característica inerente, a contração de polimerização que pode ser associada à manifestações clínicas indesejáveis como sensibilidade pós-operatória, infiltração marginal e cáries recorrentes. O objetivo geral deste estudo foi investigar a influência de fatores como carregamento oclusal, propriedades mecânicas dos materiais, uso de forramento cavitário, condições de ambiente e técnica restauradora no comportamento biomecânico de restaurações em resina composta em dentes posteriores por meio de estudos laboratoriais e computacionais. Este estudo foi dividido em cinco objetivos específicos; **objetivo 1**: investigar o efeito da condição de carregamento oclusal e das propriedades mecânicas de resinas compostas nas tensões de contração de polimerização de resinas compostas em pré-molares; **objetivo 2**: investigar o efeito das condições ambientais, determinadas pela temperatura e umidade, nas propriedades mecânicas e no comportamento biomecânico de molares com restaurações diretas extensas em resina composta; **objetivo 3**: investigar o efeito do uso de base de ionômero de vidro como protetor pulpar e da técnica de inserção de resina composta no comportamento biomecânico de restaurações molares com restaurações diretas extensão em resina composta, especificamente na deformação de cúspide em diferentes momentos e o reflexo na resistência à fratura; **objetivo 4**: investigar o efeito dos mesmos parâmetros avaliados no objetivo 3 nas propriedades mecânicas dos materiais restauradores, adaptação marginal e geração de tensões de contração de polimerização; **objetivo 5**: gerar síntese dos achados dos objetivos 1, 2, 3 e 4 em um artigo de comunicação aos clínicos brasileiros cumprindo a função social da geração do conhecimento. Os métodos experimentais utilizados foram extensometria para deformação de cúspide e para cálculo de contração pós-gel, fadiga térmica e mecânica, resistência à fratura, teste de microtração, microscopia eletrônica de varredura para análise de modo de fratura e adaptação marginal, teste de indentação dinâmico para cálculo de dureza Vickers e módulo elástico, teste de indentação para cálculo de dureza Knoop, análise por elementos finitos 2D e 3D. Após análise estatística dos resultados pode-se concluir que materiais com

maiores valores de módulo elástico causam maiores tensões de contração; contato oclusal localizado na margem da restauração de resina composta posterior aumentam as tensões geradas na interface; o carregamento oclusal aumenta os níveis de tensões em dentes restaurados mesmo quando utilizados resinas composta de baixos valores de contração de polimerização; contatos oclusais estáveis no centro da restauração resultaram em melhor distribuição de tensões; umidade e temperatura que simulam as condições de ambiente oral afetam significativamente a contração pós-gel, módulo de elasticidade, deformação de cúspide, resistência adesiva e tensões de contração em dentes com restaurações diretas em resinas compostas; simulação do ambiente bucal deve ser realizada nos testes de laboratório para avaliar estes parâmetros biomecânicos; a ordem de preenchimento dos incrementos de resina composta, se iniciado pelas caixas proximais ou pela cúspide vestibular, não influenciou na deformação de cúspide, resistência à fratura, modo de fratura, adaptação marginal e tensões geradas de molares restaurados com resina composta; a deformação de cúspide e as tensões de contração diminuíram com a presença de ionômero de vidro modificado por resina usado como material de proteção do complexo dentinho-pulpar em restaurações posteriores; a resistência à fratura e modo de fratura não foram influenciados pela presença de material de base em molares restaurados com resina composta; a margem restauradora com maior desadaptação em molares classe II MOD é a margem gengival. O clínico deve se ater as condições de controle técnico e fazer uso de materiais restauradores adequados em termos de propriedades mecânicas e contração de polimerização objetivando potencializar o sucesso de restaurações diretas em resina composta em dentes posteriores.

ABSTRACT

ABSTRACT

The composite resins have been widely used over years in posterior restorations. However, the composite resins have an inherent characteristic called polymerization shrinkage which may be associated with undesirable clinical manifestations such as post-operative sensitivity, microleakage and recurrent caries. The aim of this study was to investigate the influence of some factors such as occlusal loading, restorative technique, mechanical properties of materials, use of liner and environment conditions on the biomechanical behavior of direct composite resin restorations in posterior teeth through laboratory and computational studies. This study was divided into five specific objectives; **objective 1:** To investigate the effect of occlusal loading and mechanical properties of composites on shrinkage stress in premolars; **objective 2:** To investigate the effect of environmental conditions, such as temperature and humidity, mechanical properties on biomechanical behavior of molars with class II MOD; **objective 3:** to investigate the effect of glass ionomer resin liner and filling technique on biomechanical behavior of class II MOD composite resin restoration, specifically analysing cuspal strain by strain gage test, termal and mechanical fatigue and fracture resistance; **objective 4:** to investigate the effect of the same parameters of objective 3 on mechanical properties of restorative materials, marginal adaptation and shrinkage stress distribution; **objetivo 5:** To generate an article with all conclusions about shrinkage and posterior restorations by the Brazilian clinical communication contributing with the social function of knowledge generation. The methods used on the all studies were cuspal strain by strain gage test, post-gel measurments by strain gage test, thermal and mechanical fatigue, fracture resistance, marginal adaptation and fracture mode under scanning electron microscopy, dynamic indentation test for calculation of Vickers Hardness and elastic modulus, indentation test for hardness Knoop calculation, finite element analysis 2D and 3D. After data analysis it can be concluded that materials with higher elastic modulus cause greater shrinkage stress; occlusal loading on the margin of restoration cause great stress concentration at interface; occlusal stable contact in the center of restoration cause low stress concentration; high temperature and humidity affect the post-gel shrinkage, elastic modulus, cuspal strain, bond strength and stress shrinkage in the teeth restored with direct

composite resins; the simulation of oral environment should be performed in laboratory tests to evaluate the shrinkage and cuspal strain; the order of filling technique, represented by sequence of the oblique increments, had no influence the cuspal strain, fracture resistance, fracture mode, marginal adaptation and stress distribution in molars restored with composite resin; cuspal strain and shrinkage stress decreased significantly with the presence of resin modified glass ionomer resin liner in direct posterior composite resin restorations; the fracture resistance and fracture mode was not influenced by the presence of liner in molars restored with composite resin; gingival margin had higher gap formation than proximal margins in molar restored with direct composite resin restoration.

INTRODUÇÃO E REFERENCIAL TEÓRICO

1. INTRODUÇÃO E REFERENCIAL TEÓRICO

As resinas compostas representam classe de materiais amplamente utilizados na odontologia restauradora. Além de propriedades estéticas aceitáveis, as resinas apresentam adesão às estruturas dentais permitindo maior preservação dos tecidos sadios (Ferracane *et al.,* 2011). No entanto, uma característica inerente aos materiais poliméricos conhecida como contração de polimerização ainda constitui problema relevante destes materiais podendo causar tensões residuais no remanescente dental mesmo quando não está em função mastigatória (Versluis *et al.*, 2011, Soares *et al.,* 2013, Bicalho *et al.,* 2014a, Bicalho *et al.,* 2014b). A contração de polimerização pode ser dividida em duas fases relacionadas com o desenvolvimento do módulo de elasticidade, fase pré-gel e fase pós-gel (Davidson *et al.,* 1984; Feilzer *et al.,* 1990). Na fase de pré-gel o material é capaz de fluir, aliviando as tensões no interior da restauração (Versluis & Tantbirojn, 2009). Após a geleificação do material as tensões são geradas devido ao aumento no módulo de elasticidade, assim, a rigidez resulta em transferência das tensões para a estrutura ou interface dente/restauração (Versluis & Tantbirojn, 2009).

A presença de tensões residuais resulta na mudança do comportamento do dente restaurado e vários sinais clínicos podem estar associados, como geração de fendas marginais, propagação de microfissuras no esmalte, sensibilidade pós-operatória, infiltração e cáries secundárias (Bausch *et al.,* 1982, Jensen & Chan, 1985). Sendo este um dos fatores determinantes pela grande substituição destas restaurações (Kopperud *et al.,* 2012). As cargas mastigatórias podem gerar processo de fadiga que contribui para a concentração de tensões no complexo restaurador e interfaces, acentuando a ocorrência destes sinais e sintomas (Versluis *et al.,* 2011).

As propriedades mecânicas das resinas compostas usadas nos dentes posteriores devem atender aos princípios de resistência e adesão suficiente para suportar cargas mastigatórias (Soares *et al.,* 2013). O mecanismo mais moderno usado pelas indústrias para criar novos compósitos envolve modificações em componentes monoméricos e na quantidade de cargas. Monômeros como bis-GMA e TEGDMA podem apresentar até 12,5% de contração volumétrica. Este valor pode ser reduzido com o acréscimo de partículas inorgânicas (Labella *et al.,* 1999). A contração de polimerização é dependente da concentração da carga, das características de polimerização, do volume dos incrementos e do tamanho da cavidade (Petrovic & Atanackovic, 2008; Ferracane *et al.,* 2005; Soares *et al.,* 2013; Bicalho *et al.,* 2014a; Bicalho *et al.,* 2014b). O volume dos incrementos inseridos em cavidade posterior deve ser o suficiente para que as propriedades mecânicas como módulo elástico e dureza, sejam mantidas satisfatoriamente. O uso de incrementos de 2 mm de espessura atendem bem a estes requisitos (Bicalho *et al.,* 2014a e Bicalho *et al.,* 2014b). Incrementos muito pequenos devem ser evitados por resultarem em somatória de contração a cada polimerização realizada no processo restaurador, aumentando as tensões geradas e as deflexões de cúspides (Bicalho *et al.,* 2014a e Bicalho *et al.,* 2014b). Em cavidades extensas estes fatores inerentes ao material se associam a determinantes clínicos de extensão do preparo, localização do dente no arco dental e a intensidade de carga aplicada. Estes fatores podem potencializar o desgaste ou fratura destas restaurações. O desgaste abrasivo é um processo natural que ocorre sempre que se movem duas superfícies em contato. Por outro lado, a fratura marginal em dentes posteriores restaurados com resina composta tem sido relatada em muitos estudos clínicos (Mjor *et al.,* 1992; Bryant *et al.,* 1992). Assim, oclusão balanceada parece ser fator chave para minimizar estas duas intercorrências que interferem no sucesso de restaurações em dentes posteriores (Versluis & Darannee, 2009).

Para mensurar a contração de polimerização de resinas compostas tem sido empregado dilatômetros de mercúrio (Boaro *et al.,* 2010) e métodos transdutores (Watts & Cash, 1991). No entanto, estas técnicas fornecem apenas valores de contração volumétrica total. Uma versão modificada do método de extensometria tem sido usado para determinar a contração pós-gel de compósitos, (Sakaguchi *et al.,* 1991; Soares *et al.,* 2013; Bicalho *et al,* 2014a), que é a fase onde as tensões são desenvolvidas (Versluis & Tantbirojn, 2009). Deformação de cúspide gerada pela contração de resinas compostas em dentes posteriores também tem sido medida experimentalmente com extensômetros (Bicalho *et al.,* 2014a). Neste contexto, a interação entre o ambiente térmico e umidade pode ter efeito negativo sobre os materiais restauradores poliméricos (El-Safty *et al.,* 2013). O aumento da temperatura diminui a viscosidade da resina composta, desta forma há também aumento do volume livre e melhora da molhabilidade molecular. O aumento do grau de conversão é normalmente acompanhado por aumento da contração de polimerização (Watts & Alnazzawia *et al.,* 2014; Shah & Stansbury *et al.,* 2014). Todos os métodos utilizados para medir a deformação de cúspide ou contração pós-gel são realizados em temperatura ambiente (23°C) e humidade ambiente (50%), sendo que na realidade clínica estes materiais estão submetidos à condições de umidade e temperatura mais elevadas, principalmente quando o isolamento absoluto não é utilizado.

Protocolos clínicos e materiais restauradores têm sido desenvolvidos para minimizar a contração de polimerização e tensão nos dentes posteriores. Técnicas de preenchimento têm sido frequentemente indicadas para diminuir os efeitos da contração de polimerização e das tensões geradas (Bicalho *et al.,* 2014a; Bicalho *et al.,* 2014b). Para atuar de forma sinérgica na redução dos efeitos colaterais indesejados da contração de polimerização e ainda minimizar os efeitos biológicos em cavidades profundas, uma camada intermediária entre a resina composta e a parede pulpar tem sido proposta. Materiais ionoméricos convencional ou modificado por resina tem sido recomendados como material intermediário (Kwon *et al.,* 2010). Eles substituem parte do volume de resina composta, podendo reduzir consequentemente os efeitos colaterais da contração de polimerização.

As restaurações classe II MOD são convencionalmente restauradas iniciando-se a inserção dos incrementos pelas caixas proximais, desta forma a classe II transforma-se em uma classe I, sendo posterior finalizada a restauração (Peutzfeldt & Asmussen *et al.,* 2004). Esta forma é descrita na literatura como facilitador da execução da escultura anatômica do dente. No entanto pouco se relata na literatura sobre benefícios ou malefícios da ordem de inserção destes incrementos na contração de polimerização do material e deformação de cúspide. Pode-se especular que a transformação inicial de uma cavidade classe II em cavidade classe I, reduzindo o “compliance” da cavidade poderia resultar em maior geração de tensões de contração de polimerização. Por outro lado a inserção inicial em apenas uma das cúspides pode gerar maior dificuldade de inserção posterior nas paredes gengivais das caixas proximais o que poderia refletir em maior desadaptação, defeitos marginais e maior inclusão de bolhas no interior da resina composta. A definição da sequência de inserção dos incrementos deve ser estudada para verificação de possíveis vantagens e desvantagens relacionadas aos efeitos da contração de polimerização.

A Odontologia Brasileira tem se destacado pela crescente produção intelectual de forma quantitativa e qualitativa representando hoje o segundo país mais produtivo na odontologia Mundial (Scariot *et al.,* 2011). Porém não se acompanha na mesma intensidade a divulgação de conhecimento com evidência científica comprovada internacional aos clínicos brasileiros. Os eventos científicos nacionais têm se tornado cada vez mais foco de divulgação mercantil de produtos sem se ater a divulgação de técnicas e aspectos básicos da ciência dos materiais que tragam imediato benefício à prática clínica. Revistas nacionais, publicadas na língua portuguesa, de ampla tiragem que cheguem aos consultórios odontológicos deve ser um horizonte para que de forma complementar possa divulgar os principais achados científicos que são pesquisados nas Universidades Brasileiras.

Desta forma, parece pertinente utilizar associação de metodologias não destrutivos e destrutivas à métodos computacionais para analisar de forma integradas e progressiva diferentes fatores envolvidos na confecção de restaurações de dentes posteriores em resina composta. Como isso gerando artigos a serem submetidos aos periódicos de alto fator de impacto da odontologia mundial e ao mesmo tempo gerar síntese destes achados em artigo de comunicação aos clínicos brasileiros cumprindo a função social da geração do conhecimento.

OBJETIVOS

2. OBJETIVOS

Objetivo Geral

Avaliar o efeito de parâmetros técnicos dos materiais restauradores envolvidos no comportamento biomecânico de restaurações posteriores em resinas compostas

Objetivos específicos

Objetivo específico 1

Capítulo 1 - *Effect of occlusal loading and mechanical properties of composite resin on stress generated in posterior restoration*

O objetivo deste estudo foi investigar o efeito da condição de carregamento oclusal e das propriedades mecânicas de resinas compostas nas tensões de contração de polimerização de resinas compostas em pré-molares.

Objetivo específico 2

Capítulo 2 - *Effect of temperature and humidity on post-gel shrinkage, cusp deformation, bond strength and shrinkage stress - Construction of equipment to simulate oral environment*

O objetivo deste estudo foi investigar o efeito das condições ambientais, determinadas pela temperatura e umidade, nas propriedades mecânicas e no comportamento biomecânico de molares com restaurações diretas extensas em resina composta.

Objetivo específico 3

Capítulo 3 – *Effect of glass ionomer liner and filling technique on biomechanics performance of posterior composite restoration – Part I, cuspal strain, fracture resistance and fracture mode.*

O objetivo deste estudo foi investigar o efeito biomecânico do uso de ionômero de vidro modificado por resina como protetor pulpar e da técnica de inserção de resina composta, representada pela sequência dos incrementos, no comportamento biomecânico de restaurações diretas extensas em resina compostas confeccionadas em molares. Especificamente na deformação de cúspide, na resistência e modo de fratura.

Objetivo específico 4

Capítulo 4 - *Effect of glass ionomer liner and filling technique on biomechanics performance of posterior composite restoration Part II – marginal adaptation, mechanical properties and stress distributions.*

O objetivo deste estudo foi investigar o efeito biomecânicos dos mesmos parâmetros avaliados no objetivo específico 3, especificamente nas propriedades da restauração, adaptação marginal e geração de tensões de contração de polimerização.

Objetivo específico 5

Capítulo 5 - *Restaurações de resinas compostas em dentes posteriores – Controlando os efeitos da contração de polimerização*

O objetivo deste trabalho foi gerar uma síntese dos achados dos objetivos 1, 2, 3 e 4 compilados em um artigo de comunicação aos clínicos brasileiros cumprindo a função social da geração do conhecimento.

CAPÍTULOS

3.1 CAPÍTULO 1

Artigo enviado e publicado no periódico American Journal of Dentistry

Effect of occlusal loading and mechanical properties of composite resin on stress generated in posterior restoration

3. CAPÍTULOS

3.1 CAPÍTULO 1

Artigo enviado e publicado para publicação no periódico American Journal of Dentistry

Effect of occlusal loading and mechanical properties of composite resin on stress generated in posterior restoration

Aline A. Bicalho 1, Daranee Tantbirojn 2, Antheunis Versluis 3, Carlos J. Soares 4.

1. DDS, MS, PhD Student, Dental School, Federal University of Uberlandia, Uberlandia, Brazil.
2. DDS, MS, PhD, Associate Professor, Department of Restorative Dentistry, College of Dentistry, University of Tennessee Health Science Center, Memphis, TN, USA.
3. PhD, Professor and Director Biomaterials Research, Department of Bioscience Research, College of Dentistry, University of Tennessee Health Science Center, Memphis, TN, USA.
4. DDS, MS, PhD, Professor and Chairman, Department of Operative Dentistry and Dental Materials, Dental School, Federal University of Uberlandia, Uberlandia, Brazil.

Corresponding Author:
Prof. Dr. Carlos José Soares.
Biomechanic Research Group
Department of Operative Dentistry and Dental Materials
Dental School, Federal University of Uberlândia.
Av. Pará, n° 1720, CEP 38400-902, Bloco B, 2B24, Uberlândia, Minas Gerais, Brasil
Phone: 55-34-3218 22 55 Fax: 55-34- 3218 2279.
E-mail: carlosjsoares@umuarama.ufu.br

Keywords: Shrinkage; stress; elastic modulus; dental composites; occlusal load; margin fracture.

Effect of occlusal loading and mechanical properties of composite resin on stress generated in posterior restoration

Objectives**.** The aim of this study was to investigate the effect of occlusal load condition in association with the mechanical properties of resin composite, expressed by elastic modulus and post-gel shrinkage, on stresses in a premolar restored with various composite resins. ***Methods***. Five resin composites (4 Seasons, Ivoclar-Vivadent; Beaultifil II, Shofu; Filtek LS, Filtek Z250, and Z100, 3M-ESPE) indicated for restoring posterior teeth were tested. Elastic modulus was measured using Knoop indentation tests (n=5). Post-gel shrinkage was measured with strain gauges (n=10). Finite element analysis was used to calculate the stresses in a two-dimensional pre-molar model under 4 conditions: Wc, without occlusal contact, representing stresses due to composite shrinkage only; Ct, contact generated between enamel of restored tooth with antagonist tooth; Cm, contact on tooth/composite restoration margin; Cc, stable centric contact on the composite restoration. ***Results***. Elastic modulus varied between 12.6 (Filtek LS) and 21.5 (Z100) GPa; post-gel shrinkage varied between 0.11 (Filtek LS) and 0.96 (Z100) vol%. Composites with higher elastic modulus and post-gel shrinkage increased stress in the restored tooth. Occlusal contact on the tooth/composite restoration margin increased the stresses around the margin of the restoration. Stable centric contact on the restoration resulted in better stress distribution.

Clinical Significance. Stresses in the restored tooth increased with increasing elastic modulus and post-gel shrinkage. Contact close to the restoration margin increased the local stress concentration regardless of composite properties. Occlusal adjustment after posterior restoration to prevent contact at the margin is important to improve stress distribution and preserve the restoration integrity.

Introduction

Resin composites represent a class of materials widely used in restorative dentistry. Besides aesthetic quality, resin composites can be directly bonded to tooth structure without unnecessary removal of healthy tissues.[1] However, composite materials shrink during polymerization, which may cause residual stresses in restored teeth even when not in function.[2,3]

Residual stresses can alter the behavior of a restored tooth, such as causing cusp deflection.[4,5] This may affect clinical performance and play a role in clinical symptoms associated with shrinkage stresses, such as inadequate adaptation, microcrack propagation, marginal loss, post-operative sensitivity, microleakage, and secondary caries.[6,7] These clinical consequences may not be noticeable until functioning, when new stress concentrations are created by adding cyclic masticatory loads to pre-stressed restored teeth.[2]

Polymerization shrinkage is unavoidable due to the composition of restorative composites a mixture of monomers and ceramic fillers. Monomers like Bis-GMA and TEGDMA exhibit up to 12.5% volumetric shrinkage. Shrinkage reduces to 2-6% when fillers are added.[8] New polymer technology can reduce shrinkage further. For example, novel silorane monomers have polymerization shrinkage values of less than 1% using cationic ring-opening polymerization.[9] This lower shrinkage reportedly decreased shrinkage stress by 27% compared to methacrylate-based composites.[10] Filler particle size and shape in the composites can also affect the shrinkage values,[11,12] because volume contraction depends on filler concentration, polymerization characteristics, restorative procedure, and light intensity used for photoactivation (Petrovic & Atanackovic, 2008; Ferracane, 2005; Soares et al. 2013; Bicalho et al. 2014b).[3,5,13,14]

Although shrinkage is an important consideration in the development of new restorative composites, other properties should also be considered. Mechanical properties of composites used in posterior teeth should be able to support masticatory loading and re-establish the restorative function.[3] Occlusal contacts in the occlusal margin are likely to be a major factor in marginal fractures.[15-18] These fractures have also been associated with sensitivity, recurrent caries and failure of a restoration. Considering that shrinkage stresses are often also concentrated at the occlusal margin,[17] the combination of shrinkage stresses and occlusal loading may be a determining factor in the mechanical performance of a restorative complex.

Few have studied the dynamic generation of stresses in composite restorations with consideration of polymerization shrinkage, mechanical properties and occlusal contacts. The purpose of this study was to explore the effects of the occlusal contact loading of posterior teeth restored with various composite resins, representing mechanical and shrinkage properties. The null hypothesis was that the different composites would not influence stress conditions during occlusal contact movements.

Materials and Methods

Five dental composites indicated by manufactures for restoring posterior teeth were tested in this study (Table 1).

Post-gel shrinkage measurements

Composite post-gel shrinkage was determined using the strain gauge method similar as previously described.[3,19,20] The composite was shaped into a hemisphere (N = 10), about 1.5 mm high and 3 to 4 mm wide, placed on top of a biaxial strain gauge (CEA-06-032WT-120, Measurements Group, Raleigh, NC, USA) that measured shrinkage strains in two perpendicular directions. The perpendicular strains were averaged since the material properties were homogeneous and isotropic on a macro scale. The composite was light-cured using a quartz–tungsten–halogen (QTH) unit (XL2500, 3M ESPE, St Paul, MN, USA) with the light tip placed at 1 mm distance from the surface of the composite. The radiant exposure was set at 24 J/cm^2 (600 mW/cm^2 × 40 s). A strain conditioner (2101A Series, Micro Measurements Group) converted electrical resistance changes in the strain gauge to voltage changes through a quarter-bridge circuit with an internal reference resistance. Microstrain resulting from polymerization shrinkage was monitored for 10 min, starting from the beginning of photoactivation. The post-gel shrinkage value at 10 min was used in the finite element analysis. The mean shrinkage strain, which is the linear shrinkage was converted to percentage and multiplied by three to obtain the volumetric shrinkage. One-way ANOVA followed by Tukey HSD post-hoc tests ($\alpha = .05$) were used to determine the statistical significance among the post-gel shrinkage values for the different composite resins.

Elastic modulus determination

Elastic modulus was determined using the Knoop indentation method.[21] A 2 mm thick stone mold with a 5 mm diameter circular opening was used to fabricate the test specimens. The stone mold was placed on a glass slide, and filled with dental composite. Another glass slide was placed on top of the mold to cover the composite. Digital pressure was applied on the glass slide to obtain a smooth flat surface. The composite was light activated for 40 seconds through both top and bottom glass slides (XL 2500, 3M ESPE). Five Knoop indentations were made to obtain an average value for each sample (N = 5). To calculate elastic modulus from Knoop indentation, the decrease in the length of the indentation diagonals caused by elastic recovery of a material is related to the hardness/modulus ratio H/E by equation:

$$\alpha$$

where ***b/a*** is the ratio of the diagonal dimensions ***a*** and ***b***, in the fully loaded state, given by a by a constant 0.140647. ***b'/a'*** is the ratio of the altered dimensions when fully recovered and $\boldsymbol{\alpha}\mathbf{1}$ = 0.45 is a proportionality constant. One-way ANOVA followed by Tukey HSD post-hoc tests (α= .05) were used for the statistical analysis of elastic modulus.

Finite element stress analysis

To calculate residual stresses in the tooth, a two-dimensional finite element simulation was carried out of an MOD-cavity with the cavity floor in dentin. The geometrical model was based on a digitized bucco-lingual cross section of a maxillary premolar (Figure 1). Coordinates were obtained using ImageJ software (public domain, Java-based image processing and analysis software developed at the National Institutes of Health, USA). The cross-section was meshed using plane strain elements for the tooth structure and plane stress elements for the composite (linear, four-nodes, isoparametric, and arbitrary quadrilateral). Only the cervical portion of the root was simulated since the rest of the root did not affect the coronal stress distribution.[3] A simplified boundary condition was assumed at the cut-plane of the root (fixed zero-displacements in both horizontal and vertical directions). The elastic modulus of enamel was 84 GPa (principal direction, perpendicular to the pulp surface) and 42 GPa in transverse directions, with Poisson's ratio of 0.30. The dentin elastic modulus was 18 GPa and the Poisson's ratio 0.23.[22] The shrinkage and elastic modulus values of the composites were obtained from the experimental data. The Poisson's ratios were chosen to be the same for all composites at 0.24. Polymerization shrinkage was simulated by thermal analogy. Temperature was reduced by 1°C, while the linear shrinkage value was entered as the coefficient of linear thermal expansion.

A premolar antagonist was created to simulate a dynamic loading from an occlusal masticatory movement. Figure 1 shows the dimensions of the antagonist cusp. The applied properties (enamel and dentin) were the same as for the restored tooth, while the boundary conditions were also placed on the cut-plane of the root. Displacements (stroke) on horizontal direction were prescribed while the tooth was left to move freely in vertical direction but no rotation was allowed. A vertical load of 20N was applied to simulate the masticatory biting/chewing force. Coefficient of friction was 0.25.

The finite element stress analysis was performed using MSC.Mentat (pre- and post-processor) and MSC.Marc (solver) software (MSC Software Corporation, Santa Ana, CA, USA). Modified von Mises equivalent stresses were used to express the stress state. This is a modification of the well-known von Mises criterion to account for materials that have different strengths in compression and tension.[22] The compressive-tensile strength ratios used were 37.3, 3.0, and 6.25 for the enamel, dentin, and composite, respectively.[23] Four stress distributions were determined (Figure 2): Wc, without occlusal contact, representing the effect created by composite shrinkage only; Ct, contact generated between antagonist tooth and enamel of restored tooth next to the restoration margin; Cm, contact on the composite aspect of the restoration margin; Cc, stable contact on the composite restoration in the centric occlusion position.

Results

Post-gel shrinkage

The mean values and standard deviations for the post-gel shrinkage of the composites are presented in Table 2 in linear (microstrain) and volume-percent terms. One-way ANOVA revealed statistical difference among the composites ($p < 0.001$). The Tukey HSD test showed that Z100 had the highest mean shrinkage value (0.96 ± 0.04%) and Filtek LS had the lowest value (0.11 ± 0.01%).

Elastic modulus

Means and standard deviations for elastic modulus values of the composites are presented in Table 2. One-way ANOVA revealed statistical difference among the composites ($p < 0.001$). The Tukey HSD test showed that Z100 (21.5 ± 1.3 GPa) had the highest elastic modulus and Filtek LS (12.6 ± 1.3 GPa) had the lowest values.

Finite element analysis

Stress distributions for five composites and are shown in Figure 2. Z100 and Beautiful II caused the highest stress values, Filtek Z250 and 4 Seasons presented intermediate values, while Filtek LS generated the lowest stress values along the restoration interfaces, irrespective of type of loading. The occlusal contact on the tooth enamel intensified the cervical stresses of the loading cusp. The antagonist tooth contact in the centric position (contact in composite) resulted in more homogeneous stress distribution. Occlusal contact on the restoration margin increased the stress levels along the margin of the composite restoration. Higher post-gel shrinkage and elastic modulus resulted in higher polymerization stresses, irrespective of the contact condition.

Discussion

The aim of this study was to investigate how occlusal contact loading affects the stress conditions in a composite restored posterior tooth. The study showed that the magnitude of the stress depends on the occlusal contact type and on the post-gel shrinkage and elastic modulus of the restorative composite resins. Therefore the null hypothesis was rejected.

Posterior teeth are designed for preparation and processing of food through a biomechanical process. The anatomy of the maxillary and mandibular posterior teeth is modeled in nature to create the occlusal table suitable for masticatory function. Contacts between the antagonists occur during the functional activities of chewing.[24] Restoring a compromised tooth therefore implies re-establishing of the natural mechanical response and transfer of masticatory forces.[2] Although the entire dentition is exposed to mechanical forces, the occlusal stress is higher in the posterior teeth as compared to the anterior teeth.[25,26] Posterior composite restorations can therefore be expected to have a higher failure risk.

In this study, stresses in restored posterior teeth were analyzed using finite element analysis. The results showed that initially, without occlusal contact, stresses are generated inside the tooth model caused solely by the polymerization shrinkage. For given tooth and cavity properties and shapes, these stresses are mainly determined by elastic modulus and post-gel shrinkage of the composite material. The elastic modulus of composite generally increases with increasing filler content. Moreover, an increase in elastic modulus of the composite materials has also been attributed to increased bonding of the inorganic matrix to the fillers and shortening of polymer chains.[27,28] Ranking of the elastic modulus values of composites investigated in this study is similar to the reported filler content, which varied from 55 to 69% by volume. Results from finite element analysis show increasing stress levels in the composite restoration with increasing elastic modulus. This is not surprising, since the stress value is a function of the elastic modulus and deformation. For the simulated conditions in this study, the deformation was represented mainly by the post-gel shrinkage. Figure 2 shows that Beautifull II and Z100 have similar elastic modulus values but the Z100 restoration causes higher shrinkage stresses due to its higher post-gel shrinkage (Table 2). It is important to note that stress values in the different composite materials should not be compared directly, because the significance of stress is related to the strength of a material. Stresses in the tooth tissues, on the other hand, can be compared between the different groups. The stress analysis showed that the residual shrinkage stresses in the tooth (enamel and dentin) increased with increasing elastic modulus and post-gel shrinkage of the composite.

Shrinkage stress concentrations were found at the margin of the restorations (Figure 3). These elevated stress conditions may contribute to marginal debonding and subsequently marginal discoloration. Marginal debonding of visible-light cured resin composites from dentin cavity walls due to polymerization shrinkage has long been identified as a major clinical concern.[6,29] When teeth are brought into occlusal contact, stresses in the tooth-restoration complex can be locally moderated or enlarged by pre-existing residual shrinkage stresses. Marginal integrity of restorative materials is important factor for the long-term performance of any restoration.[18] Marginal fracture for resin-composites, especially close to occlusal contact areas has been reported by many clinical studies.[15,16,30] Watts *et al*.[17] showed that the force-to-fracture increased linearly, for all materials, as the distance from the edge increased. The present study showed that the stress concentration generated by polymerization shrinkage in combination with occlusal contact close to the margin might contribute to this process.

Retrospective clinical evaluation showed that fracture of restorations was the main reason of failure in “occlusal-stress-risk” patients.[30] The residual shrinkage stress caused high stress concentrations on the restorative margins. On the other hand, if the occlusal contact is located at the margin of a composite restoration, the increased stress concentration may increase the risk of marginal fracture.

This study illustrated that composites that cause low shrinkage stresses in restored teeth generate stress concentrations at restoration margins leading to increased failure risks. Even if marginal deterioration is too small to be perceived clinically, it may increase retention of pigments, increasing marginal discoloration. As marginal staining can be confused with marginal caries, such restorations may be replaced prematurely.[31] To decrease the risk of marginal failure, verification of occlusal contacts before and during cavity preparation is recommended to avoid occlusal contact on the interface of a restoration. Additionally, occlusal adjustment is recommended to eliminate possible composite resin excess in this area because premature or exaggerated contacts could also be responsible for post-operative sensitivity during mastication.[32-34] Observing these clinical procedures with an understanding of the balance between mechanical properties offered by various composite resins may improve the clinical performance of posterior composite restorations.

Conclusions

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

- Elastic modulus and post-gel shrinkage varied significantly among the dental composites tested. Higher the post-gel and elastic modulus resulted in higher residual shrinkage stress.
- Occlusal contact increased stress levels in restored teeth, even when shrinkage stress was low.
- Occlusal contact located on the composite aspect of the restoration margin increased the stress at margin of the restoration.
- Stable occlusal centric contact on the composite restoration resulted in better stress distribution.

Acknowledgments

This project was funded by a post-doctoral grant from the CNPq- National Council for Scientific and Technological Development to Dr. Soares and grant from FAPEMIG.

References

1- Ferracane JL. Resin composite--state of the art. *Dent Mater* 2011; 27: 29-38.

2- Versluis A, Versluis-Tantbirojn D. Filling cavities or restoring teeth? *J Tenn Dent Assoc* 2011; 91: 36-42.

3- Soares CJ, Bicalho AA, Tantbirojn D, Versluis A. Polymerization shrinkage stresses in a premolar restored with different composite resins and different incremental techniques. *J Adhes Dent* 2013; 15: 341-50.

4- Bicalho A, Pereira R, Zanatta R, Franco S, Tantbirojn D, Versluis A, Soares C. Incremental filling technique and composite material-part I: cuspal deformation, bond strength, and physical properties. *Oper Dent* 2014; 39: 71-82.

5- Bicalho A, Valdívia A, Barreto B, Tantbirojn D, Versluis A, Soares C. Incremental Filling Technique and Composite Material-Part II: Shrinkage and Shrinkage Stresses. *Oper Dent* 2014; 39: 83-92.

6- Bausch JR, De Lange C, Davidson CL, Peters A, De Gee AJ. The clinical significance of the polymerization shrinkage of composite resin restorative materials. *J Prosthet Dent* 1982; 48:59-67.

7- Jensen ME, Chan DCN. Polymerization shrinkage and microleakage. In: Vanherle G, Smith DC, editors. *Posterior composite resin dental restorative materials.* Utrecht: Peter Szulc Publishing Company; 1985: 243-62.

8- Labella R, Lambrechts P, Van Meerbeek B, Vanherle G. Polymerization shrinkage and elasticity of flowable composites and filled adhesives. *Dent Mater* 1999; 15: 128-37.

9- Weinmann W, Thalacker C, Guggenberger R. Siloranes in dental composites. *Dent Mater* 2005; 21: 68-74.

10- Ilie N, Jelen E, Clementino-Luedemann T, Hickel R. Low-shrinkage composite for dental application. *Dent Mater J* 2007; 26: 149-55.

11- Satterthwaite JD, Vogel K, Watts DC. Effect of resin-composite filler particle size and shape on shrinkage-strain. *Dent Mater* 2009; 25: 1612-5.

12- Boaro LCC, Gonçalves F, Guimarães TC, Ferracane JL, Versluis A, Braga RR. Polymerization stress, shrinkage and elastic modulus of current low-shrinkage restorative composites. *Dent Mater* 2010; 26: 1144–50.

13- Petrovic LM, Atanackovic TM. A model for shrinkage strain in photopolymerization of dental composites. *Dent Mater* 2008; 24: 556-60.

14- Ferracane JL. Developing a more complete understanding of stresses produced in dental composites during polymerization. *Dent Mater* 2005; 21: 36-42.

15- Mjor IA, Toflenetti F. Placement and replacement of resin based composite restoration in Italy. *Oper Dent* 1992; 17:82-5.

16- Bryant RW, Marzbani N, Hodge K. Occlusal margin defects around different types of composite resin restorations in posterior teeth. *Operative Dentistry* 1992; 17: 215-21.

17- Watts DC, Issa M, Ibrahim A, Wakiaga J, Al-Samadani K, Al-Azraqi M, Silikas N. Edge strength of resin-composite margins. *Dent Mater* 2008; 24: 129-33.

18- Baroudi K, Silikas N, Watts DC. Edge-strength of flowable resin-composites. *J Dent 2008*; 36 : 63-8.

19- Sakaguchi RL, Sasik CT, Bunczak MA, Douglas WH. Strain gauge method for measuring polymerization contraction of composite resins. *J Dent* 1991; 19: 312–6.

20- Sakaguchi RL, Versluis A, Douglas WH. Analysis of strain gauge method for measurement of post-gel shrinkage in composite resins. *Dent Mater* 1997; 13: 233-9.

21- Marshall DB, Noma T, Evans AG. A simple method for determining elastic-modulus-to-hardness ratios using Knoop indentation measurements. *J Am Ceram Soc* 1982; 65: 175-6.

22- Versluis A, Tantbirojn D, Douglas WH. Why do shear bond tests pull out dentin? *J Dent Res* 1997; 76: 1298-307.

23- Craig RG. Evaluation of an automatic mixing system for an addition silicone impression material. *J Am Dent Assoc* 1985; 110: 213-5.

24- Benazzi S, Kullmer O, Grosse IR, Weber GW. Brief communication: comparing loading scenarios in lower first molar supporting bone structure using 3D finite element analysis. *Am J Phys Anthropol* 2012; 147: 128-34.

25- Tortopidis D, Lyons MF, Baxendale RH, Gilmour WH. The variability of bite force measurement between sessions, in different positions within the dental arch. *J Oral Rehabil* 1998; 25: 681-6.

26- Johnsen SE, Svensson KG, Trulsson M. Forces applied by anterior and posterior teeth and roles of periodontal afferents during hold-and-split tasks in human subjects. *Exp Brain Res* 2007; 178: 126–134.

27- Masouras K, Silikas N, Watts DC. Correlation of filler content and elastic properties of resin-composites. *Dent Mater* 2008; 24: 932-9.

28- Gonçalves F, Kawano Y, Braga RR. Contraction stress related to composite inorganic content. *Dent Mater* 2010; 26: 704-9.

29- Feilzer AJ, de Gee AJ, Davidson CL. Curing contraction of composites and glass-ionomer cements. *J Prosthet Dent* 1988; 59: 297-300.

30- Van de Sande FH, Opdam NJ, Rodolpho PA, Correa MB, Demarco FF, Cenci MS. Patient risk factors' influence on survival of posterior composites. *J Dent Res* 2013; 92: 78-83.

31- Heintze SD, Rousson V. Clinical effectiveness of direct class II restorations - a meta-analysis. *J Adhes Dent* 2012; 14: 407-31.

32- Pashley DH. Dynamics of the pulpo-dentin complex. *Crit Rev Oral Biol Med* 1996; 7**:** 104-133.

33- Hickel R & Manhart J. Longevity of restorations in posterior teeth and reasons for failure *J Adhes Dent* 2001; 3**:** 45-64.

34- Briso AL, Mestrener SR, Delício G, Sundfeld RH, Bedran-Russo AK, de Alexandre RS, Ambrosano GM. Clinical assessment of postoperative sensitivity in posterior composite restorations. *Oper Dent* 2007; 32: 421-6.

Tables

Table 1 - Dental composites tested in the study (information provided by the respective manufacturers).

Dental Composites	wt. %	vol. %	Filler type	Matrix	Manufacturer
Filtek LS	76	55	Quartz and Yttrium Fluoride (0.1 - 2.0 µm)	TEGDMA and ECHCPMS	3M-Espe, St. Paul, MN, USA
4 Seasons	76	58	Ba glass filler, ytterbium trifluoride, Ba-Al-fluorsilicate glass and high dispersed silica (0.01–2.0µm mean 0.6µm)	Bis-GMA, TEGMA and UDMA	Ivoclar-Vivadent, Schaan, Liechtenstein
Filtek Z250	84	60	Zirconia and silica (0.1 - 3.5 µm)	Bis-GMA, UDMA, Bis-EMA	3M-Espe, St. Paul, MN, USA
Beaultifil II	83	69	multi-functional glass and S-PRG filler based on fluoroboralumino silicate glass (0.01–4.0µm; mean 0.8µm)	Bis-GMA, TEGDMA	Shofu Dental Corp., Kyoto, Japan
Z100	85	66	Zirconia and silica (0.2 - 4.5 µm)	Bis-GMA and TEGDMA	3M-Espe, St. Paul, MN, USA

BisGMA, bisphenol-A glycol dimethacrylate; TEGDMA, triethylene glycol dimethacrylate; BisEMA, bisphenol-A hexaethoxylated dimethacrylate; UDMA, urethane dimethacrylate; ECHCPMS,3,4-epoxycyclohexylcyclopolymethylsiloxane.

Table 2 – Mean and standard deviation of post-gel shrinkage (linear and volumetric), Knoop hardness, and elastic modulus. The volumetric shrinkage was obtained from the linear shrinkage, and the elastic modulus was calculated from the Knoop hardness.

Dental composites	Post-gel shrinkage (microstrain)	Post-gel shrinkage (Vol-%)	Knoop hardness (KHN)	Elastic modulus (GPa)
Filtek LS	376 (45)^{A}	0.11 ± 0.01	51.3 (1.6)^{D}	12.6 (1.3)^{D}
4 Seasons	1378 (282)^{B}	0.41 ± 0.08	41.8 (1.6)^{E}	14.9 (1.4)^{C}
Filtek Z250	1701(152)^{C}	0.51 ± 0.05	81.0 (1.1)^{B}	18.7 (0.7)^{B}
Beaultifill II	2642 (303)^{D}	0.78 ± 0.8	70.3 (1.5)^{C}	21.3 (1.4)^{A}
Z100	3215 (123)^{E}	0.96 ± 0,04	91.1(5.1)^{A}	21.5 (1.3)^{A}

Mean values with same superscript letters are not significantly different (significance level 0.05).

Legends

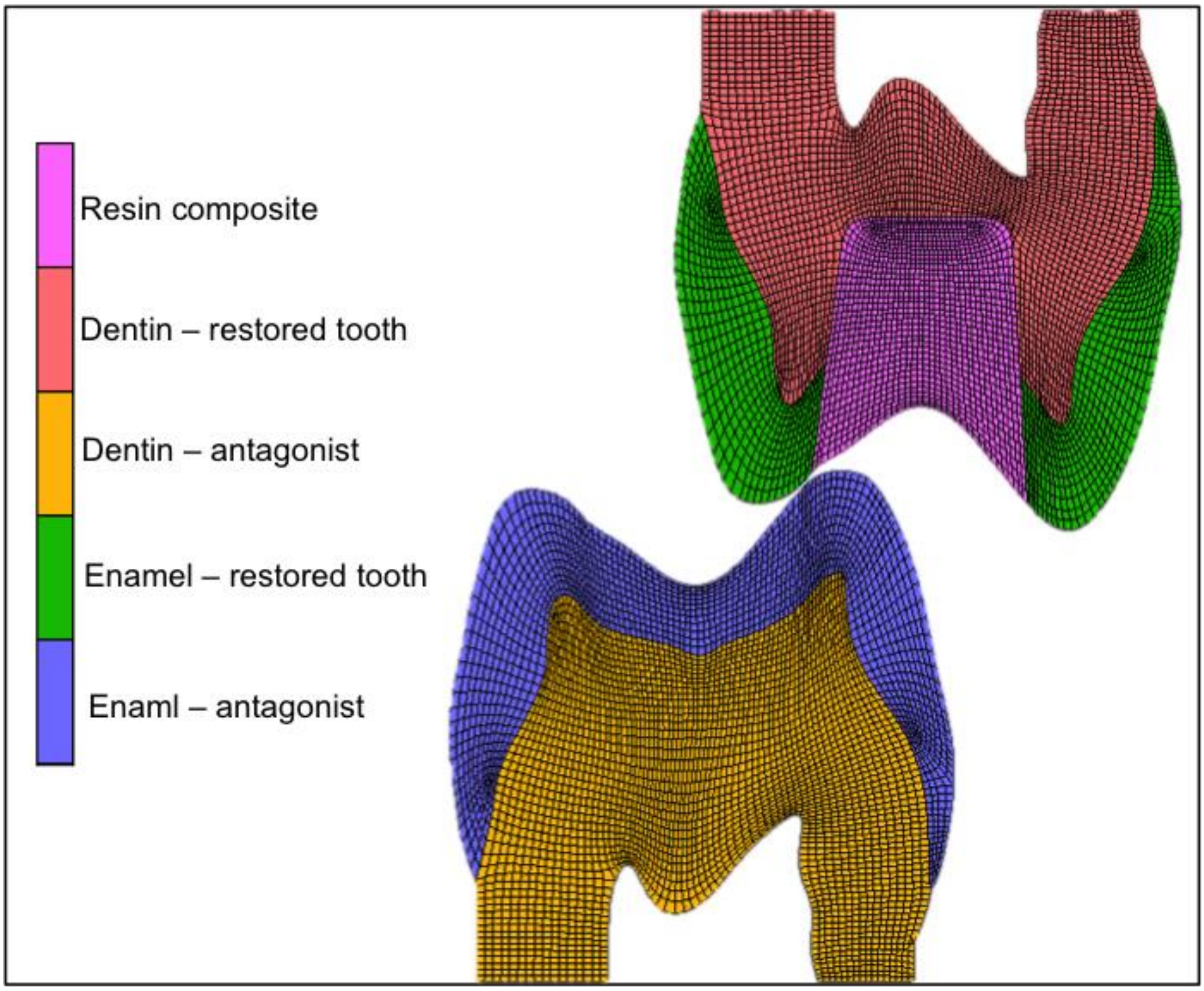

Figure 1. Finite element mesh of the digitized premolar with composite restoration and simulated antagonist.

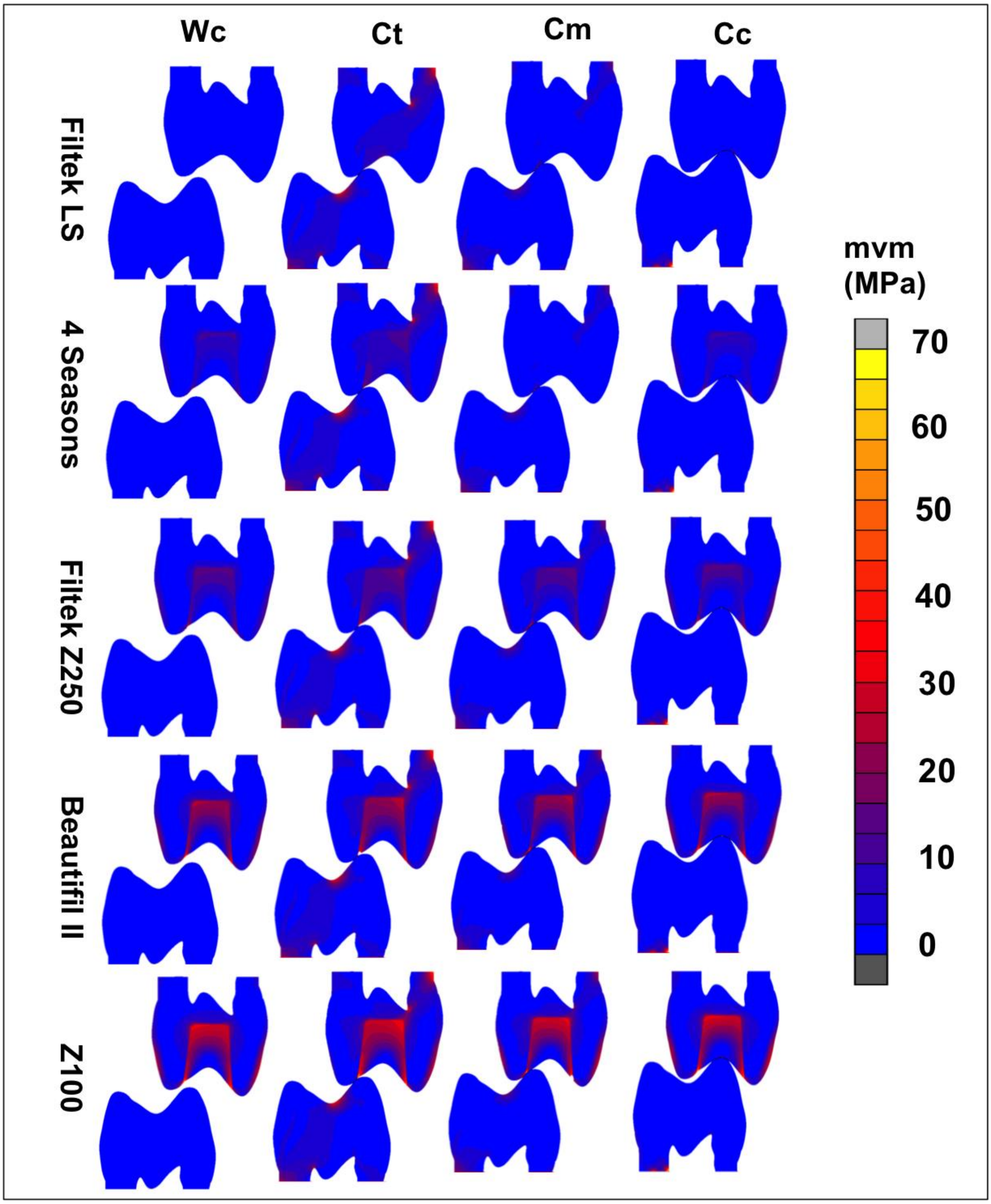

Figure 2. Stress distributions (modified von Mises equivalent stress) due to shrinkage and occlusal contact for the premolar restored with 5 dental composites. Wc, without occlusal contact; Ct, contact between enamel of restored tooth and antagonist tooth; Cm, contact on tooth/composite restoration margin; Cc, stable contact on the composite restoration.

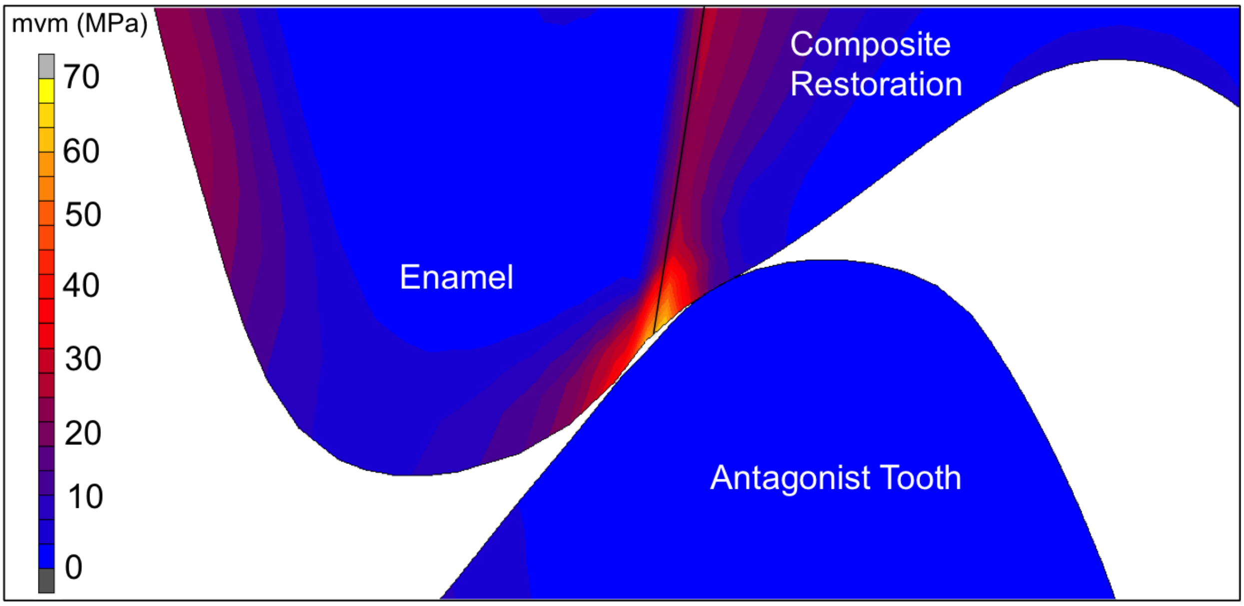

Figure 3. Stress concentration (modified von Mises; MPa) detail at the restoration margin when the occlusal contact is on the composite aspect of the restoration margin ('Cm').

CAPÍTULOS

CAPÍTULO 2

Artigo a ser enviado para publicação no periódico Dental Materials

Effect of temperature and humidity on post-gel shrinkage, cusp deformation, bond strength and shrinkage stress - Construction of equipment to simulate oral environment

CAPÍTULO 2

Artigo a ser enviado para publicação no periódico Dental Materials

Effect of temperature and humidity on post-gel shrinkage, cusp deformation, bond strength and shrinkage stress - Construction of equipment to simulate oral environment

Aline A. Bicalho 1, Silas J.B. Sousa 2, Camila M.P. Rosatto 3, Daranee Tantbirojn 4, Antheunis Versluis 5, Carlos J. Soares 6.

1. DDS, MS, PhD Student, Dental School, Federal University of Uberlandia, Uberlandia, Brazil.
2. DDS, Dental School, Federal University of Uberlandia, Uberlandia, Brazil.
3. DDS, MS Student, Dental School, Federal University of Uberlandia, Uberlandia, Brazil.
4. DDS, MS, Associate Professor, Department of Restorative Dentistry, College of Dentistry, University of Tennessee Health Science Center, Memphis, TN
5. PhD, Professor and Director Biomaterials Research, Department of Bioscience Research, College of Dentistry, University of Tennessee Health Science Center, Memphis, TN
6. Professor and Chairman, Department of Operative Dentistry and Dental Materials, Dental School, Federal University of Uberlandia, Uberlandia, Brazil.

Corresponding Author:
Prof. Dr. Carlos José Soares.
Biomechanic Research Group
Department of Operative Dentistry and Dental Materials
Dental School, Federal University of Uberlândia.
Av. Pará, n° 1720, CEP 38400-902, Bloco B, 2B24, Uberlândia, Minas Gerais, Brasil
Phone: 55-34-3218 22 55 Fax: 55-34- 3218 2279.
E-mail: carlosjsoares@umuarama.ufu.br

Keywords: Shrinkage; cusp deformation; strain gauge; finite element; temperature; humidity; dental composites.

Abstract

Objectives: to evaluate the effect of composite resins and environment condition on post-gel shrinkage (Shr), cuspal strains (CS), microtensile bond strength (μTBS), elastic modulus (E) and shrinkage stress of the composites in molars with large class II restorations.

Methods: The Sixty human molars received standardized Class II mesio-oclusal-distal cavity preparations. Restorations were made with two composites (CHA, Charisma Diamond, Heraus Kulzer and IPS Direct, Ivoclar-Vivadent) using three environment conditions (23^{o}C/50% humidity, 37^{o}C/50% humidity and 37^{o}C/90% humidity) simulated in the specific equipment developed for this purpose. Shr was measured using the strain gauge technique (n=10). CS was measured using strain gauges. After, half of the teeth (n=5) were used to assess the elastic modulus (E) and Knoop hardness (KHN) at different depths using microhardness indentation. The other half (n=5) was used to measure the μTBS. Two composites and three environment conditions for restoring a molar were simulated in a two-dimensional FEA. Polymerization shrinkage was modeled using Shr data. The Shr, CS, μTBS, KHN and E data were statistically analyzed using two-way ANOVA and Tukey test (P = 0.05).

Results: Both composite presented similar Shr, CS, μTBS and shrinkage stress. CHA resin showed higher elastic modulus than IPS resin. The increasing of temperature and humidity increased significantly the Shr, CS and shrinkage stress. The μTBS were similar for groups with lower humidity irrespective of temperature and higher when compared to the higher humidity condition. Lingual cusp showed higher CS and shrinkage stress than buccal cusp. E and KHN were constant through the depth for CHA. The E and KHN values were affected by environment condition only for IPS resin, mainly in deeper region of the cavity.

Conclusions: Increasing the temperature and humidity at environment condition the caused higher post-gel shrinkage and cusp deformation values with higher stresses in the remaining tooth structure and tooth/restoration interface for both composites tested. The equipment developed for the simulation of oral environment conditions precisely helps in performance of the in vitro studies.

Clinical significance: The use of simulation of body temperature and humidity of the environment of the restorative is important to better determine the biomechanics behaviors of the composite resin restoration. Clinically avoiding the higher humidity at the restorative procedure environment, using rubber dam isolation reduces the cusp strain and shrinkage stress and improve the bonding strength of posterior composite restorations.

1. **Introduction**

Composite resins are used every day in almost dental clinic to create posterior tooth-colored restorations. Even with major developments in new restorative materials, resin composites still present a volume reduction due to the polymerization shrinkage [1-3]. These materials are bonded to previously prepared dental cavities, so the polymerization shrinkage will lead to the generation of internal stresses, compromising the mechanical stability of the restoration and may lead to failure [4]. As a consequence is possible to verify verified cusp deflection, [2,3] that can result in enamel microcrack, [5] and marginal gap [6]. Theses consequences may result in post-operative sensitivity, discolored margins, recurrent caries and fractures in the restoration margins [7-9]. These findings are the main reason for the replacement of restorations nowadays [10].

Shrinkage is a characteristic of all polymers and can be divided in two phases related with the development of elastic modulus [11,12]. In the pre-gel phase the composite is able to flow, which relieves the stresses within the restoration [13]. After gelation the composite develops shrinkage stresses because of the increasing in elastic modulus, thus the rigidity of composite allows the stress transference from the tooth structure or tooth/restoration interface [13]. Mercury dilatometer [14] and transducer methods [15] have been used to measure the polymerization shrinkage. However these techniques provide only the total shrinkage values. An enhanced version of a previously reported strain gauge method has been used to determine the post-gel shrinkage, [1,2,16] which is the phase where stresses are developed [13]. Cusp deflection is also experimentally measured using strain gauge test [2] or using free to contact the receptors of the deflection measuring gauge [17].

The interaction between the thermal environment and moisture can have a detrimental effect on polymer-based restorative materials [18]. When the temperature increase the resin composite viscosity decrease, increasing free volume and improving molecular mobility [19]. Increasing degree of conversion is normally accompanied by increased shrinkage [19,20]. All the methods used to measure cusp deflection or post-gel shrinkage have tested this material property only with room temperature (23^{o}C) and humidity (50%). However the mechanical properties of resin-composites are influenced not only by their chemical composition, but also by the environment to which they are exposed [21]. The adhesion to tooth substrate might reflect the contraction stress behavior of a composite resin during polymerization [2,22].

It is important to develop in vitro equipment with versatility for obtaining standardized post-gel shrinkage and cusp deformation values in different temperatures and humidity conditions. Therefore, the aim of this study was to test the efficiency of the new equipment to measure of post-gel shrinkage and cusp deflection or molars restores with two composite resins at different environmental conditions. The null hypothesis was that the restorative materials and environment conditions would not affect mechanical properties, cuspal deformation, bond strength and shrinkage stress in restored molars.

2. **Materials and Methods**

Two resin composites and the dedicated adhesive system with manufactures indication for the restorations of posterior teeth were tested in this study wer IPS Direct e Charisma Diamond. The post-gel shrinkage and cusp deformation were tested at laboratorial environment temperature and humidity (22 ± 2 ºC and 50± 3 % relative humidity); simulating the use of rubber dam, represented by the absolute isolation of operatory area (temperature: 37±2ºC; and humidity: 50±3ºC %), and simulating the oral environment without rubber dam (temperature: 35±2ºC; and humidity: 90±3ºC %).

2.1 Post-gel shrinkage and cusp deformation

The post-gel shrinkage was developed at Dentistry School of Federal University of Uberlandia, MG, Brazil. The principal components of the entire device were two precision mechanical micrometers and one dial indicator with a 0.01 mm accuracy (Mitutoyo Am. Corp., Ontario, Canada), a rod for supporting the light source, a stainless steel bases (25.0 mm x 25.0 mm x 4.0 mm - length x width x height) (10.0 mm x 10.0 mm x 5.0 mm – length x width x height), a mobile table which is coupled to two precision micrometers and a metal holder to keep the sample stable. It is advisable to use the machine over a plane and flat surface to avoid any risk of visual imperfections due to inclination.

The equipment has attached to the table control the system to specimen fixation to maintain the tooth stable during the restorative procedure. This device is in patent lawsuit. Then is possible to fix strain gauges at the external cusp surfaces measuring the cusp deformation. To measure the post-gel shrinkage one accessory was developed that consist in a cylindrical flat surface where the strain gauge is positioned and also with a light-cell fixed on. Therefore at the same time that composite shrinkage is recorded the light intensity is monitored. The laboratorial environment temperature and humidity was obtained by the use of the equipment without the acrylic chamber (22^{o}C and 50% relative humidity – 22/50). The use or not of rubber dam was represented by the body temperature: 37^{o}C and lower humidity, 50% (37/50) and high humidity, 90% (37/90).

2.2 Post-gel shrinkage measurements

Composite post-gel shrinkage was determined using the strain gauge method [1,23]. A Teflon matrix was made to standardize the volume of the composite resin increment before its insertion into the cavity. The composite (N = 10), was inserted into a matrix with 2 mm x 2 mm x 1 mm thickness and placed on top of a biaxial strain gauge shaped into a hemisphere about 1.5 mm high and 3 to 4 mm wide, placed on top of a biaxial strain gauge (CEA-06-032WT-120, Measurements Group, Raleigh, NC, USA). The perpendicular strains were averaged since the material properties were homogeneous and isotropic on a macro scale. The composite was light-cured using a quartz–tungsten–halogen (QTH) unit (XL2500, 3M ESPE, St Paul, MN, USA) with the light tip placed at 1 mm distance from the surface of the composite. The radiant exposure was set at 24 J/cm^2 (600 mW/cm^2 × 40 s). A strain conditioner (2101A Series, Micro Measurements Group) converted electrical resistance changes in the strain gauge to voltage changes through a quarter-bridge circuit with an internal reference resistance. Microstrain resulting from polymerization shrinkage was monitored for 10 min, starting from the beginning of photoactivation. The post-gel shrinkage value at 10 min was used in the finite element analysis. The mean shrinkage strain, which is the linear shrinkage was converted to percentage and multiplied by three to obtain the volumetric shrinkage. Data were analyzed using two-way ANOVA followed by Tukey HSD post-hoc tests (α= .05).

2.3. Cuspal strain (CS)

The experimental design is shown on Fig. 1. Sixty extracted intact, caries-free human third molars were used with approval from the University Ethics Committee in Human Research. The teeth were selected to have an inter-cuspal width within a maximum deviation of not more than 10% of the determined mean. The measured inter-cuspal width varied between 5.06 to 6.02 mm. The teeth were embedded in a polystyrene resin (Cristal, Piracicaba, SP, Brazil) up to 2.0 mm below the cervical line to simulate alveolar bone [2]. The teeth were cleaned using a rubber cup and fine pumice water slurry and distributed into six groups each of ten teeth. The teeth were restored and used for cuspal deflection measurement using strain gauges, and afterwards for the measurement of Knoop hardness (VH) and elastic modulus (E) using the continuing indentation method. All restored teeth had Class II cavities with 4.5 mm inter-cuspal width and 5 mm depth, prepared with a diamond bur (#3099 diamond bur, KG Sorensen, Barueri, SP, Brazil) in a high-speed hand-piece with copious air-water spray using a cavity preparation machine [24]. This machine consisted of a high-speed handpiece (EXTRA torque 605 C; KaVo do Brasil) coupled to a mobile base. The mobile base moves vertically and horizontally with 3 precision micrometric heads (152-389; Mitutoyo Sul Americana Ltda, Suzano, Brazil), attaining a 0.002-mm level of accuracy.

Cuspal deformation was measured with strain gauges (PA-06-060CC-350L, Excel Sensores, SP, Brazil), which had an internal electrical resistance of 350 Ω, a gauge factor of 2.07, and a grid size of 21.02 mm2. The gauge factor is a proportional constant between electrical resistance variation and strain. The strain gauges were bonded to the cervical area of the buccal and lingual surfaces (n=10) with cyanoacrylate adhesive (Super Bonder; Loctite, São Paulo, Brazil), and the wires were connected to a data acquisition device (ADS0500IP; Lynx Tecnologia Eletrônica, Saão Paulo, SP, Brazil). The strain gauges were placed in the region where a finite element model had indicated the presence of the highest polymerization stresses (Bicalho et al., 2014a). In addition, two strain gauges were fixed to another intact tooth to compensate for dimensional deviations due to temperature effects. Both resin composites used in this study were IPS Empress Direct (Ivoclar-Vivadent) and Charisma Diamond (Heraeus Kulzer) were used in association with a self-etching adhesive systems Clearfill SE Bond (Kuraray) according to the manufacturers' instructions. The cavities were restored using three environment conditions: 22^{o}C and 50% humidity relative (22/50); 37^{o}C and 50% humidity relative (37/50); 37^{o}C and 90% humidity relative (37/90). Average volumes of composite per increment were 27.66 mm^3. A Teflon matrix with the cavity was used to standardize each composite resin increment before the insertion into the cavity (Bicalho et al., 2014b). Each increment was lightcured for 20 seconds using a light source with 550 W/ cm^2 output (Demetron Kerr; Orange, CA, USA) by placing from the occlusal direction closest to the cavity. The total energy used was 176 J/cm^2. The cuspal deformation data were obtained from the strain gauges through data analysis software (AqDados 7.02 and AqAnalisys; Lynx). The strain values were recorded at 4 Hz during the restorative procedure and continued for 10 minutes after curing the last increment. The cusp deformation was tested at 3 experimental conditions simulation temperature and humidity. The cuspal deformation values were tested for normal distribution (Shapiro-Wilk, $P<0.05$) and equality of variances (Levene test, $p<0.05$), followed by parametric statistical tests. Data were analyzed using Two-way ANOVA and multiple comparisons were made using the Tukey test.

2.4 Elastic modulus and Knoop hardness determination

Elastic modulus was determined using the Knoop indentation method (Soares et al., 2013). Five Knoop indentations were made on each region (center, mesial and distal of the restoration Fig.2) to obtain an average value for each depth of each sample (N = 5). Half of the samples used in cuspal deformation measurements were used for calculating the mechanical properties (E) and Knoop Hardness (KHN) of the composites at five depths. Each restored tooth was sectioned in the buccal-lingual direction into two halves using a precision saw (Isomet, Buehler). One section per tooth was randomly selected for assessment of the mechanical properties. The specimens were embedded with polystyrene resin (Instrumental Instrumentos de Medição Ltda, São Paulo, SP, Brazil). Prior to testing, the surfaces were finished with silicon-carbide paper (#600, 800, 1200, and 2000 grit sizes; Norton, Campinas, SP, Brazil) and polished with metallographic Diamond pastes (6-, 3-, 1-, and 1/4-lm sizes; Arotec, São Paulo, SP, Brazil). To calculate elastic modulus from Knoop indentation, the decrease in the length of the indentation diagonals caused by elastic recovery of a material is related to the hardness/modulus ratio H/E by equation:

$$\mathbf{b'/a' = b/a - \alpha 1\ (H/E)}$$

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

Two-way ANOVA followed by Tukey HSD post-hoc tests ($\alpha=0.05$) were used for the statistical analysis of elastic modulus.

2.5 Bond strength (μTBS)

The other half of the restored teeth was stored for 24 h in distilled water at 37 ºC, after which the occlusal surface was removed and discarded. The specimens were sectioned bucco-lingually into six slabs of 1 mm thickness using a low speed diamond saw (Isomet, Buehler, Lake Bluff, IL, USA) under water cooling. Each slab was serially sectioned horizontally to harvest two sticks with 1.0 mm X 1.0 mm cross-sections at two cavity depths (10 to 12 sticks for each depth). In each experimental group ten to twelve sticks of each tooth were subjected to the microtensile bond strength (μTBS) test (n=30; 12 teeth per group).

For the μTBS, the ends of the specimen were glued to a microtensile device in the testing machine (EMIC DL 2000 São José dos Pinhais, Paraná, Brazil) using cyanoacrylate glue (Super Bonder Flex Gel, Henkel Loctite Adesivos Ltda, Itapevi, SP, Brazil) covering all the faces of the specimens [25,26] and subjected to a tensile load at a crosshead speed of 1 mm/min. The cross-sectional area of each stick was measured using a digital caliper (Mitutoyo CD15, Mitutoyo Co., Kawasaki, Japan). The μTBS was calculated by dividing the fracture load by the surface area, measured to the nearest 0.01 mm with the digital caliper.

2.6 Finite element stress analysis

To calculate residual stresses in the tooth, a two-dimensional finite element simulation was carried out of an MOD-cavity with the cavity floor in dentin. The geometrical model was based on a digitized bucco-lingual cross section of a mandibular molar. Coordinates were obtained using ImageJ software (public domain, Java-based image processing and analysis software, National Institutes of Health, USA). The cross-section was meshed using plane strain elements for the tooth structure and plane stress elements for the composite (linear, four-nodes, isoparametric, and arbitrary quadrilateral). Only the cervical portion of the root was simulated since the rest of the root did not affect the coronal stress distribution (Bicalho et al., 2014b). A simplified boundary condition was assumed at the cut-plane of the root (fixed zero-displacements in both horizontal and vertical directions). The elastic modulus of enamel was 84 GPa (principal direction, perpendicular to the pulp surface) and 42 GPa in transverse directions, with Poisson's ratio of 0.30. The dentin elastic modulus was 18 GPa and the Poisson's ratio 0.23 [27]. The shrinkage and elastic modulus values of the composites were obtained from the experimental data. The Poisson's ratios were chosen to be the same for all composites at 0.24. Polymerization shrinkage was simulated by thermal analogy. Temperature was reduced by 1°C, while the linear shrinkage value was entered as the coefficient of linear thermal expansion.

The finite element stress analysis was performed using MSC.Mentat (pre- and post-processor) and MSC.Marc (solver) software (MSC Software Corporation, Santa Ana, CA, USA). Modified von Mises equivalent stresses were used to express the stress state. This is a modification of the well-known von Mises criterion to account for materials that have different strengths in compression and tension [27]. The compressive-tensile strength ratios used were 37.3, 3.0, and 6.25 for the enamel, dentin, and composite, respectively [28].

2.7 Statistical analysis

The Shr, CS, KHN, E and µTBS values were tested for normal distribution (Shapiro-Wilk, $P<0.05$) and equality of variances (Levene test, $p<0.05$), followed by parametric statistical tests. Data were analyzed using Two-way ANOVA and multiple comparisons were made using the Tukey test. All tests employed a 0.05 level of statistical significance and all statistical analyses were carried out with the statistical package SigmaPlot® System version 12.0 (Systat Institute Inc, San Jose, CA, USA).

3. Results

3.1. Post-gel Shrinkage

The post-gel shrinkage values for the two composite (CHA and IPS) and the three environment conditions (23^oC/50%, 37^oC/50% and 37^oC/90%) are shown in Table 1. CHA and IPS had similar post-gel shrinkage values (P=0.211). Significant effect was observed for environment condition (P<0.001). Increasing the temperature and humidity the cusp deformation increased significantly for both composite resin (23^oC/50% < 37^oC/50% < 37^oC/90%).

3.2. Cuspal Deformation

The behavior and values of the cuspal deformation (strain) for the two composite (CHA and IPS) and the three environment conditions (23^oC/50%, 37^oC/50% and 37^oC/90%) are shown in Table 2. The IPS and CHA resin had similar cusp deformation values irrespective of environment conditions and cuspal type (lingual or buccal). The lingual cusp had higher deformation than lingual cusp for all experimental conditions and resin composite tested. The environment condition influenced significantly the cusp deformation, increasing the temperature and humidity the cusp deformation increased significantly for both materials.

3.3 Elastic Modulus

The E values in GPa for the two composite and the three environment conditions are shown in Fig. 2. CHA and IPS maintained a constant elastic modulus throughout the depth of the restoration independent of the environment condition. CHA resin presented higher elastic modulus values than IPS independent of the environment condition. The

IPS resin at 22^{o}C/50% had similar E values at 37^{o}C/50% and lower values than 37^{o}C/90%. The CHA resin had no influence of environment condition on E values.

3.4 Knoop harndess indentation

The E values in GPa for the two composite and the three environment conditions are shown in Fig. 3. CHA and IPS maintained a constant elastic modulus throughout the depth of the restoration independent of the environment condition. CHA resin presented higher elastic modulus values than IPS independent of the environment condition. The IPS resin at 22^{o}C/50% had similar E values at 37^{o}C/50% and lower values than 37^{o}C/90%. The CHA resin had no influence of environment condition on E values***3.5***

3.5 Bond strength (µTBS)

The µTBS values in MPa (mean and standard deviation) for the two composite resins and the three environment conditions are shown in Table 3. ANOVA revealed a statistically significant difference among the environment conditions ($p<0.001$). However no significant difference was found between composite resins ($p=0.362$) neither for the interactions of composite resins and environment conditions ($p=0.138$).

Restorations produced at 37^{o}C/90% of humidity had significantly lower µTBS than with the other two tested environments conditions, irrespective of composite resins. . No significant difference was found among Charisma Diamond and IPS Empress Direct, irrespective of the environment conditions. No significant difference was found among Charisma Diamond and IPS Empress Direct, irrespective of the environment conditions.

3.6 Finite Element Results

Stress distributions for all groups and are shown in Fig. 4. No influence on shrinkage stress was observed for composite resin factor. The 22^{o}C/55% environment condition resulted in lower shrinkage stress in the base of the lingual and buccal cusps. The stress levels increased when the temperature and humidity increased.

4. Discussion

The null hypothesis was rejected; the composite resin affected significantly the post-gel shrinkage and the elastic modulus and the environment conditions affected all the all properties tested (Shr, CS, μTBS, KHN and E) and also the residual shrinkage stress.

To calculate the shrinkage stresses, polymerization shrinkage behavior must be modeled. Since not all shrinkage generates stresses, a "post-gel" shrinkage value was used in the analysis. Post-gel shrinkage was defined as the portion of the total polymerization shrinkage that causes stresses, and was measured using the strain gauge technique. The post-gel shrinkage of Charisma Diamond tested at room temperature and humidity (0.46% by volume) was similar to IPS Direct (0.45%), which is consistent with previously published data of conventional composite resin [1]. Therefore these composite should not to be ranked as low-shrinkage resin composites. Several methods have been proposed to measure shrinkage; the principle underlying these methods is similar [19,27,29]. However, results for the same material may differ among methods due to testing configuration [19]. Both composites had significantly higher post-gel shrinkage when was simulated the high temperature (37^{o}C/50%) and more when was increase the temperature and the humidity (37^{o}C/90%). Unlike the gel point, which is a well-defined point in conversion, vitrification is dependent on the reaction conditions since it is determined by mobility restrictions that are affected by factors such as temperature. Increasing the temperature is normally accompanied by the increasing of the degree of conversion and consequently by increased shrinkage [19,20]. Additionally the increase of temperature may cause reduction the time of the pre-gel phase of the polymerization reaction [30]. Previous study showed that the volumetric polymerization shrinkage of different composite resin measured using a drop shape analysis at humidity that simulated oral environment (37^{o}C) was significantly higher than when was tested at room temperature (23^{o}C) [31]. Other study testing increasing of temperature and humidity resulted in higher shrinkage values of the composite resin, thus favoring the onset of clinical undesirable situations [32].

The elastic modulus of both tested resin composites maintained constant throughout the depth of the restoration independent of the environment condition. This may be explained by the incremental technique used to restore the MOD cavity. The use of 2.0mm filling technique resulted in less CS with the same µTBS and UTS than 1.0mm increments, without affecting elastic modulus and Vickers hardness through the depth of the composite [2]. The Charisma Diamond demonstrated significantly higher elastic modulus than IPS Direct irrespective of the environment condition. This finding may be explained by the difference of the filler content between both composite. IPS Direct has 72% by weight [33] and the Charisma Diamond has 81% by weight of filler content [34]. It is important to take into account that increasing filler content generally results in an increased elastic modulus [1,14]. Additionally the high elastic modulus of CHA resin could be justified by the greater number of crosslinking monomers that carry the urethane polymer chain having greater molecular flexibility before glassy phase of the material [35]. The IPS Direct resin was had elastic modulus values affected by environment conditions; on the other hand Charisma Diamond had similar values for three experimental conditions tested. This finding could be explained by the higher percentage of the monomer content on IPS Direct and the monomer composition. The humidity and temperature have been reported in the literature as factors that decrease the stiffness of resin materials thus modifying the properties in the oral environment in relation to laboratory environments [35,36]. The higher monomer percentage resulted in more negative influence by the residual humidity presented into the deep cavity resulting in lower values in the deep cavity when compared with the values obtained at the top of the restoration. Previous study confirmed that the elastic and viscous moduli are dependent on measurement temperature and concluded that increasing temperature leads to a decrease in elastic modulus, and an increase in viscous modulus [37].

The cups deformation measured by using strain gauge test has been validated by finite element analysis [3]. The cuspal deformation is associated directly with post-gel shrinkage [2]. The similarity of the cuspal deformation values of Charisma Diamond and IPS Direct may be explained by the similarity of post-gel shrinkage values. The small difference verified between the values of the elastic modulus for both composites tested was not sufficient to result in more cusp deformation nether residual shrinkage stress. Resin composites polymerization at higher temperature compared to room temperature may be accompanied by an increase in degree of conversion, shrinkage strain, and polymerization rate [19,38]. This aspect could explain the higher cusp deflection for experimental conditions that increased the temperature and mainly when was simulated the higher temperature and humidity. The lingual cusps had higher cuspal deformation than buccal cusps for both composite and all environment conditions. This result can be explained by the amount of remaining tooth structure. Third molars had narrower cervical areas lingual than buccal, and thus the lingual cusps can be expected to be less stiff than the buccal cusps [2].

Excellent bonding and properties are critical for optimal clinical performance of a restoration. Some conditions of intraoral temperature and humidity may not impair the bond strength for specific adhesive systems [39]. In this case, an adequate relative isolation seems to be a good alternative under the specific clinical conditions in which rubber dam isolation is either impossible or very difficult to perform [39]. However, the amount of water saturated in the exhaled air by mouth is reported to be about 27 mg/dm^3 and its possible effects on dental practice requires careful evaluation [40,41]. Restorative procedures performed inn clinical conditions with high flux of the saliva and with more difficulty of the humidity contamination, like was simulated in the present study the bond strength obtained could be compromised. This result is consistent with other studies [41,42] and could be attributed to the humidity environment might contaminate the surface during the restorative procedure and also by the higher shrinkage stress. Additionally, the excess water may influence the mechanical properties of adhesive layer of the one-step self-etch adhesives by inhibiting the optimal polymerization of the monomers [42]. This experimental conditional is similar to restorations procedures performed without rubber dam isolation mainly in upper molars. The results of the present study reinforce the largely statement that is recommended to perform posterior composite restoration in posterior teeth only with rubber dam isolation.

Shrinkage stress of resins composite can be responsible by post-operative sensitivity and other complications such as microcrack and marginal microleakage. Transient shrinkage stress during polymerization causes tooth deformations, which is considered indicative of tooth microcracks and resin–dentin bond failure [43]. Marginal gaps created by polymerization shrinkage do not appear to increase the risk for secondary caries, but can lead to marginal staining, which may be diagnosed as secondary caries [44].

Finite element analysis may collaborate with the understanding of biomechanical problems of teeth restored with composites [1,45]. In the present study IPS presented similar stress shrinkage distribution when compared with CHA. This was expected because post-gel shrinkage is the great determinant of shrinkage stress, and the both materials presented similar post-gel shrinkage. Studies have demonstrated that post-gel shrinkage can have more direct relation with stress when compared with elastic modulus [1]. When the temperature and humidity increase may be seeing that the stress concentrated inside restoration is high, the same happens in the base of cuspal. This means that warm and humidity are harmful and can lead to failure the complex restoration.

The simulation condition of the body temperature and humidity resulted in higher shrinkage stress and cusp deflection. Therefore the establishment of the experimental conditions more similarly to the oral environment, during post-gel and cusp deformation is recommended. The experimental condition that simulated absence of rubber dam isolation represented the extreme condition with higher shrinkage stress and cusp deflection. Although, same studies have shown that the self-etching primer adhesives tested are unaffected by the degree of dentin wetness or ambient air humidity exposure prior to application [39,46]. Unless considered necessary for other clinical reasons, use of rubber-dam is not compulsory [46]. However, more humidity present in the oral environment could play important rule for post-operatory sensitivity caused by increasing of cusp deflection and residual shrinkage stress. Reduction of the cusp deflection and shrinkage stress could be extrapolated as one more advantage of the rubber dam isolation.

5. Conclusions

Within the limitations of this study it was concluded that the environment conditions affected significantly the post-gel shrinkage, elastic modulus, cusp strain, μTBS and shrinkage stress of teeth restored with composite resins. Charisma Diamond and IPS Direct presented similar shrinkage stress, cusp deformation and shrinkage stress. The elastic modulus of Charisma Diamond was higher than IPS Direct. The simulation of the oral environment becomes desirable for testing in the laboratory to assess contraction and shrinkage stress and cusp deformation.

Acknowledgements

This project was supported by CNPq and granted from FAPEMIG. This project was developed on CPBio, Biomechanics, Biomaterials and Cell Biology Research Center.

References

[1] Soares CJ, Bicalho AA, Tantbirojn D, Versluis A. Polymerization shrinkage stresses in a premolar restored with different composite resins and different incremental techniques. J Adhes Dent. 2013 Aug;15(4):341-50.

[2] Bicalho A, Pereira R, Zanatta R, Franco S, Tantbirojn D, Versluis A, Soares C. Incremental filling technique and composite material-part I: cuspal deformation, bond strength, and physical properties. Oper Dent. 2014 Mar-Apr;39(2):e71-82.

[3] Bicalho A, Valdívia A, Barreto B, Tantbirojn D, Versluis A, Soares C. Incremental Filling Technique and Composite Material-Part II: Shrinkage and Shrinkage Stresses. Oper Dent. 2014 Mar-Apr;39(2):e83-92.

[4] Koplin C, Jaeger R, Hahn P. Kinetic model for the coupled volumetric and thermal behavior of dental composites. Dental Materials 2008;24(8):1017–24.

[5] Batalha-Silva S, de Andrada MA, Maia HP, Magne P. Fatigue resistance and crack propensity of large MOD composite resin restorations: direct versus CAD/CAM inlays. Dent Mater. 2013 Mar;29(3):324-31.

[6] Takahashi H, Finger WJ, Wegner K, Utterodt A, Komatsu M, Wöstmann B, BalkenholcM. Factors influencing marginal cavity adaptation of nanofiller containing resin composite restorations. Dent Mater. 2010 Dec;26(12):1166-75.

[7] Bausch JR, De Lange C, Davidson CL, Peters A, De Gee AJ. The clinical significance of the polymerization shrinkage of composite resin restorative materials. J Prosthet Dent 1982;48:59–67.

[8] Jensen ME, Chan DCN. Polymerization shrinkage and microleakage. In: Vanherle G, Smith DC, editors. Posterior composite resin dental restorative materials. Utrecht: Peter Szulc Publishing Company; 1985. p. 243–62.

[9] Tantbirojn D, Pfeifer C, Braga R, Versluis A. Do low-shrink composites reduce polymerization shrinkage effects? J Dent Res 2011;90:596–601.

[10] Kopperud SE, Tveit AB, Gaarden T, Sandvik L, Espelid I. Longevity of posterior dental restorations and reasons for failure. Eur J Oral Sci. 2012 Dec;120(6):539-48.

[11] Davidson CL, de Gee AJ, Feilzer A (1984) The competition between the composite-dentin bond strength and the polymerization contraction stress Journal of Dental Research 63(12) 1396-1399.

[12] Feilzer AJ, de Gee AJ, Davidson CL. Curing contraction of composites and glass-ionomer cements. J Prosthet Dent 1988;59:297–300.

[13] Versluis A, Tantbirojn D. Relationship between shrinkage and stress. In: Daskalaki A (ed). Dental computing and applications: advanced techniques for clinical dentistry. Hershey, PA: IGI Global, 2009:45-64.

[14] Boaro LC, Gonçalves F, Guimarães TC, Ferracane JL, Versluis A, Braga RR. Polymerization stress, shrinkage and elastic modulus of current low-shrinkage restorative composites. Dent Mater. 2010 Dec;26(12):1144-50.

[15] Watts DC, Cash AJ. Determination of polymerization shrinkage kinetics in visible-light-cured materials: methods development. Dent Mater. 1991Oct;7(4):281-7.

[16] Sakaguchi RL, Versluis A, Douglas WH. Analysis of strain gauge method for measurement of post-gel shrinkage in composite resins. Dent Mater 1997;13:233–9.

[17] Palin WM, Hadis MA, Leprince JG, Leloup G, Boland L, Fleming GJ, Krastl G, Watts DC. Reduced polymerization stress of MAPO-containing resin composites with increased curing speed, degree of conversion and mechanical properties. Dent Mater. 2014 May;30(5):507-16.

[18] El-Safty S, Silikas N, Watts DC. Temperature-dependence of creep behaviour of dental resin-composites. J Dent. 2013 Apr;41(4):287-96.

[19] Watts DC, Alnazzawi A. Temperature-dependent polymerization shrinkage stress kinetics of resin-composites. Dent Mater. 2014 Jun;30(6):654-60.

[20] Shah PK, Stansbury JW. Role of filler and functional group conversion in the evolution of properties in polymeric dental restoratives. Dent Mater. 2014 May;30(5):586-93.

[21] Oden A, Ruyter IE, Oysaed H. Creep and recovery of composites for use in posterior teeth during static and dynamic compression. Dental Materials 1988;4:147–50.

[22] F e Silva AL, Pereira GD, Dias CT, Sartini Paulillo LA. Effect of the composite photoactivation mode on microtensile bond strength and Knoop microhardness. Dent Mater. 2006 Mar;22(3):203-10.

[23] Sakaguchi RL, Versluis A, Douglas WH. Analysis of strain gage method for measurement of post-gel shrinkage in resin composites. Dent Mater. 1997 Jul;13(4):233-9.

[24] Soares CJ, Fonseca RB, Gomide HA, Correr-Sobrinho L. Cavity preparation machine for the standardization of in vitro preparations. Braz Oral Res. 2008 Jul-Sep;22(3):281-7.

[25] Soares CJ, Soares PV, Santos-Filho PC, Armstrong SR. Microtensile specimen attachment and shape--finite element analysis. J Dent Res. 2008 Jan;87(1):89-93.

[26] Raposo LH, Armstrong SR, Maia RR, Qian F, Geraldeli S, Soares CJ. Effect of specimen gripping device, geometry and fixation method on microtensile bond strength, failure mode and stress distribution: laboratory and finite elemento analyses. Dent Mater. 2012 May;28(5):e50-62.

[27] Versluis A, Tantbirojn D, Douglas WH. Why do shear bond tests pull out dentin? J Dent Res 1997; 76: 1298-307.

[28] Craig RG. Evaluation of an automatic mixing system for an addition silicone impression material. J Am Dent Assoc 1985; 110: 213-5.

[29] Braga RR, Ballester RY, Ferracane JL. Factors involved in the development of polymerization shrinkage stress in resin-composites: a systematic review. Dent Mater. 2005 Oct;21(10):962-70.

[30] El-Korashy DI. Post-gel shrinkage strain and Degree of conversion of Preheated resin composite cured using different regimens. Operative dentistry, v. 35, n.2, p.172-179, 2010.

[31] Tiba A, Charlton DG, Vanderwalle KS, Cohen ME. Volumetric polymerization shrinkage of resin composites under simulated intraoral temperature and humidity conditions. Oper Dent. 2005 Nov-Dec;30(6):696-701.

[32] Osternack F, Caldas D, Almeida J, Souza E, Mazur R. Effects of Preheating and Precooling on the Hardness and Shrinkage of a Composite Resin Cured With QTH and LED. Oper Dent. 2012 Oct 22.

[33] Cao L, Zhao X, Gong X, Zhao S. An in vitro investigation of wear resistance and hardness of composite resins. Int J Clin Exp Med. 2013 Jun 26;6(6):423-30.

[34] Salazar DC, Dennison J, Yaman P. Inorganic and prepolymerized filler analysis of four resin composites. Oper Dent. 2013 Nov-Dec;38(6):E201-9. doi: 10.2341/12-474-L.

[35] Papadogiannis D, Tolidis K, Lakes R, Papadogiannis Y. Viscoelastic properties of low-shrinking composite resins compared to packable composite resins. Dent Mat Journal, v. 30, n. 3, p. 350-357, 2011.

[36] Sideridou ID, Karabela MM, Vouvoudi EC. Dynamic thermomechanical properties and sorption characteristics of two commercial light cured dental resin composites. Dent Mat, v. 24, p. 737–743, 2008.

[37] Stansbury JW. Dimethacrylate network formation and polymer property evolution as determined by the selection of monomers and curing conditions. Dent Mater. 2012 Jan;28(1):13-22.

[38] Daronch M, Rueggeberg FA, De Goes MF, Giudici R. Polymerization kinetics of pre-heated composite. J Dent Res. 2006 Jan;85(1):38-43.

[39] Saraiva LO, Aguiar TR, Costa L, Cavalcanti AN, Giannini M, Mathias P. Influence of Intraoral Temperature and Relative Humidity on the Dentin BondStrength: An in Situ Study. J Esthet Restor Dent. 2014 Mar 14.

[40] Varene P, Ferrus L, Manier G, Gire J. Heat and water respiratory exchanges: comparison between mouth and nose breathing in humans. Clin Physiol 1986; 6: 405-414.

[41] Bavbek AB, Demir E, Goktas B, Ozcopur B, Behram B, Eskitascioglu G, Ozcan M. Micro-shear bond strength of adhesive resins to enamel at different relative humidity conditions. Dent Mater J. 2013;32(3):468-75.

[42] Vaz RR, Hipolito VD, D'Alpino PH, Goes MF. Bond strength and interfacial micromorphology of etch-and-rinse and self- adhesive resin cements to dentin. J Prosthodont 2012; 21: 101-111.

[43] Chuang SF, Chang CH, Yaman P, Chang LT. Influence of enamel wetness on resin composite restorations using various dentine bonding agents: part I-effects on marginal quality and enamel microcrack formation. J Dent. 2006 May;34(5):343-51.

[44] Sarrett DC. Clinical challenges and the relevance of materials testing for posterior composite restorations. Dent Mater. 2005 Jan;21(1):9-20.

[45] Jafarpour S, El-Badrawy W, Jazi HS, McComb D. Effect of composite insertion technique on cuspal deflection using an in vitro simulation model. Oper Dent.2012 May-Jun;37(3):299-305.

[46] Werner JF, Tani C. Effect of relative humidity on bond strength of self-etching adhesives to dentin. J Adhes Dent. 2002 Winter;4(4):277-82.

Tables

Table 1- Post-gel Shrinkage volumetric values – Mean (standard deviation) in (%) after 10 minutes of acquisition dates.

Composite resins	Environment Conditions			Pooled Average
	22°C/50%	37°C/50%	37°C/90%	
Charisma Diamond	0.45 (0.04)	0.51 (0.06)	0.59 (0.04)	**0.52 (0.05)** [A]
IPS Empress Direct	0.46 (0.04)	0.52 (0.05)	0.63 (0.06)	**0.54 (0.05)** [A]
Pool Average	**0.45 (0.04)** [a]	**0.52 (0.05)** [b]	**0.61 (0.05)** [c]	

For pooled averages, distinct letters indicate significant statistical differences ($p < 0.05$).

Table 2- Cuspal deformation values – mean (Standard Deviation) in µS (n= 10 teeth) for each group.

Composite resins	Environment Conditions						Pooled Average
	Buccal cuspal			Lingual cuspal			
	22°C/50%	37°C/50%	37°C/90%	22°C/50%	37°C/50%	37°C/90%	
Charisma Diamond	133 (75)	277 (155)	349 (149)	269 (119)	362 (95)	469 (150)	**310 (125)**[A]
IPS Empress Direct	158 (48)	225 (39)	298 (122)	302 (96)	346 (103)	430 (122)	**293 (88)**[A]
Pooled Average	**146 (51)**[a]	**251 (129)**[b]	**324 (131)**[c]	**286 (107)**[a]	**354 (96)**[b]	**450 (136)**[c]	
Pooled Average Cusp factor		**240 (101)**[α]			**363 (113)**[β]		

For pooled averages, distinct letters and symbols indicate significant statistical differences ($p < 0.05$).

Table 3 – Microtensile bond strength mean values (MPa) for each group (n = 5 teeth – 6 sticks per location of the restoration per tooth).

Composite Resins	Mean (SD) microtensile bond strength (MPa)			Pooled average
	22°C/50%	37°C/50%	37°C/90%	
Charisma Diamond	23.9 (7.7)	22.2 (5.7)	14.5 (2.2)	**20.2 (5.0)[a]**
IPS Empress Direct	19.4 (2.9)	18.7 (4.2)	13.9 (1.4)	**17.0 (2.7)[a]**
Pooled average	**21.7 (4.9)[A]**	**20.5 (4.8)[A]**	**14.3 (1.6)[B]**	

For pooled averages, distinct letters indicate significant statistical differences ($p < 0.05$).

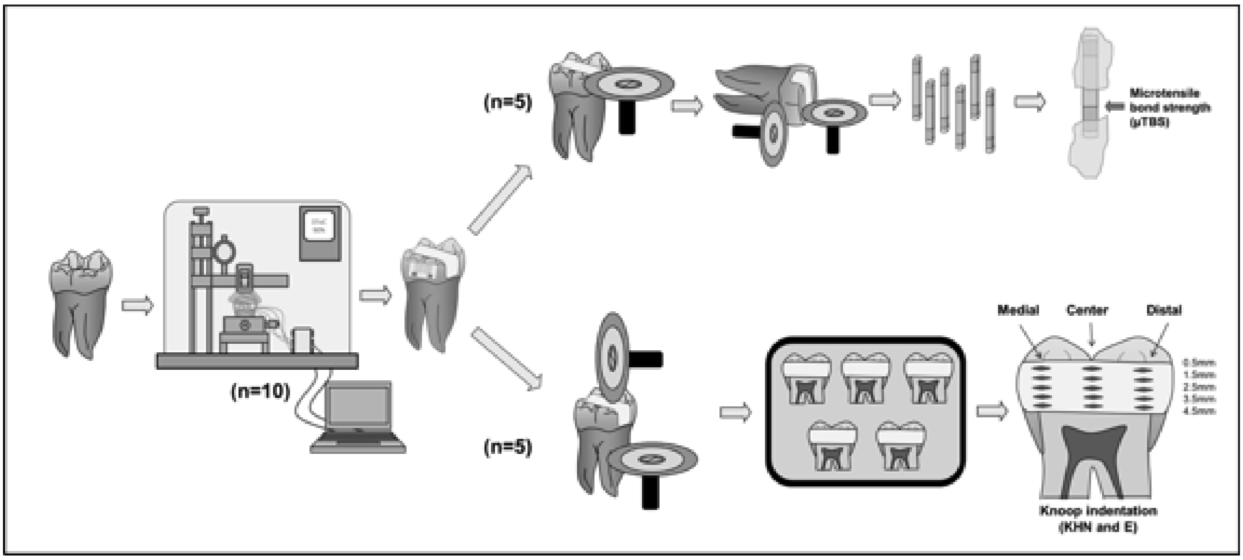

Figure 1. Schematic illustration describing the sample preparation for the strain gauge test used to measure the cusp deformation (n=10) and after that used to measure microtensile bond strength (n=5) or to measure elastic modulus and Knoop hardness indentation (n=5).

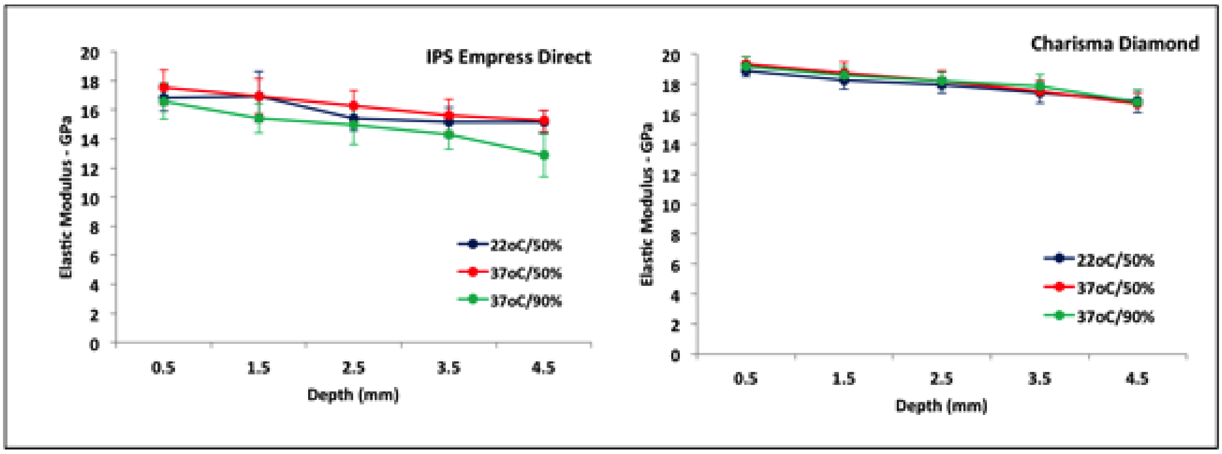

Figure 2. Elastic modulus at various restoration depths for (A) IPS Empress Direct; (B) Charisma Diamond.

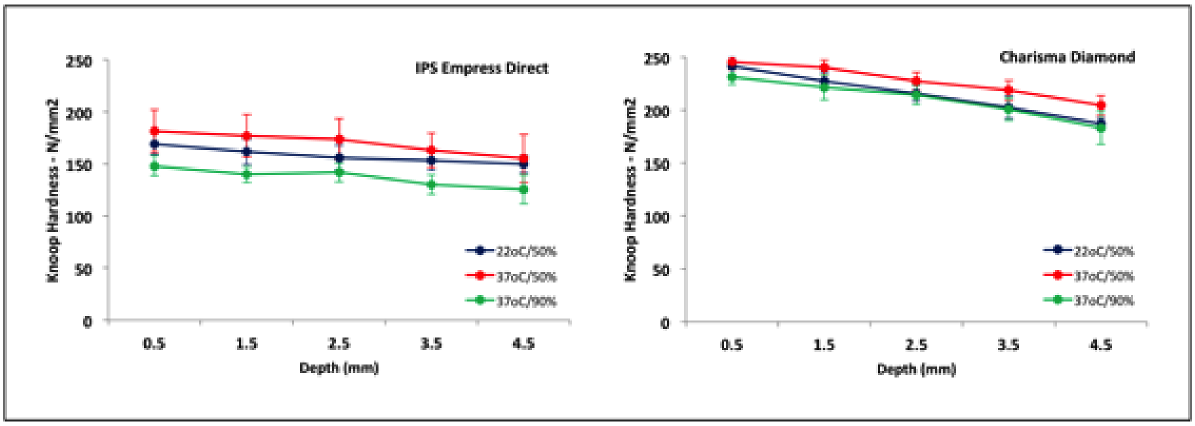

Figure 3. Knoop hardness at various restoration depths for (A) IPS Empress Direct; (B) Charisma Diamond.

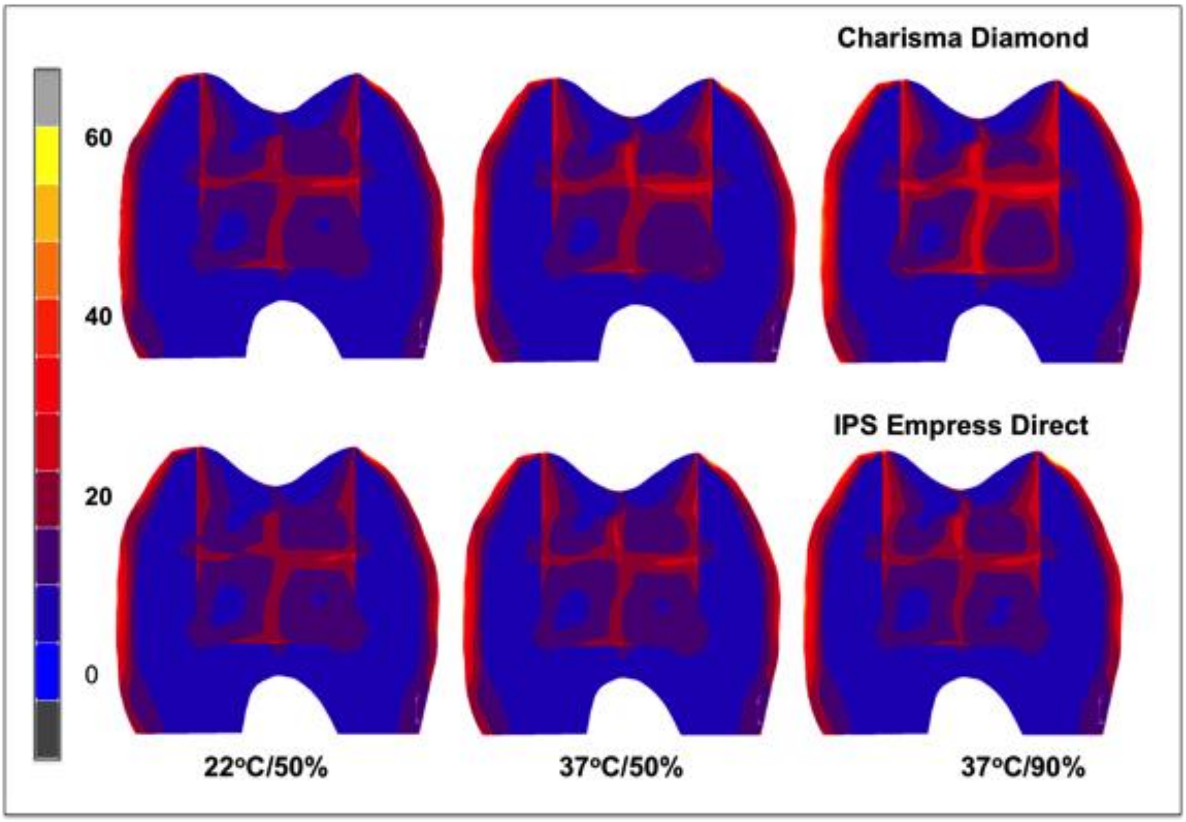

Figure 4. Stress distributions calculated by finite element analysis (modified von Mises equivalent stresses, MPa).

CAPÍTULOS

3.3 CAPÍTULO 3

Artigo a ser enviado para publicação no periódico Operative Dentistry

Effect of glass ionomer liner and filling technique on biomechanics performance of posterior composite restoration – Part I, cuspal strain, fracture resistance and fracture mode.

3.3 CAPÍTULO 3

Artigo a ser enviado para publicação no periódico Operative Dentistry

Effect of glass ionomer liner and filling technique on biomechanics performance of posterior composite restoration – Part I, cuspal strain, fracture resistance and fracture mode.

Mechanical properties and biomechanical behavior in molars restored with composite

Aline A. Bicalho 1, Mariana S. Ferreira 1, Renata A. da Silva 1, Darannee Tantbirojn 2, Antheunis Versluis 2, Carlos J. Soares 1.

1. Department of Operative Dentistry and Dental Materials, Dental School, Federal University of Uberlandia, Uberlandia, Brazil.
2. Department of Bioscience Research, College of Dentistry, University of Tennessee Health Science Center, Memphis, TN

Corresponding Author:

Prof. Dr. Carlos José Soares.

Biomechanic Research Group

Department of Operative Dentistry and Dental Materials

Dental School, Federal University of Uberlândia.

Av. Pará, n° 1720, CEP 38400-902, Bloco B, 2B24, Uberlândia, Minas Gerais, Brasil

Phone: 55-34-3218 22 55 Fax: 55-34- 3218 2279.

E-mail: carlosjsoares@umuarama.ufu.br

Keywords: Post-gel shrinkage; cuspal strain; filling technique; dental composites; intermediary layer.

Effect of glass ionomer liner and filling technique on biomechanics performance of posterior composite restoration – Part I, cuspal strain, fracture resistance and fracture mode.

SUMMARY

Objectives: to evaluate the effect of resin modified glass ionomer (RMGI) liner and filling technique on cuspal strain (CS), fracture resistance (FR) and fracture mode (FM) in molars with large class II restorations.

Methods: Forty human molars received standardized class II mesio-oclusal-distal cavity preparations and restorations with composite resin (Filtek Supreme, 3M-ESPE; SU) and were randomly divided into 4 groups based on two study factors: presence of intermediary layer: Ion, use of RMGI liner (Vitremer, 3M-ESPE) or NIon, absence of liner; and filling technique: Ps, incremental filling cavity starting by proximal surface; Bw, incremental filling cavity starting by buccal wall. The tests were performed at 22°C and 50% of relative humidity. Cuspal strain was measured in three moments; during the restorative procedure (CS-re), representing occlusion force, simulated with 100N loading (CS-oc) and at maximum fracture load (CS-fr) using strain gage test. The fracture resistance (N) was assessed under compressive load in a universal testing machine. Fracture modes were recorded based on the degree of tooth structure and restoration damage using optical microscopy and scanning electron microscopy (SEM). Data of CS and FR were analyzed using two-way ANOVA followed by Tukey Test, and FM data were analyzed using Qui-square test (α=.05).

Results: Two-way analyses showed no significant differences for the filling technique. The liner resulted in significantly higher fracture resistance values (P<.001). CS-re values had no influence by filling technique nether for liner presence. CS-oc and CS-fr

of were significantly lower when was used Ion liner. Fracture resistance and fracture mode had no influence by filling technique nether for liner presence.

Conclusions*:* The presence of RMGI liner resulted in lower cuspal strain values during restorative procedure regardless of filling technique. The sequence of the increments of composite resin had no effect of Cs, Fs and Fm.

Clinical significance: Using resin modified glass ionomer liner before incrementally insertion of composite resin in class II molars cause lower cuspal strain with probably lower post-operative sensitivity in large and deep posterior cavities.

INTRODUCTION

Restorative resin composites have been used in dentistry in large scale for dental restorations but in spite of the undeniable technological advances introduced during years, still present undesirable characteristics associated with the volumetric shrinkage.[1] Resin-composites used for dental restorative materials undergo volumetric contraction when polymerized due to molecular densification, this shrinkage-strain, if it is not occurring freely, leads to tensile forces within the material at the interface of the composite and cavity wall.[2] Polymerization shrinkage of composite resins has been a clinical concern and the associated stresses are thought to play a role in microleakage, recurrent caries and post-operative sensitivity.[3,4] Shrinkage strain manifest themselves most directly in cuspal strain and shrinkage stress of restored teeth.[5-7] Stress generated by polymerization shrinkage and cuspal strain depends on multiple factors, such as photo activation time, mechanical properties of materials and filling technique.[6-9]

The restored teeth with composite resin suffer cuspal strain during the restorative procedure as a consequence of polymerization shrinkage.[6] However this cuspal strain also occurs when the restored tooth is subjected to masticatory loads due to compressive axial forces.[10,11] The failure of posterior restorations due to fractures of the tooth or the restorative material is a significant clinical problem.[12] The deformation, fracture resistance, and failure mode of restored teeth are the result of the interaction among multiple factors, such as restorative preparation design, magnitude and type of load, mechanical properties of restoration, and the use of low-modulus intermediate layers.[13-15] These parameters can be investigated both with destructive testing, like a fracture resistance test, and nondestructive measuring of deformation.[14] The shrinkage stress may cause crack on the dental structure remaining impacting on the fracture resistance after fatigue.[16] It is also suggested that mechanical loading should be restricted during the first few hours after completion of a resin-based restoration.[17] Because the oral cavity has thermal cycling during food intake and functional load, which may result in slow incremental structural degradation.[18] Therefore the combination of destructive and non-destructive tests in laboratory studies brings relevant information about the prediction of failure of the restorative process. Using nondestructive methods like strain-gauge during restorative procedure, occlusal loading and at the moment of the limit of the failure of the tooth restoration complex may help to understand the mechanics of the fracture failure of posterior teeth restored with different techniques.

Several alternative clinical techniques have been introduced to address the problems of sealing and stress in Class II cavities. Among these is the replacement of a substantial part of the resin composite with glass ionomer cement, which the cement is fully enclosed by a resin composite.[19] RMGI has also been recommended as a liner material, because they replace some of the dentin volume reducing the side effects of polymerization shrinkage.[20] The higher tensile and flexural strength of RMGI compared with conventional glass ionomer cement,[21] may impact positively on fracture resistance of the posterior teeth with large cavities restored with composite resin.

Restorative protocols and restorative materials have been developed to minimize polymerization shrinkage and their clinical effects. The adequate volume of the resin composite used on incremental filling technique has been indicated to decrease the effects of shrinkage and stress generated.[7] Recent published functional and aesthetic guidelines for posterior composite resin restoration recommend the stratification of the restorative material initiating by proximal surfaces using triangular-shaped increments to reduce the shrinkage stress.[22] If the class II restoration starts by proximal surface, the class II that has low C-factor is automatically transformed in class I with higher C-factor.[23] However if the class II restoration is performed inserting the sequence of the increments filling completely the buccal or lingual cusp, the insertion of the last increments may create internal defects. No study has tested the effect of the filling increment technique regarding the sequence of the increment stratification sequence on fracture resistance and fracture mode.

Therefore the purpose of this study was to investigate the effect of the filling technique, defined by the sequence of the insertion of increments and the use of RMGI liner on cuspal strain measured during restorative procedure, during simulated occlusion load after thermo-mechanical fatigue, at the moment of the maximum loading fracture, and also on the fracture resistance and fracture mode in molars with an extensive and deep class II restoration considered the filling technique and intermediary layer. The null hypothesis was that the filling techniques and liner presence would not affect the cuspal strain, fracture resistance and fracture mode values.

MATERIALS AND METHODS

Teeth selection, embedment process and cavity preparation

Forty extracted intact caries-free human molars were used with approval from the University Ethics Committee in Human Research. The teeth were selected to have an inter-cuspal width within a maximum deviation of not more than 10% of the determined mean. The measured inter-cuspal width varied between 5.17 to 6.13 mm. The teeth were embedded in a polystyrene resin (Cristal, Piracicaba, SP, Brazil) up to 2.0 mm below the cervical line to simulate alveolar bone. The teeth were cleaned using a rubber cup and fine pumice water slurry and distributed into four groups (n = 10). The roots were covered with a 0.2-mm layer of a polyether impression material (Impregum; 3M ESPE, St Paul, Minn) to simulate the periodontal ligament, and embedded in a polystyrene resin (Cristal, Piracicaba, Sao Paulo, Brazil) up to 2 mm below the cementoenamel junction to simulate the alveolar bone.[24]

The ten teeth per group had Class II cavities with 4.5 mm inter-cuspal width and 5 mm depth, using a diamond bur (#3099 diamond bur, KG Sorensen, Barueri, SP, Brazil) in a high-speed hand-piece with copious air-water spray prepared standardized with cavity preparation machine.[25]

Cuspal strain during restorative procedure (CS-re)

Cuspal strain was measured with strain gauges (PA-06-060CC-350L, Excel Sensores, SP, Brazil), which had an internal electrical resistance of 350 Ω, a gauge factor of 2.13 and a grid size of 21.02 mm^2, were used ten teeth per group. The gauge factor is a proportional constant between electrical resistance variation and strain. The strain gauges were bonded to the 2 mm below the cervical area of the buccal and lingual surfaces with cyanoacrylate adhesive (Super Bonder; Loctite, Sao Paulo, Brazil), and the wires were connected to a data acquisition device (ADS0500IP; Lynx Tecnologia Eletrônica, São Paulo, SP, Brazil). In addition, two strain gauges were fixed to another intact tooth, to compensate dimensional deviations due to temperature effects. For better simulation of clinicians parameters was used the environment control device that to maintains constant temperature and humidity values (37 °C of temperature and 50% of humidity relative) simulating the body temperature and rubber dam isolation. Adjacent teeth were simulated with a fixation of resin tooth in the mesial and distal sides of the molar prepared. This fixation was performed with acrylic resin on the cylinder of polystyrene resin. This technique was realized for to avoid a fixation of matrix.

The materials used in this study were a conventional composite resin Filtek Supreme (3M-ESPE; SU) and a resin modified glass ionomer resin cement, Vitremer (3M-ESPE; Ion). Self-etching adhesive system (Clearfil SE Bond – Kuraray) was used according to the manufacturer instructions. The cavities were restored in accordance of 2 study factors: filling technique and RMGI liner. Two filling techniques were simulated: Ps, incremental filling technique represented by 8 increments of 2,0mm starting by proximal surface (2 increments to reconstruct the medial proximal surface; 2 increments to reconstruct the distal proximal surface; and 4 increments reconstructing occlusal box; or Bw, the same incremental filling technique stating by buccal wall (4 increments to reconstruct the buccal cusp and 4 increments to reconstruct lingual box). Two RMGI liner conditions were created: Ion, application of intermediary layer of 1.5mm in thickness on the pulpal floor distant 2.0 mm from the gingival margins or Nion, represented by restoration made only with composite resin without liner. The RMGI was manipulated and inserted using commercial syringe (Centrix, Shelton, CT, USA) following manufacture instructions. The RMGI liner was was light-cured for 20 s using light source with 600W/cm^2 output (Demetron Kerr; Orange, CA, USA) by placing from the occlusal direction closest to the cavity (Figure 2). The Average volume of composite per increment used was 13.83 mm^3 (no more than 2 mm of thickness). Each increment was light-cured for 20 s. The cuspal strain data was obtained from the strain gauges through data analysis software of data acquisition device. The strain values were recorded at 4 Hz during the restorative procedure and continued for 10 minutes after curing the last increment.

Thermal fatigue, mechanical fatigue and cuspal strain during occlusion procedure (CS-oc)

After cuspal strain measurements, thermal variations were induced in a thermal cycling machine (Thermal Cycler ER-26000; ERIOS equipamentos, São Paulo, SP, Brazil). All specimens were subjected to 6000 cycles, simulating 5 years of clinical service.[26,27] Thermal cycling was performed in bath temperatures of 5°C, 37°C, and 55°C. The dwell time was 30 seconds and the transfer time was 10 seconds, resulting in 2 minutes for each cycle. After the samples were subjected to mechanical fatigue with 1.200.000 cycles (2Hz) of axial compressive loading on occlusal cusps (50N) in a (Mechanical Fatigue ER-11000; ERIOS equipamentos, São Paulo, SP, Brazil). To measure the cusp strain simulating the occlusal loading the samples were subjected to axial compressive loading at 0.5 mm/min, applied with a 6.0 mm diameter sphere shaped tip, up to 100 N limit, in a mechanical testing machine (DL 2000; EMIC, São José dos Pinhais, PR, Brazil).

Cuspal strain during fracture procedure (CS-fr), fracture resistance and fracture mode

Axial compressive loading with a metal sphere 6 mm in diameter at a crosshead speed of 0.5 mm/min in a universal testing machine (DL2000; EMIC, São Jose dos Pinhais, PR, Brazil). The load required (N) to cause catastrophic fracture of specimens was recorded by a 500 N load cell hardwired to a computer with control and data acquisition software (TESC; EMIC). At the maximum loading necessary to cause sample failure, the cuspal strain (CS-fr) was measured again with strain gage test. Fracture modes were recorded, based on the degree of tooth structure and restoration damage using optical microscopy and scanning electron microscopy (SEM), and then assigned to 5 modified categories.[28] (I) fractures involving a small portion of the coronal tooth structure; (II) fractures involving a small portion of the coronal tooth structure and cohesive failure of the restoration; (III) fractures involving the tooth structure, cohesive and/or adhesive failure of the restoration, with root involvement that can be restored in association without periodontal surgery; (IV) fractures involving the tooth structure, cohesive and/or adhesive failure of the restoration, with root involvement that can be restored in association with periodontal surgery; and (V) severe root and crown fracture, which determine extraction of the tooth.

Statistical Analysis

The cuspal strain and fracture resistance data were tested for normal distribution (Shapiro-Wilk, $p>0.05$) and equality of variances (Levene's test, $p>0.05$), followed by parametric statistical tests. Two-way analysis of variance (ANOVA) was performed followed by Tukey test. Fracture modes frequency was analyzed using Q-square test. All tests employed a 0.05 level of statistical significance and all statistical analyses were carried out with the statistical package Sigma Plot v.12.1 (SAS Institute Inc, Cary, NC, USA).

RESULTS

Cuspal strain during restorative procedure (CS-re)

The behavior and values of the cuspal deformation (strain) for the two filling techniques and the presence of the RMGI liner for the experimental groups measured during restorative procedure on buccal and lingual are presented in Table 1. ANOVA revealed significant difference in cusp deformation during restorative procedure for the RMGI liner presence (P = 0.005). However no difference was found for filling technique (P = 0.528), for cups type (P = 0.070), for the interaction between the filling technique and RMGI liner presence (P = 0.914), for the interaction between the filling technique and cusp type (P = 0.955), for the interaction between the cusp type and RMGI liner presence (P = 0.655), nor the interaction among the three study factors (P = 0.907).

Cuspal strain during occlusion procedure (CS-occlusion)

The behavior and values of the cuspal deformation (strain) for the two filling techniques and the RMGI liner presence measured during oclusal loading (100N) are presented in Table 2. ANOVA revealed significant difference in cusp deformation during restorative procedure for the RMGI liner presence (P = 0.010). However no difference was found for filling technique (P = 0.328), for cups type (P = 0.519), for the interaction between the filling technique and RMGI liner presence (P = 0.703), for the interaction between the filling technique and cusp type (P = 0.376), for the interaction between the cusp technique and RMGI liner presence (P = 0.431), nor the interaction among the three study factors (P = 0.654).

Cuspal strain during fracture procedure (CS-fracture)

The behavior and values of the cuspal deformation (strain) for the two filling techniques and the RMGI liner presence measured during fracture test on buccal and lingual are presented in Table 3. ANOVA revealed significant difference in cusp deformation during restorative procedure for the RMGI liner presence (P = 0.014). However no difference was found for filling technique (P = 0.243), for cups type (P = 0.754), for the interaction between the filling technique and RMGI liner presence (P = 0.914), for the interaction between the filling technique and cusp type (P = 0.345), for the interaction between the cusp technique and RMGI liner presence (P = 0.564), nor the interaction among the three study factors (P = 0.777).

Fracture Resistance

The fracture resistance values in N (mean and standard deviation) for the two filling techniques and the RMGI liner presence are presented in Table 4. ANOVA revealed no difference in fracture resistance for the type of filling technique (P = 0.721), for RMGI liner presence (P = 0.150) nor the interaction between the filling technique and RMGI liner presence (P = 0.703).

Fracture mode

Fracture mode distribution for all groups ate shown in Table 5. Qui-square test revealed no difference among the fracture mode for all groups (P = 0.280). SEM images showed that the fractured samples of the groups restored with or without RMGI liner demonstrated that fracture initiation is located on the dentin remaining of the cusp (Figure 2 and 3).

DISCUSSION

The null hypothesis was rejected; the RMGI liner presence would affect the cuspal strain in all moments (restorative procedure, occlusion loading and maximum fracture loading), however no influence was verified for fracture resistance and fracture mode. There are a number of factors that may interfere with resistance to fracture, such as the tooth embedment method, type of load application device, and crosshead speed.[13] Thus, the experimental methods used for in vitro analyses do not faithfully represent real clinical conditions, in which failures occur primarily due to fatigue.[29] To minimize the discrepancy between experimental assessments and clinical failures, different methods have been used, such as the simulation of the thermo-mechanical fatigue that reproduce the challenging process that posterior restorations suffered in oral environment.[16,18] The periodontal ligament simulation has no significant effect on cusp strain measurement, because the shrinkage residual stress is limited to coronal portion of the tooth.[6] Since this study tested also the fracture resistance and fracture mode, the PDL was simulated to improve the stress dissipation to the root portion approximating the fracture test to clinical reality.[13,24]

Cuspal strain of a composite restored tooth is influenced by some factors, including the size of the cavity, the properties of the restorative material, and the filling technique.[6,30,31] The standardization of the cavity is an important characteristic to be considered in assessing the effects of the cusp deformation caused by other factors.[6] In this study the size of the cavity was standardized for all samples with the use of preparation cavity machine. Assuming similar tooth properties, shapes, and sizes, the main variables causing differences in cuspal deformation were therefore the properties of the materials and the filling techniques. This study found that lingual cusp had higher cuspal deformation than buccal cusp regardless of filling techniques or RMGI liner presence. This result can be explained by the amount of remaining tooth structure. Molars had narrower cervical areas lingual than buccal,[32] and thus the lingual cusps can be expected to be less stiff than the buccal cusps.

Resin composites used for dental restorative materials undergo volumetric contraction when polymerized due to molecular densification.[33] This shrinkage strain leads to tensile forces within the material or at the interface of the composite and cavity wall; the development of shrinkage stress is complex, with many factors having an effect.[2,34] The deleterious clinical effects of shrinkage stress can be gap formation, microleakage, post-operative sensitive or cuspal movement that is deformed under the applied stress.[35] In this study, the groups that were restored with composite resin only presented higher cuspal strain values, probably because the composite resin has higher value of post-gel shrinkage than RMGI.[36,37]

The measurement of the cuspal strain during the restorative procedure is able to identify how much the cusp deforms in response to polymerization shrinkage of restorative material.[7] However, the cusp does not deform only by the shrinkage of the restorative material, cusps also deforms in response to masticatory loading.[11] After restoration, the complex tooth/restoration is subjected to cyclic loading and thermal changes over the years. The cyclic fatigue is an important method to simulate the aging of restorative complex over the years.[38] When the samples were subjected to axial loading of 100 N after the fatigue test was showed that the filling technique remained insignificant in the cuspal strain; however the use of RGMI liner resulted in lower values of cuspal strain. The RGMI used as liner present coefficient of thermal expansion similar to dentin.[39] The use of the RGMI liner, material with also lower post-gel shrinkage, reduces the volume of the composite resin, explain the lower cusp deformation. However, when teeth were subjected to extreme occlusal forces, all groups showed the same behavior, and also had the same modes of fracture.

Restoring initially the proximal box of class II, that determine the modification of the in class I cavity, facilitate the sculpture and the anatomy reconstruction.[22] In this study, the filling technique did not influence the cuspal deformation in all moments and also the fracture resistance and fracture modes of molars. The sequence of the stratification of the composite restorations had no influence on the defects into the composite mass that reflect in also similar fracture resistance. It may explain by the complete polymerization of the composite resin along the depth of the cavity.[6] Although the stratification of the increments may create voids and internal defects, the sequence of the increments tend to produce similar internal characteristic of the composite, impacting at the same way on their mechanical performance. The posterior teeth with great structural loss will fail in the as catastrophic mode irrespective of RMGI liner is used. The fracture mode images under scanning electron microscopy of all groups show the source of the failure, it is possible to identify the beginning of the crack that occurs at the base of cuspal weakened. This fact is important because the use of an intermediate material decreases the structural deformation when the tooth is subjected to normal occlusal load mastigatory (100 N). However when the load is to high this layer is not sufficient able to dissipate the stress and the structural limit determine fractures involving more frequently the lingual cusp with the fracture line initiating on the base of the cusp. It is important to use the stress analysis in molar simulating these parameters to determine the stress concentration in this area and also on the pulpal floor. The stress and strain in these regions may result in crack propagation on the base of the cusp and also the pulp sensitivity.

CONCLUSIONS

Within the limitations of this *in vitro* study, it can be concluded that:

- The order of filling technique had no influence the on cuspal strain, fracture resistance and fracture mode of molars restored with composite materials.
- The cuspal strain decreased with the presence of RMGI liner during restorative, occlusion and fracture procedure.
- The fracture resistance and fracture mode was not influence by filling technique and RMGI liner presence.

Acknowledgements

This project was supported by CAPES and FAPEMIG.

REFERENCES

1. Boaro LC, Gonçalves F, Guimarães TC, Ferracane JL, Versluis A, Braga RR (2010) Polymerization stress, shrinkage and elastic modulus of current low-shrinkage restorative composites *Dental Materials* **26(12)** 1144-50, doi: 10.1016/j.dental.2010.08.003.
2. Satterthwaite JD, Maisuria A, Vogel K, Watts DC (2012) Effect of resin-composite filler particle size and shape on shrinkage-stress *Dental Materials* **28(6)** 609-14, doi: 10.1016/j.dental.2012.01.007.
3. Versluis A, Douglas WH, Cross M, Sakaguchi RL (1996) Does an incremental filling technique reduce polymerization shrinkage stresses? *Journal of Dental Research* **75(3)** 871-8.
4. Mjor IA, Toffenetti F (2000) Secondary caries: a literature review with case reports *Quintessence International* **31(3)** 165-79.

5. Taha NA, Palamara JE, Messer HH (2009) Cuspal deflection, strain and microleakage of endodontically treated premolar teeth restored with direct resin composites *Journal of Dentistry* **37(9)** 724-30, doi: 10.1016/j.jdent.2009.05.027.
6. Bicalho AA, Pereira RD, Zanatta RF, Franco SD, Tantbirojn D, Versluis A, Soares CJ (2014) Incremental filling technique and composite material--part I: cuspal deformation, bond strength, and physical properties *Operative Dentistry* **39(2)** E71-82, doi: 10.2341/12-441-L.
7. Bicalho A, Valdívia A, Barreto B, Tantbirojn D, Versluis A, Soares C (2014) Incremental Filling Technique and Composite Material-Part II: Shrinkage and Shrinkage Stresses *Operative Dentistry* 39(2) E83-92 , doi: 10,2341/12-442-L.
8. Tantbirojn D, Versluis A, Pintado MR, DeLong R, Douglas WH (2004) Tooth deformation patterns in molars after composite restoration *Dental Materials* **20(6)** 535-42.
9. Soares CJ, Bicalho AA, Tantbirojn D, Versluis A (2013) Polymerization shrinkage stresses in a premolar restored with different composite resins and different incremental techniques *The Journal of Adhesive Dentistry* **15(4)** 341-50, doi: 10.3290/j.jad.a29012.
10. González-López S, Vilchez Díaz MA, de Haro-Gasquet F, Ceballos L, de Haro-Muñoz C (2007) Cuspal flexure of teeth with composite restorations subjected to occlusal loading *The Journal of Adhesive Dentistry* **9(1)** 11-5.
11. Zamboni SC, Nogueira L, Bottino MA, Sobrinho LC, Valandro LF (2014) The effect of mechanical loading on the cusp defection of premolars restored with direct and indirect techniques *The Journal of Contemporary Dental Practice* **15(1)** 75-81.

12. Güray-Efes B, Yaman BC, Gümüştaş B, Tıryakı M (2013) The effects of glass ionomer and flowable composite liners on the fracture resistance of open-sandwich class II restorations *Dental Materials Journal* **32(6)** 877-82.

13. Soares CJ, Martins LR, Fonseca RB, Correr-Sobrinho L, Fernandes Neto AJ (2006) Influence of cavity preparation design on fracture resistance of posterior Leucite-reinforced ceramic restorations *The Journal of Prosthetic Dentistry* **95(6)** 421-9.

14. Soares PV, Santos-Filho PC, Martins LR, Soares CJ (2008) Influence of restorative technique on the biomechanical behavior of endodontically treated maxillary premolars. Part I: fracture resistance and fracture mode *The Journal of Prosthetic Dentistry* **99(1)**30-7, doi: 10.1016/S0022-3913(08)60006-2.

15. Akbarian G, Ameri H, Chasteen JE, Ghavamnasiri M (2014) Fracture resistance of premolar teeth restored with silorane-based or dimethacrylate-based composite resins *Journal of Esthetic and Restorative Dentistry* **26(3)** 200-7, doi: 10.1111/jerd.12060.

16. Batalha-Silva S, de Andrada MA, Maia HP, Magne P (2013) Fatigue resistance and crack propensity of large MOD composite resin restorations: direct versus CAD/CAM inlays *Dental Materials* **29(3**) 324-31, doi: 10.1016/j.dental.2012.11.013.

17. Kikuti WY, Chaves FO, Di Hipólito V, Rodrigues FP, D'Alpino PH (2012) Fracture resistance of teeth restored with different resin-based restorative systems *Brazilian Oral Research* **26(3)** 275-81.

18. Valdivia AD, Raposo LH, Simamoto-Júnior PC, Novais VR, Soares CJ (2012) The effect of fiber post presence and restorative technique on the biomechanical behavior of endodontically treated maxillary incisors: an in vitro study *The Journal of Prosthetic Dentistry* **108(3)** 147-57, doi: 10.1016/S0022-3913(12)60138-3.

19. Knibbs P (1992) The clinical performance of a glass polyalkenoate (glass ionomer) cement used in a "sandwich" technique with a composite resin to restore class II cavities *Brazilian Dental Journal* **172(3)** 102-107.

20. Kwon OH, Kim DH, Park SH (2010) The influence of elastic modulus of base material on the marginal adaptation of direct composite restoration *Operative Dentistry* **35(4)** 441-7, doi: 10.2341/09-372-L.

21. Xie D, Brantley WA, Culbertson BM, Wang G (2000) Mechanical properties and microstructures of glass-ionomer cements *Dental Materials* **16(2)** 129-38.

22. Deliperi S (2012) Functional and aesthetic guidelines for stress-reduced direct posterior composite restorations *Operative Dentistry* **37(4**) 425-31, doi: 10.2341/11-082-T.

23. Feilzer AJ, De Gee AJ, Davidson CL (1987) Setting stress in composite resin in relation to configuration of the restoration *Journal of Dental Research* **66(11**) 1636–9.

24. Soares CJ, Pizi EC, Fonseca RB, Martins LR (2005) Influence of root embedment material and periodontal ligament simulation on fracture resistance tests *Brazilian Oral Research* **19(1)** 11-6.

25. Soares CJ, Fonseca RB, Gomide HA, Correr-Sobrinho L (2008) Cavity preparation machine for the standardization of in vitro preparations *Brazilian Oral Research* **22(3**) 281-7.

26. Hahnel S, Henrich A, Bürgers R, Handel G, Rosentritt M (2010) Investigation of mechanical properties of modern dental composites after artificial aging for one year *Operative Dentistry* **35(4)** 412-9 doi: 10.2341/09-337-L.

27. Naumann M, Sterzenbach G, Rosentritt M, Beuer F, Frankenberger R (2010) In vitro performance of self-adhesive resin cements for post-and-core build-ups:

influence of chewing simulation or 1-year storage in 0.5% chloramine solution *Acta Biomaterialia* **(6)11** 4389-95, doi: 10.1016/j.actbio.2010.05.023.

28. Burke FJ (1992) Tooth fracture in vivo and in vitro *Journal of Dentistry* **20(3)** 131-9.
29. Hondrum SO (1992) A review of the strength properties of dental ceramics. Fracture mode analysis according to predefined scales *The Journal of Prosthetic Dentistry* **67(6)** 859-65.
30. Versluis A, Tantbirojn D, Douglas WH (1997) Why do shear bond tests pull out dentin? *Journal of Dental Research* **76(6)** 1298-307.
31. Versluis A, Versluis-Tantbirojn D (2011) Filling cavities or restoring teeth? The *Jornal of the Tennessee Dental Association* **91(2)** 36-42.
32. Lee J, Yoo Y, Perinpanayagam H, Ha B, Lim S, Oh S, Gu Y, Chang S, Zhu Q, Kum K (2014) Three dimensional modeling and concurrent measurements of root anatomy in mandibular first molar mesial roots using micro-computed tomography *International Endodontic Journal* 2014 **6(2)**, doi: 10.1111/iej.12326.
33. Lee SK, Kim TW, Son SA, Park JK, Kim JH, Kim HI, Kwon YH (2013) Influence of light-curing units on the polymerization of low-shrinkage composite resins. *Dental Materials* **32(5)** 688-94
34. Meira JB, Braga RR, Ballester RY, Tanaka CB, Versluis A (2011) Understanding contradictory data in contraction stress tests *Journal of Dental Research* **90(3)** 365-70, doi: 10.1177/0022034510388039.
35. Masouras K, Silikas N, Watts DC (2008) Correlation of filler content and elastic properties of resin-composites *Dental Materials* **24(7)** 932-939.
36. Karaman E, Ozgunaltay G (2013) Cuspal deflection in premolar teeth restored using current composite resins with and without resin-modified glass ionomer liner *Operative Dentistry* **38(3)** 282-9, doi: 10.2341/11-400-L.

37. Oliveira L, Mota EG, Borges GA, Burnett LH Jr, Spohr AM (2014) Influence of immediate dentin sealing techniques on cuspal deflection and fracture resistance of teeth restored with composite resin inlays *Operative Dentistry* **39(1)** 72-80, doi: 10.2341/12-100-L.

38. Salaverry A, Borges GA, Mota EG, Burnett Júnior LH, Spohr AM (2013) Effect of resin cements and aging on cuspal deflection and fracture resistance of teeth restored with composite resin inlays *The Journal of Adhesive Dentistry* **15(6)** 561-8, doi: doi: 10.3290/j.jad.a29608.

39. Grisanti LP 2nd, Troendle KB, Summitt JB (2004) Support of occlusal enamel provided by bonded restorations *Operative Dentistry* **29(1)** 49-53.

Tables

Table 1 – Cuspal deformation (μS) during restorative procedure measured by strain gauges (n = 10 teeth).

Presence of RMGI liner	Mean (Standard deviation)					
	Buccal			Lingual		
	Proximal surface	**Buccal wall**	**Pooled average**	**Proximal surface**	**Buccal wall**	**Pooled average**
With RMGI liner	53.7 (21.9)	58.6 (30.0)	**56.2 (25.7)** [a]	65.2 (14.4)	67.7 (35.3)	**66.5 (26.3)** [b]
Without RMGI liner	71.5 (23.3)	76.4 (17.0)	**73.9 (20.0)** [b]	87.0 (45.7)	92.7 (48.6)	**89.8 (46.0)** [a]
Pooled Average	**62.6 (23.8)** [A]	**67.5 (25.4)** [A]		**80.2 (41.8)**[A]	**76.1 (36.6)**[A]	

Different uppercase letters in rows to compare restorative technique, lowercase letters in columns to compare composite resin for each cusp; indicate significant difference for pairwise comparison between buccal and lingual cusps ($p < 0.05$).

Table 2 – Cuspal deformation (μS) during occlusal simulation (100N) measured by strain gauges (n = 10 teeth).

Presence of RMGI liner	**Mean (Standard deviation)**					
	Buccal			**Lingual**		
	Proximal surface	**Buccal wall**	**Pooled average**	**Proximal surface**	**Buccal wall**	**Pooled average**
With RMGI liner	95.9 (28.9)	102.8 (24.9)	**92.9 (26.4)[a]**	98.2 (18.2)	97.2 (29.1)	**97.7 (23.6)[a]**
Without RMGI liner	109.2 (39.2)	115.7 (26.5)	**112.4 (32.7)[b]**	118.3 (47.1)	122.2 (49.0)	**130.2 (48.4)[b]**
Pooled Average	**102.5 (34.2)[A]**	**102.8 (28.3)[A]**		**108.3 (36.3)[A]**	**119.5 (45.5)[A]**	

Different uppercase letters in rows to compare restorative technique, lowercase letters in columns to compare composite resin for each cusp; indicate significant difference for pairwise comparison between buccal and lingual cusps ($p < 0.05$).

Table 3 – Cuspal deformation (µS) during fracture test measured by strain gauges (n = 10 teeth).

Presence of RMGI liner	Mean (Standard deviation)					
	Buccal			Lingual		
	Proximal surface	Buccal wall	Pooled average	Proximal surface	Buccal wall	Pooled average
With RMGI liner	6842.2 (2144.6)	7652.4 (1728.4)	**7247.3 (1940.7)** [b]	7265.2 (2162.5)	7929.9 (1733.5)	**7597.5 (1937.8)**[b]
Without RMGI liner	5638.6 (1686.4)	6096.7 (989.5)	**5867.6 (1366.1)** [a]	6135.3 (1667.1)	6494.9 (1005.5)	**6315.1 (1352.6)**[a]
Pooled Average	**6096.7 (989.5)**[A]	**6874.5 (1586.1)**[A]		**6700.3 (1966.6)**[A]	**7212.4 (1563.4)**[A]	

Different uppercase letters in rows to compare restorative technique, lowercase letters in columns to compare composite resin for each cusp; indicate significant difference for pairwise comparison between buccal and lingual cusps ($p < 0.05$).

Table 4 – Fracture resistance (N) measured by axial compressive fracture test (n = 10 teeth).

Composite Resins	**Mean (Standard deviation)**		
	Proximal surface	**Buccal wall**	**Pooled Average**
With RMGI liner	1420.7 (347.1)	1417.8 (371.3)	**1419.3 (383.1) [a]**
Without RMGI liner	1200.5 (391.8)	1289.0 (390.0)	**1244.3 (383.1) [a]**
Pooled Average	**1310.6 (377.5) [A]**	**1353.4 (376.4) [A]**	

Different uppercase letters in rows to compare restorative technique, lowercase letters in columns to compare composite resin for each cusp; indicate significant difference for pairwise comparison between buccal and lingual cusps ($p < 0.05$).

Table 5 - Distribution (%) of fracture mode analysis of each group (n = 10)

Fracture mode	**Proximal surface**		**Buccal wall**	
	With RMGI liner	**Without RMGI liner**	**With RMGI liner**	**Without RMGI liner**
Type I	-	-	-	-
Type II	10	20	40	20
Type III	70	40	10	40
Type IV	20	30	30	40
Type V	-	10	20	-

Fracture types: I, Fracture with involvement of the core and/or post; II, Root fracture in the cervical third; III, Root fracture in the middle third; IV, Root fracture in the apical third; V, Longitudinal root fracture.

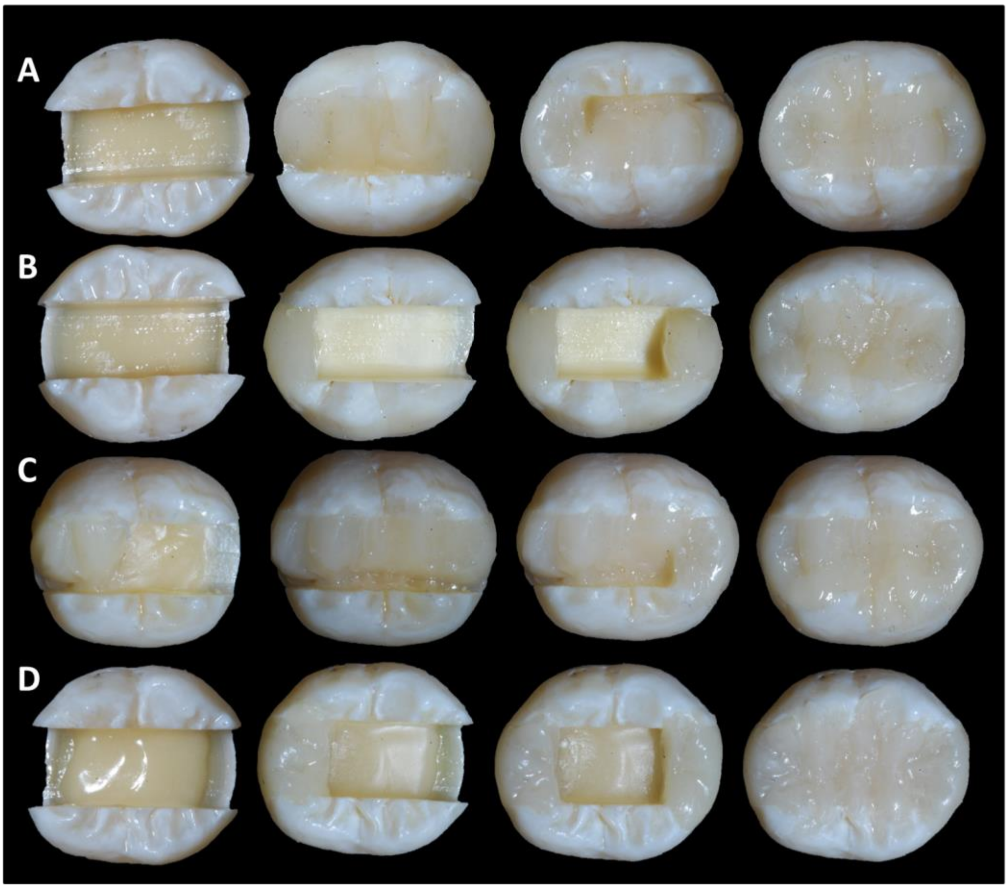

Figure 1. The sequence of restorative procedures for all experimental groups. A - Nion-Bw group; B – Nion-Ps group; C – Ion-Bw group; D – Ion-Ps group.

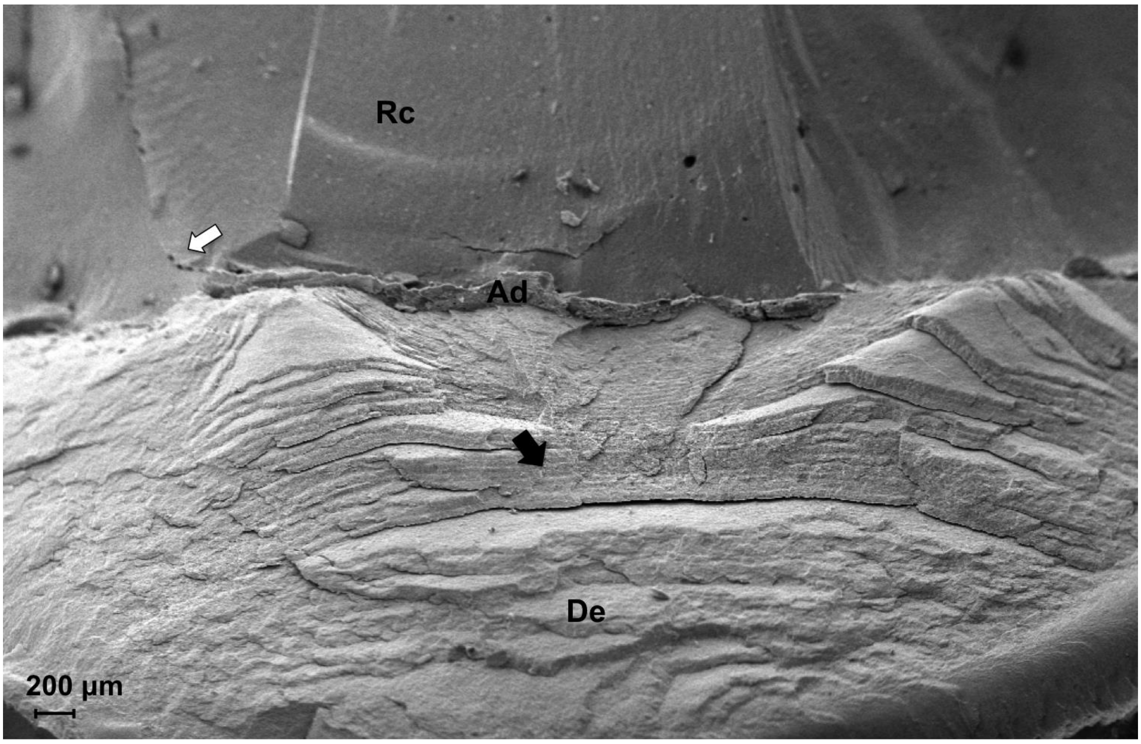

Figure 2. Image illustrating the typical fracture model of sample restored only with composite resin. Black arrow indicates the twist hackle marking. White arrow indicating the bubbles presence between proximal and occlusal increments that coincides with fracture line. Rc, resin composite; Ad, Adhesive system layer; De, Dentin.

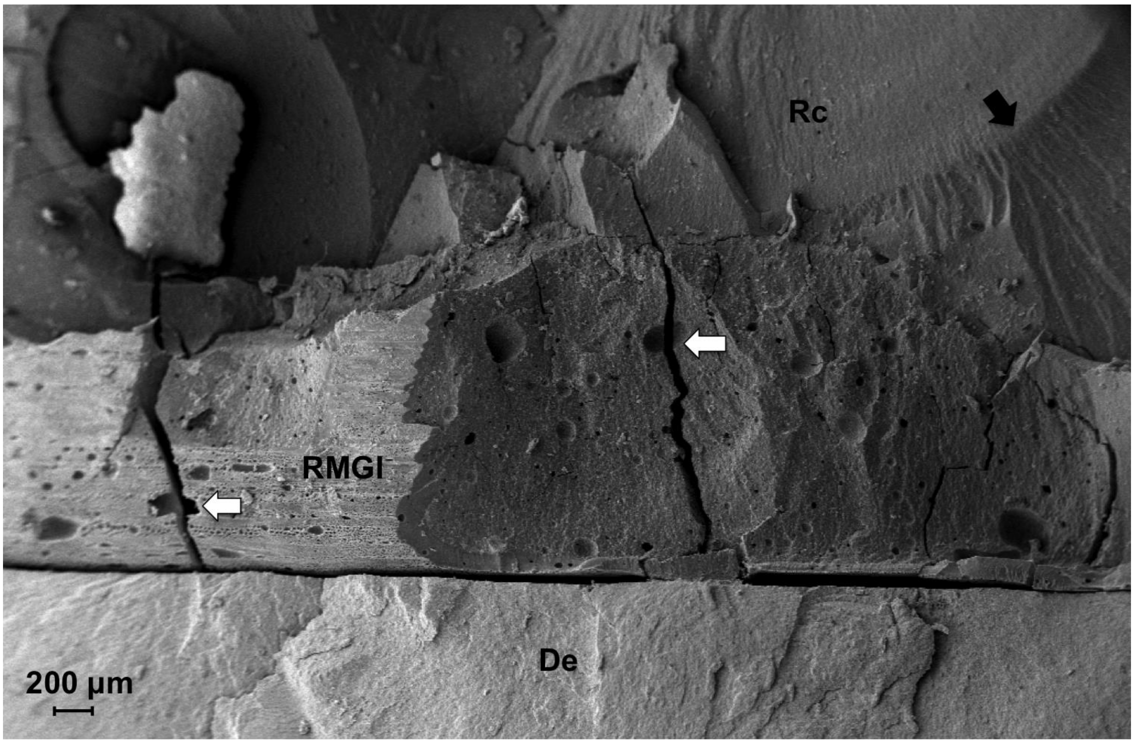

Figure 3. Image illustrating the typical fracture model of sample restored with the association of resin modified glass ionomer and composite resin. Black arrow indicates the fracture line on brittle material. White arrow indicates the bubbles presence on glass ionomer base. Rc, Resin composite; RMGI, Resin modified glass ionomer cement; De, dentin.

CAPÍTULOS

3.4 CAPÍTULO 4

Artigo a ser enviado para publicação no periódico Operative Dentistry

Effect of glass ionomer liner and filling technique on biomechanics performance of posterior composite restoration Part II – marginal adaptation, mechanical properties and stress distributions.

3.4 CAPÍTULO 4

Artigo a ser enviado para publicação no periódico Operative Dentistry

Effect of glass ionomer liner and filling technique on biomechanics performance of posterior composite restoration Part II – marginal adaptation, mechanical properties and stress distributions.

Mechanical properties and biomechanical behavior in molars restored with composite

Aline A. Bicalho 1, Camila M. P. Rosatto 1, Júlia G. Ruggiero 1, Darannee Tantbirojn 2, Antheunis Versluis 2, Carlos J. Soares 1.

3. Department of Operative Dentistry and Dental Materials, Dental School, Federal University of Uberlandia, Uberlandia, Brazil.
4. Department of Bioscience Research, College of Dentistry, University of Tennessee Health Science Center, Memphis, TN

Corresponding Author:
Prof. Dr. Carlos José Soares.
Biomechanic Research Group
Department of Operative Dentistry and Dental Materials
Dental School, Federal University of Uberlândia.
Av. Pará, n° 1720, CEP 38400-902, Bloco B, 2B24, Uberlândia, Minas Gerais, Brasil
Phone: 55-34-3218 22 55 Fax: 55-34- 3218 2279.
E-mail: carlosjsoares@umuarama.ufu.br

Keywords: mechanical properties; marginal adaptation; filling technique; dental composites; intermediary layer.

Effect of glass ionomer liner and filling technique on biomechanics performance of posterior composite restoration Part II – marginal adaptation, mechanical properties and stress distributions.

SUMMARY

Objectives: to evaluate the effect of resin modified glass ionomer (RMGI) liner and filling technique on marginal adaptation, mechanical properties and stress distributions in molars with large class II restorations.

Methods: Twenty human molars received standardized class II mesio-oclusal-distal cavity preparations and restorations with composite resin (Filtek Supreme, 3M-ESPE; SU) and were randomly divided into 4 groups based on two study factors: presence of liner: Ion, use of resin modified glass ionomer liner, RMGI (Vitremer, 3M-ESPE) or NIon, absence of liner; and filling technique: Ps, incremental filling cavity starting by proximal surface; Bw, incremental filling cavity starting by buccal wall. The tests were performed at 22^{o}C and 50% of relative humidity. Elastic modulus (E) and Vickers Hardness (VH) was measured using dynamic indentation test in 4 deeps and 3 regions of the cavity (mesial, center and distal). Marginal adaptation (gingival, buccal and lingual margin) was analyzed under scanning electron microscopy (SEM) regarding the gap presence. Data of E and VH were analyzed using ANOVA followed by Tukey Test. Marginal adaptation were analyzed using McNemar’s test ($\alpha = 0.05$). Finite Element analysis 3D was developed and stress distribution analyzed qualitatively.

Results: E and VH maintained constant for all depths for both restorative techniques and location of the restoration, RMGI values was significantly lower than the composite resin (P=0.001). Gingival margin had significant more gap formation than buccal and lingual margins (P=0.012). No significant difference was found regarding gap formation for RMGI line and filling technique. The stress concentration at the bottom of the cavity (pulpal floor) was higher in the groups without RMGI liner.

Conclusions: The presence of RMGI liner resulted in lower stress concentration at the bottom of the cavity (pulpal floor). The sequence of the increments of composite resin and the presence of liner had no effect on E, VH and marginal adaptation.

Clinical significance: Using resin modified glass ionomer liner before incrementally insertion of composite resin in class II molars cause lower stress concentration with probably lower post-operative sensitivity in large and deep posterior cavities.

INTRODUCTION

Multisurface restorations in permanent premolars and molars are the most frequent type of dental restorations.[1] The development of the composite resin attends the esthetic and bonding principals, however, there is an undesirable characteristic, polymerization shrinkage, which impact of the success of restorations in posterior teeth.[2] The polymerization shrinkage can be associated with the possibility post-operative sensitivity and gap formation resulting in marginal stain.[3,4] The polymerization shrinkage causes residual stresses in the tooth/restoration complex that may be responsible for the failure of composite restorations.[5,6] These consequences have been reported as the main reasons for replacing composite resin restorations in posterior teeth.[7] The success of composite resin restorations may also be associated directly to their mechanical properties such as hardness and elastic modulus.[2] The hardness reflects the ability of the restoration to resist masticatory forces while the elastic modulus is directly reflected in the generation of shrinkage stress that will dissipate through the tooth structure and restorative material.[8]

Class II cavity preparations, specifically those involving both proximal surfaces, are described by clinicians as one of the most challenging restorative procedures.[9] Restorative protocols and restorative materials have been developed to minimize polymerization shrinkage and their clinical effects. Clinically, even when the incremental filling technique is used, the post-operative sensitivity is frequently recorded.[10] To reduce the side effects undesirable by polymerization shrinkage, an intermediary layer between the composite resin and the pulp floor has been proposed.[11,12] Resin modified glass ionomer (RMGI) has also been recommended as a liner material, because they replace some of the dentin volume reducing the side effects of polymerization shrinkage.[13]

When restoring a class II cavity in composite resin starting the filling of restorative material by proximal surface the sculpture of restoration is facilitated because the class II cavity is transformed in class I cavity. The shrinkage stress seems to be lower if the restoration has a higher ratio of unbonded/bonded area. This concept is already expressed by the relationship between C-Factor and stress.[14] If the incremental technique is started by proximal surface, the class II that has low C-factor is automatically transformed in class I with rigid proximal walls made with polymerized composite resin with the elastic modulus very similar to dentin. Consequently the C-factor could be interpreted as higher, creating more stress on the occlusal area that is restored posteriorly. On the other hand if the incremental technique started from only buccal or lingual wall the compliance of the cavity could be lower during all the restorative technique, creating better biomechanics performance. However, little is mentioned in the literature about the effect of cuspal strain regarding the sequence of the increment insertion used.

Continue marginal adaptation is one primary objective of composite resin posterior restorations. This problem is based on several potential mechanisms, including that composite cannot be ‘condensed’ as can amalgam, which leads to an insufficient adaptation of the matrix towards the adjacent tooth.[15] The polymerization shrinkage and the limited access to gingival may also complicate the marginal integrity definition.[15,16] A defect on marginal adaptation in class II is not a parameter to determine indication the substitution of composite resin. On the other hand, class II restorations exhibit a higher failure rate compared to other composite restorations.[17,18] The reasons for premature replacement of posterior resin restorations contradict the scientific evidence.[1] The most frequent reason for replacement given by general practitioners is caries adjacent to the restorative margin, however, most dentists confuse marginal staining with marginal caries.[1] Consequently, if the marginal adaptation is improved, indirectly the premature replacement of the may be reduced. In this way a good marginal quality should be on of the main objective for clinicians.[19] The location of the composite resin increment used on the sequence of stratification technique may impact on the marginal defects. No study has tested this parameter on the marginal adaptation.

A previous study, referred as Part I, examined the effect of filling technique and RMGI layer on cuspal strain, fracture resistance and fracture mode in molars with extensive composite resin restoration. It was found that the order of filling technique had no effect on these parameters. However, the cuspal strain decreased with the RMGI liner during restorative, occlusion and fracture procedure. The main negative response for posterior composite restoration is postoperative sensitivity; commonly this symptom tends to disappear after short period.[20] Although the cusp strain may have a relative effect on post-operative sensitivity, the shrinkage stress generated on the internal walls, mainly on the pulpal floor may impact more this symptom. The use of the finite element analysis with the specific calculation of the mechanical properties of the restorative materials could better explain the effect of the sequence of the increment stratification and the RMGI liner on the shrinkage residual stress.

Therefore the purpose of this study was to investigate the effect of filling technique and intermediary layer on marginal adaptation under scanning electron microscopy, mechanical properties under indentation test and stress generated under finite element analysis in molars class II restored with composite resin. The null hypothesis was that the restorative materials and filling techniques would not affect the marginal adaptation, mechanical properties and stress distribution.

MATERIALS AND METHODS

Teeth selection, embedment process and cavity preparation

Twenty extracted intact caries-free human third molars were used with approval from the University Ethics Committee in Human Research. The teeth were selected to have an inter-cuspal width within a maximum deviation of not more than 10% of the determined mean. The measured inter-cuspal width varied between 5.2 to 6.1 mm. The teeth were embedded in a polystyrene resin (Cristal, Piracicaba, SP, Brazil) up to 2.0 mm below the cervical line to simulate alveolar bone. The teeth were cleaned using a rubber cup and fine pumice water slurry and distributed into four groups (n=5).

The ten teeth per group had Class II cavities with 4.5 mm inter-cuspal width and 5 mm depth, using a diamond bur (#3099 diamond bur, KG Sorensen, Barueri, SP, Brazil) in a high-speed hand-piece with copious air-water spray prepared standardized with cavity preparation machine.[21] The materials used in this study were Filtek Supreme (3M-ESPE; SU) and Vitremer (3M-ESPE; Ion). Adhesive systems (Clearfil SE Bond –

Kuraray) were used according to the manufacturer instructions. The cavities were restored using two filling techniques: started the filling by proximal surface (Ps) or started the filling by buccal wall (Bw) and two restorative materials: presence (Ion) or absence (NIon) of resin modified glass ionomer as intermediary layer. The intermediary layer presented 1.5mm of thickness and it was placed with commercial syringe (Centrix, Shelton, CT, USA). Average volume of composite per increment used was 27.66 mm^3 (no more than 2 mm of thickness). Each increment was light-cured for 20 s using light source with 600W/cm^2 output (Demetron Kerr; Orange, CA, USA) by placing from the occlusal direction closest to the cavity.

Vickers Hardness (VH) and Elastic (E) modulus measurements

The restored teeth from each group were used for the analysis of mechanical properties (E and VH) of the composites at four depths. Each restored tooth was sectioned in the mesial-distal direction into two halves using a precision saw (Isomet, Buehler). One section per tooth was randomly selected for assessment of the mechanical properties. The specimens were embedded with methacrylate resin (Instrumental Instrumentos de Medição Ltda, São Paulo, SP, Brazil). Prior to testing, the surfaces were finished with silicon-carbide paper (#600, 800, 1200, and 2000 grit sizes; Norton, Campinas, SP, Brazil) and polished with metallographic Diamond pastes (6-, 3-, 1-, and 1/4-lm sizes; Arotec, São Paulo, SP, Brazil). Using a Vickers indenter (CSM Micro- Hardness Tester; CSM Instruments, Peseux, Switzerland), indentations were made every 1.0 mm from 0.5 mm to 3.5 mm, measured from the pulpal wall of the restorations in center, mesial and distal regions of the restorations. The indentation was carried out with controlled force, whereby the test load was increased or decreased at a constant speed ranging between 0 and 500 mN in 20-second intervals. The maximum force of 500 mN was held for five seconds. The load and the penetration depth of the indenter were continuously measured during the load-unload hysteresis. The universal hardness is defined as the applied force divided by the apparent area of the indentation at the maximum force. The measurements were expressed in VH units by applying the conversion factor supplied by the manufacturer. The indentation modulus was calculated from the slope of the tangent of the indentation depth curve at the maximum force and is comparable to the E of the material.

Residual Stress Calculation 3D - Finite Element analysis (FEA)

To calculate corresponding residual stress in the tooth, a 3D finite element simulation was carried out. A simplified box shaped Mesial-Occlusal-Distal (MOD) restoration with the cavity floor in dentin was created. The model was designed in 2D plane and expanded in 3D plane using MSC.Mentat (pre- and post-processor) and the finite element analysis using MSC.Marc (solver) software (MSC Software Corporation, Santa Ana, CA, USA). A simplified boundary condition was assumed at the cut-plane of the root (fixed zero-displacements in both horizontal and vertical directions). The elastic modulus of enamel was 84 GPa and Poisson's ratio 0.30, the dentin elastic modulus was 18 GPa and the Poisson's ratio 0.23.[5] The elastic modulus values of the materials represented in 4 groups were obtained in this study. The Poisson's rate was chosen to be the same for all materials at 0.24.[5] Four FEA models were created simulating the two study factors. The insertion of RMGI liner and the sequence of the stratification of the increments were simulated following the same procedures created on experimental methods. Polymerization shrinkage was simulated by thermal analogy. Temperature was reduced by 1°C, while the linear shrinkage value (post-gel shrinkage) was entered as the coefficient of linear thermal expansion. Modified von Mises equivalent stress was used to express the stress conditions, using compressive-tensile strength ratios of 37.3, 3.0, and 6.25 for the enamel, dentin, and composite, respectively.[22] Stress distribution was analyzed qualitatively taking into account the modified von Mises equivalent stress on tooth remaining.

Marginal adaptation measurement

After thermal and mechanical cycling the teeth were submitted to marginal adaptation test. All margins of restoration were finished with fined diamond bur (KG Sorensen, Barueri, SP, Brazil) and proximal margins were finished with flexible disks (SofLex Pop-On, 3M ESPE, St. Paul, USA). After finishing procedures, impressions of the teeth were made using a polyether impression material (Impregum Soft; 3M ESPE) and epoxy resin replicas were obtained (Epoxicure Resin, Buehler). The replicas were mounted on aluminum stubs and scanning electron microscopy (SEM) evaluation (EVO NA 10, Carl Zeiss, Jena, Germany) (Figure 1). SEM was carried out at a standard 200X magnification. Each margin (buccal, lingual and gingival) of the restoration were divided into 3 regions per each surface and analyzed at 200x magnification and expressed as percentages (Figure 1).

Statistical Analysis

The E and VH data were tested for normal distribution (Shapiro-Wilk, p.0.05) and equality of variances (Levene test, p.0.05), followed by parametric statistical tests. Analysis of variance (ANOVA) was performed in a split-plot arrangement, with the plot represented by the filling technique, restorative material, and their interaction and the subplot represented by depth of the cavity. Multiple comparisons were made using the Tukey test. The frequency of the gap presence was analyzed using McNemar's test (α =

0.05) for analyze of marginal adaptation. Stress distribution by FEA was analyzed qualitatively.

RESULTS

Vickers hardness (VH)

The VH values in GPa for the two filling technique and presence or absence of resin modified glass ionomer base at various depths of the restorations are shown in Fig 2. The Vickers hardness maintained constant for all depths for both restorative techniques and location of the restoration. The Vickers hardness of the resin modified was significantly lower than the composite resin, irrespective of the filling technique and location of the restoration.

Elastic modulus (E)

The E values in GPa for the two filling technique and presence or absence of resin modified glass ionomer base at various depths of the restorations are shown in Fig 1. The elastic modulus maintained constant for all depths for both restorative techniques and location of the restoration. The Elastic modulus of the resin modified was significantly lower than the composite resin, irrespective of the filling technique and location of the restoration.

Finite Element Analysis

Stress distributions for all groups and are shown in Fig. 3. The stress concentration at the bottom of the cavity (pulpal floor) was higher in the groups without resin modified glass ionomer base. Relevant stress concentration is verified the proximal cavosurface margin. The Bw filling technique produced little more stress on the external surface of the enamel than Ps filling technique.

Marginal adaptation

The distributions of the gap presence for the two filling technique and presence or absences of resin modified glass ionomer base at proximal surfaces of the restorations are shown in Table 1. McNemar's test showed the gingival margin had significant more gap formation than on buccal and lingual margins, irrespective of the tested groups. The gap presence evaluated at mesial and distal surface of the restoration on proximal surfaces (buccal and lingual) and at gingival margin.

DISCUSSION

The null hypothesis was rejected; the RMGI liner and filling technique would not affect the marginal adaptation and mechanical properties, but their affect the stress distribution. Interest in esthetic dentistry has resulted in composite resin restorations being increasingly used not only as a replacement material for failed or unaesthetic amalgams but also as the first choice to restore posterior teeth.[23] Mechanical performance, wear resistance, and esthetic potentials of composite resins have significantly improved over the past few years.[24] On the other hand, polymerization shrinkage of composite resins remains a challenge and still imposes limitations in the application of direct techniques.[25,26] Polymerization shrinkage causes detachment of the enamel margins and can form gaps that result in marginal microleakage that allows the passage of bacteria, fluids, molecules, or ions between the cavity surface and composite resin.[27,28] The marginal gap formation may also contribute with the marginal staining, which may impact in premature replacement because the marginal staining is confused with secondary caries.

Some factors are suggested by researchers to reduce the effects of polymerization shrinkage such as the order, shape and size of the incremental filling technique.[29] RMGI is a better option for using as a liner, because of their higher mechanical strength compared to the conventional glass ionomer and their ability to set on command.[30] Furthermore, RMGI have been recommended as liners under resin composites to reduce the amount of polymerization shrinkage, potential microleakage, and secondary caries.[31] However, the benefit of using RMGI liners for reducing polymerization shrinkage and microleakage is still controversial. While some researchers have reported that using RMGI liner failed to reduce gap formation and marginal sealing[32], others study have reported significant positive effects reducing microleakage.[33] In this study the use of RMGI liner as intermediary layer did not show any effect on marginal adaptation.

Class II restorations with resin composites can be placed at an acceptable standard if the gingival margin is in sound enamel, but there is much debate regarding marginal integrity that extend to dentin.[34,35] The microleakage tends to be higher when the gingival finishing line is defined in dentin.[34] The thermal and mechanical changes in the mouth are important factors from the point of microleakage and durability of the restoration due to disparity in contraction and expansion between the tooth and the restoration.[36] For this reason the specimens were submitted to thermo and mechanical cycling. This is important to turn the marginal evaluation more realistic. In this study the results showed more gap formation on gingival margin than on proximal margins (buccal and lingual), confirming that the great preoccupation in composite resin class II restorations is the gingival margin. The thickness of the enamel is smaller and also the enamel prisms orientation difficult the bonding procedure on gingival margin of class II. Also there is some evidence that marginal adaptation has a moderate correlation in cervical restorations with clinical retention and in Class II restorations (proximal enamel) with clinical marginal staining.[37]

The elastic modulus and other properties of these different types of composites have been shown to be fairly variable *in vitro* studies.[38] Shrinkage stress is generated when the composite material becomes solid enough to transfer stresses that can no longer be relieved by flow, and the post-gel shrinkage of composites is directly related to the generation of shrinkage stress.[39] The advantage of the use RMGI liner can be related to the lower modulus of elasticity of intermediary layer, which absorb stress when the restorative resin shrinks over them and transmit the contraction force to the adjacent tooth structure.[40] The difference in coefficient of thermal expansion and the elastic modulus between the composite resin and the tooth structure may result in stress concentration generating interfacial gap.

The mechanical properties such as Vickers hardness and elastic modulus were calculated with dynamic indentation test verifying that the composite shows higher values than the glass ionomer resin. The difference in composition of the both material, mainly the filler content, can explain the difference on elastic modulus. The post-gel shrinkage of RMGI is also lower than the composite resin. Biomechanically it is favorable to have less rigid material such as liner and a more rigid material to restore the entire cavity, supporting the masticatory loads. The complexity of a FEA can differ depending on the modeled structure, research question, and available knowledge or operator experience. For example, FEA can be performed using two-dimensional (2D) or three-dimensional (3D) models. The choice between these two models depends on many inter-related factors, such as the complexity of the geometry, material properties, mode of analysis, required accuracy and the applicability of general findings, and finally the time and costs involved.[39] Creating a 3D complex model can be considered more costly, because it is more labor-intensive and time-consuming and may require additional technology for acquiring 3D geometrical data and generation of models.[41]

Simplified models can provides significant results and immediate insight with relatively low operating cost and reduced analysis time.

The finite element analysis shows that groups without RMGI liner showed higher stress concentrations in the pulp cavity wall. Stress concentration that may be responsible for the effects of post-operative sensitivity. The hydrodynamic theory has been generally accepted for decades as the best explanation for the response to external stimuli. Finite element analysis showed higher stress concentration on the pulpal floor when the RMGI liner was not used. Regarding the mechanical deformation within dentine may induce dentinal fluid flow that triggers a nerve impulse; and given the concentration of nerve endings in association with odontoblastic cell bodies, mechanical deformation at the pulpal surface could trigger a nerve impulse directly.[42] Explain the frequent patient description of post-operative sensitivity in large and deeper cavities. This study has analyzed the effect of the initial transformation of class II, which has more compliance, to class I. The results showed little stress in base of cuspal in this situation. Although the sequence of the stratification of the composite restorations had little influence on the stress into the composite mass that reflect in similar biomechanics behavior.

Therefore the use of the RMGI liner besides the benefits showed in part I that reduce the cusp deflection, the reduction of the stress concentration on the pulpal floor ten confirm the recommendation of the use RMGI liner in deeper class II composite resin restorations. The order of resin filler showed no significant influence on the residual shrinkage stress. Start restoring the proximal surfaces is more valid because it has the advantage of ease in restoration sculpture.

CONCLUSIONS

Within the limitations of this *in vitro* study, it can be concluded that:

- The order of filling technique had no influence on marginal adaptation, mechanical properties and stress distribution.
- The gingival marginal present great gaps formation than proximal margins.
- The use of RMGI liner decreased the stress concentration in pulpal floor of class II restorations in composite resin.

Acknowledgments

This project was supported by CAPES and FAPEMIG.

REFERENCES

1. Heintze SD, Faouzi M, Rousson V, Ozcan M (2012) Correlation of wear in vivo and six laboratory wear methods *Dental Materials* **28(9)** 961-73. doi:10.1016/j.dental.2012.04.006.
2. Bicalho AA, Pereira RD, Zanatta RF, Franco SD, Tantbirojn D, Versluis A, Soares CJ (2014) Incremental filling technique and composite material--part I: cuspal deformation, bond strength, and physical properties *Operative Dentistry*. **39(2)** E71-82, doi: 10.2341/12-441-L.
3. Jensen ME, Chan DCN (1985) Polymerization shrinkage and microleakage In:Vanherle G, Smith DC (eds). *Posterior composite resin dental restorative materials*. Utrecht: Peter Szulc Publishing, 243-262.
4. Tantbirojn D, Versluis A, Pintado MR, DeLong R, Douglas WH (2004) Tooth deformation patterns in molars after composite restoration *Dental Materials* **20(6)** 535-542.
5. Versluis A, Versluis-Tantbirojn D (2011) Filling cavities or restoring teeth? *The Journal of the Tennessee Dental Association* **91(2)** 36-42.
6. Wilson NH, Lynch CD (2014) The teaching of posterior resin composites: planning for the future based on 25 years of research *Journal of Dentistry* **42(5)** 503-16, doi: 10.1016/j.jdent.2014.02.014.
7. Mychajiliw P, Keenan AV (2010) Defective resin composite - repair or replace? *Evidence-Based Dentistry* **11(4)** 112-3.
8. Soares CJ, Bicalho AA, Tantbirojn D, Versluis A (2013) Polymerization shrinkage stresses in a premolar restored with diferente composite resins and diferente incremental techniques. *The Journal of Adhesive Dentistry* **15(4)** 341-50, doi: 10.3290/j.jad.a29012.

9. Saber MH, El-Badrawy W, Loomans BA, Ahmed DR, Dörfer CE, El Zohairy A (2011) Creating tight proximal contacts for MOD resin composite restorations *Operative Dentistry* **36(3)** 304-10, doi: 10.2341/10-210-L.
10. Gordan VV, Mjör IA (2002) Short- and long-term clinical evaluation of post-operative sensitivity of a new resin-based restorative material and self-etching primer *Operative Dentistry* **27(6)** 543-8.
11. Peutzfeldt A, Asmussen E (2004) Determinants of in vitro gap formation of resin composites *Journal of Dentistry* **32(2)** 109-15.
12. Karaman E, Ozgunaltay G (2014) Polymerization shrinkage of different types of composite resins and microleakage with and without liner in class II cavities *Operative Dentistry* **39(3)** 325-31, doi: 10.2341/11-479-L.
13. Kwon OH, Kim DH, Park SH (2010) The influence of elastic modulus of base material on the marginal adaptation of direct composite restoration *Operative Dentistry* **35(4)** 441-7, doi: 10.2341/09-372-L.
14. Feilzer AJ, De Gee AJ, Davidson CL (1987) Setting stress in composite resin in relation to configuration of the restoration *Journal of Dental Research* **66(11)** 1636–9.
15. Rau PJ, Pioch T, Staehle HJ, Dorfer CE (2006) Influence of the rubber dam on proximal contact strengths *Operative Dentistry* **31(2)** 171–5.
16. Dorfer CE, Schriever A, Heidemann D, Staehle HJ, Pioch T (2001) Influence of rubber-dam on the reconstruction of proximal contacts with adhesive tooth-colored restorations *Journal of Adhesive Dentistry* **3(2**) 169–75.
17. Alves dos Santos MP, Luiz RR, Maia LC (2010) Randomised trial of resin-based restorations in Class I and Class II beveled preparations in primary molars: 48-month results *Journal of Dentistry* **38(6)** 451–9, doi: 10.1016/j.jdent.2010.02.004.

18. Rindal DB, Gordan VV, Litaker MS, Bader JD, Fellows JL, Qvist V, et al (2010) Methods dentists use to diagnose primary caries lesions prior to restorative treatment: findings from The Dental PBRN *Journal of Dentistry* **38 (12)**1027–32, doi: 10.1016/j.jdent.2010.09.003.
19. Roggendorf MJ, Kramer N, Appelt A, Naumann M, Frankenberger R (2011) Marginal quality of flowable 4-mm base vs. conventionally layered resin composite *Journal of Dentistry* **39(10)** 643–7, doi: 10.1016/j.jdent.2011.07.004.
20. Sundfeld RH, Scatolin RS, Oliveira FG, Machado LS, Alexandre RS, Sundefeld ML (2012) One-year clinical evaluation of composite restorations in posterior teeth: effect of adhesive systems *Operative Dentistry* **37(**6) E1-8, doi: 10.2341/10-375-C.
21. Soares CJ, Fonseca RB, Gomide HA, Correr-Sobrinho L. Cavity preparation machine for the standardization of in vitro preparations. *Brazilian Oral Research* **22(3)** 281-7.
22. Craig RG (1985) Evaluation of an automatic mixing system for an addition silicone impression material *Journal of the American Dental Association* **110**(2) 213-215.
23. Burke FJ (2013) Dental materials--what goes where? The current status of glass onomer as a material for loadbearing restorations in posterior teeth. *Dental Update* **40(10)** 840-4.
24. Ferracane J, Fisher J, Eiselé JL, Fox CH (2013) Ensuring the global availability of high-quality dental restorative materials *Advances in Dental Research* **25(1)** 41-5. doi: 10.1177/0022034513502208.
25. Yap AU, Wang HB, Siow KS, & Gan LM (2000) Polymerization shrinkage of visible-light-cured composites *Operative Dentistry* **25(2)** 98-103.
26. Takahashi H, Finger WJ, Wegner K, Utterodt A, Komatsu M, Wöstmann B, Balkenhol M (2010) Factors influencing marginal cavity adaptation of nanofiller

containing resin composite restorations *Dental Materials* **26(12)** 1166-75, doi: 10.1016/j.dental.2010.08.189.

27. Kidd EA, Beighton D (1996) Prediction of secondary caries around tooth-colored restorations: A clinical and microbiological study *Journal of Dental Research* **75(12)** 1942-1946.
28. Cenci MS, Pereira-Cenci T, Cury JA, Ten Cate JM (2009) Relationship between gap size and dentine secondary caries formation assessed in a microcosm biofilm model *Caries Research* **43(2)** 97-102, doi: 10.1159/000209341.
29. Deliperi S (2012) Functional and aesthetic guidelines for stress-reduced direct posterior composite restorations *Operative Dentistry* **37(4)** 425-31, doi: 10.2341/11-082-T.
30. Boroujeni PM, Mousavinasab SM, Hasanli E (2014) Effect of configuration factor on gap formation in hybrid composite resin, low-shrinkage composite resin and resin-modified glass ionomer *Journal of Investigative and Clinical Dentistry* **jan**, doi: 10.1111/jicd.12082.
31. Cho E, Chikawa H, Kishikawa R, Inai N, Otsuki M, Foxton RM, & Tagami J (2006) Influence of elasticity on gap formation in a lining technique with flowable composite *Dental Materials* Journal **25(3)** 538-544.
32. Chuang SF, Su KC, Wang CH, Chang CH (2011) Morphological analysis of proximal contacts in class II direct restorations with 3D image reconstruction *Journal of Dentistry* **39(6)** 448-56, doi: 10.1016/j.jdent.2011.04.001.
33. Taha NA, Palamara JE, & Messer HH (2009) Cuspal deflection, strain and microleakage of endodontically treated premolar teeth restored with direct resin composites *Journal of Dentistry* **37(9)** 724-730, doi: 10.1016/j.jdent.2009.05.027.

34. Soares CJ, Celiberto L, Dechichi P, Fonseca RB, Martins LR (2005) Marginal integrity and microleakage of direct and indirect composite inlays: SEM and stereomicroscopic evaluation *Brazilian Oral Research* **19(4**) 295-301.

35. Nanjundasetty JK, Nanda S, Panuganti V, Marigowda JC (2013) Marginal sealing ability of silorane and methacrylate resin composites in class II cavities: A scanning electron microscopic study *Journal of Conservative Dentistry* **16(6)** 503-8, doi: 10.4103/0972-0707.120952.

36. Vandewalle KS, Ferracane JL, Hilton TJ, Erickson RL, Sakaguchi RL (2004) Effect of energy density on properties and marginal integrity of posterior resin composite restorations *Dental Materials* **20(1)** 96-106.

37. Heintze SD (2013) Clinical relevance of tests on bond strength, microleakage and marginal adaptation *Dental Materials* **29(1)** 59-84, doi: 10.1016/j.dental.2012.07.158.

38. de Moraes RR, Goncalves Lde S, Lancellotti AC, Consani S, Correr-Sobrinho L, Sinhoreti MA (2009) Nanohybrid resin composites: nanofiller loaded materials or traditional microhybrid resins? *Operative Dentistry* **34(5)** 551–7, doi: 10.2341/08-043-L.

39. Versluis A, & Tantbirojn D (2009) Relationship between shrinkage and stress In: Daskalaki A (ed) Dental Computing and Applications: Advanced Techniques for Clinical Dentistry. Hershey, PA: IGI Global. 45-64.

40. Czarnecka B, Kruszelnicki A, Kao A, Strykowska M, Nicholson JW (2014) Adhesion of resin-modified glass-ionomer cements may affect the integrity of tooth structure in the open sandwich technique *Dental Materials* **(14)00** 140-7, doi: 10.1016/j.dental.2014.05.008.

41. Santos-Filho PC, Castro CG, Silva GR, Campos RE, Soares CJ (2008) Effects of post system and length on the strain and fracture resistance of root filled bovine teeth *International Endodontic Journal* **41(6**) 493-501. doi: 10.1111/j.1365-2591.2008.01383.x.
42. Linsuwanont P, Versluis A, Palamara JE, Messer HH (2008) Thermal stimulation causes tooth deformation: a possible alternative to the hydrodynamic theory? *Archives of Oral Biology* **53(3)** 261-72.

Table 1. Frequency of the gap detection on each margin of the proximal restorations medial and distal (90 thirds – 30 thirds per each margin: buccal, gingival and lingual).

Groups	Buccal margin				Gingival magin				Lingual margin				Total
	Oc	Md	Gi	Total	Bu	Md	Li	Total	Oc	Md	Gi	Total	
Nion-Bw	0	0	1	**2 (3%)**	4	6	6	**16 (26%)**	0	1	1	**2 (3%)**	20 (11%)
Nion-Ps	1	0	0	**2 (3%)**	8	4	0	**12 (20%)**	0	0	0	**0**	14 (8%)
Ion-Bw	0	0	1	**2 (3%)**	4	4	6	**14 (23%)**	0	0	0	**0**	16 (9%)
Ion-Ps	0	0	1	**2 (3%)**	6	6	2	**14 (23%)**	0	0	2	**2 (3%)**	18 (10%)

Oc, oclusal third of the buccal and lingual proximal margin; Md, middle third of the buccal and lingual proximal margin; Gi, gingival third of the buccal and lingual proximal margin. Bu, buccal third of gingival margin; Md, middle third of gingival margin; Li, lingual third of gingival margin.

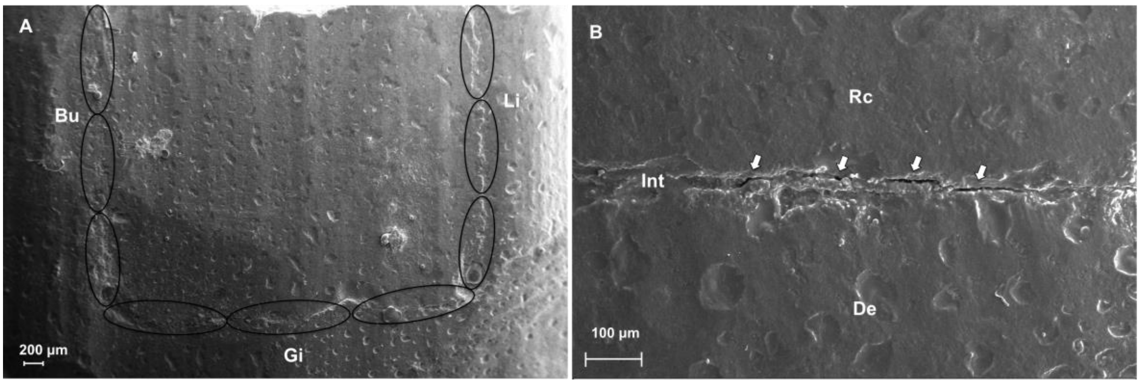

Figure 1. Example of the 9 regions subjected to semi-quantitative marginal analysis (%) in A); Example of marginal adapatation recorded as ‘Gap’ in (B). Bu, buccal margin of the restoration; Gi, gingival margin; Li, lingual margin; Rc, Resin composite area; De, dentin area. White arrow indicates the gap presence on gingival margin.

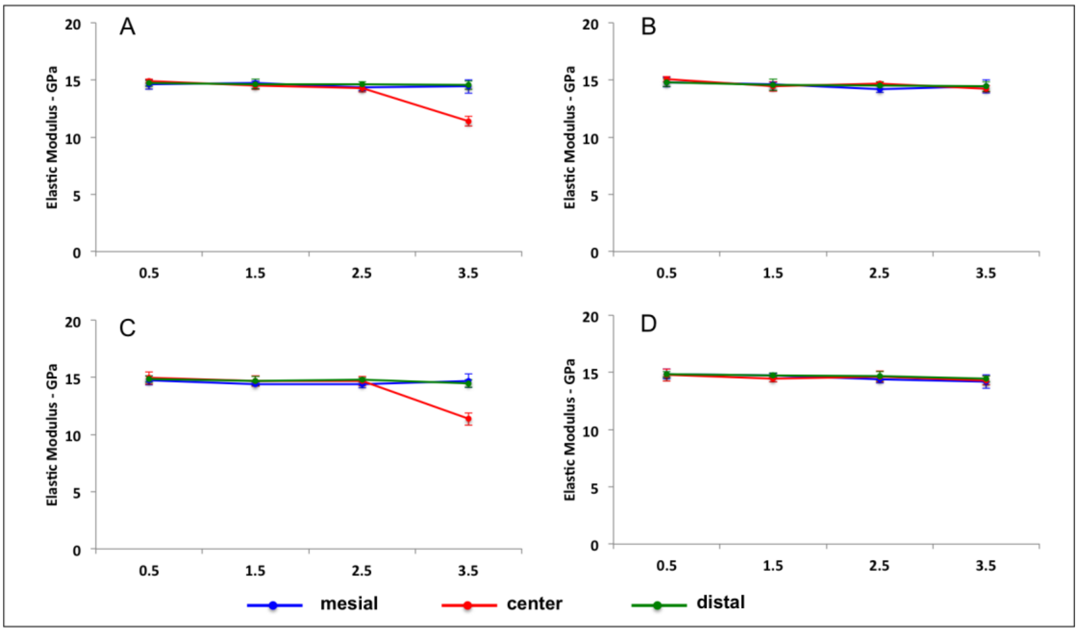

Figure 1. Elastic Modulus at various restoration depths and locations for (A) restoration starting from buccal wall with resin modified glass ionomer; (B) restoration starting from buccal wall without resin modified glass ionomer; (C) restoration starting from proximal surface with resin modified glass ionomer; (D) restoration starting from proximal surface without resin modified glass ionomer.

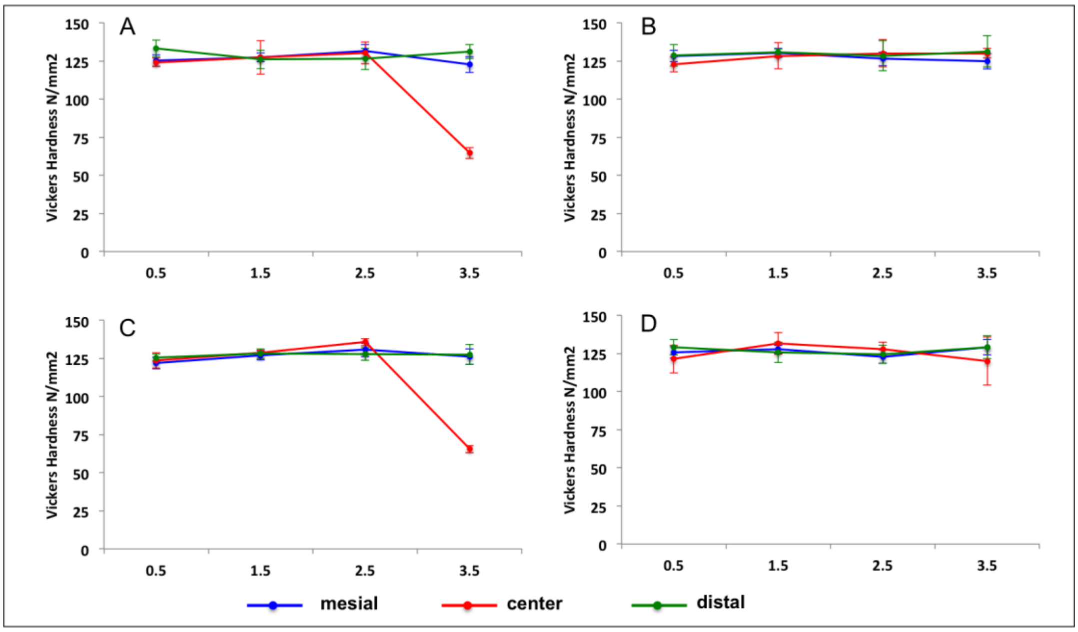

Figure 2. Vickers Hardness at various restoration depths and locations for (A) restoration starting from buccal wall with resin modified glass ionomer; (B) restoration starting from buccal wall without resin modified glass ionomer; (C) restoration starting from proximal surface with resin modified glass ionomer; (D) restoration starting from proximal surface without resin modified glass ionomer.

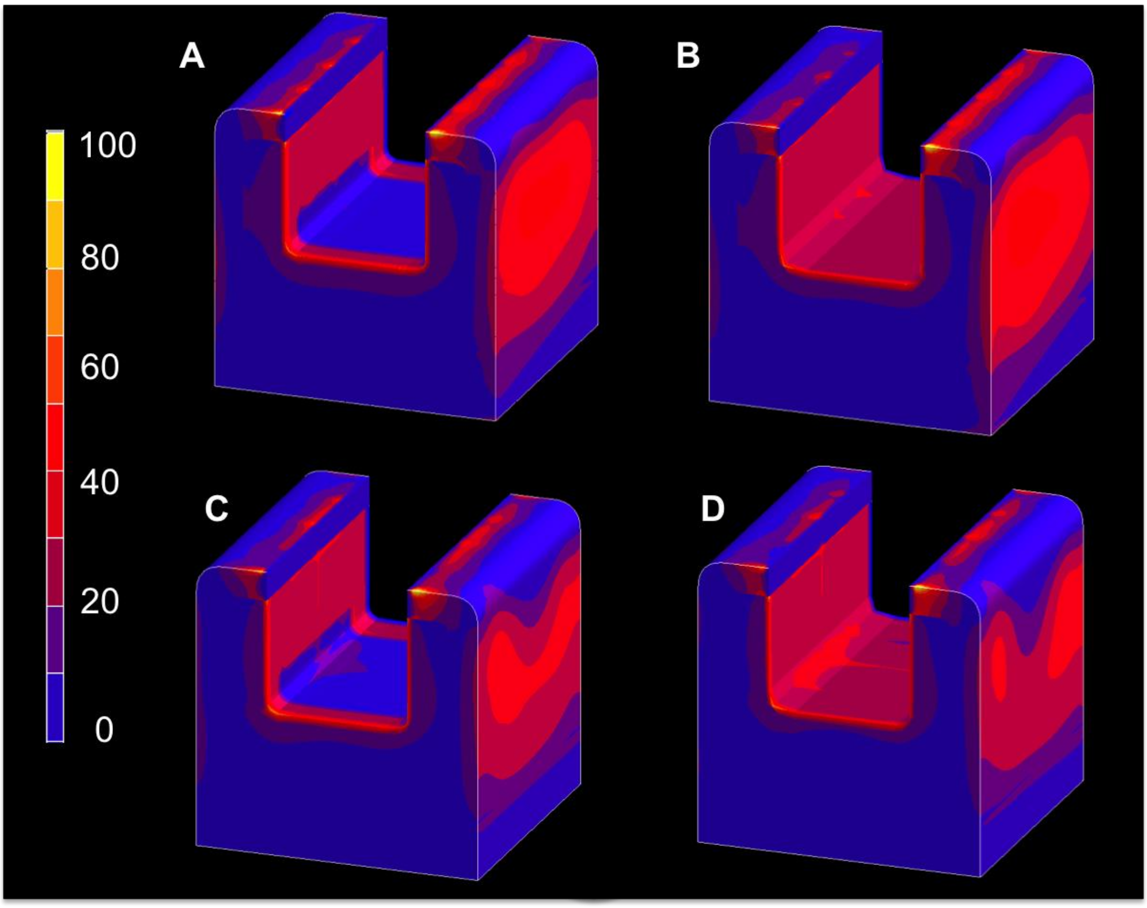

Figure 3. Stress distributions calculated by Finite Element Analysis (Modified von Mises equivalent stresses; MPa) for (A) restoration starting from buccal wall with resin modified glass ionomer liner; (B) restoration starting from buccal wall without resin modified glass ionomer liner; (C) restoration starting from proximal surface with resin modified glass ionomer liner; (D) restoration starting from proximal surface without resin modified glass ionomer liner.

CAPÍTULOS

3.5 CAPÍTULO 5

Artigo a ser enviado para publicação no periódico Clínica – International Journal of Brazilian Dentistry

Restaurações de resinas compostas em dentes posteriores – Controlando os efeitos da contração de polimerização

Composite resin restorations in posterior teeth – controlling the effects of polymerization shrinkage.

3.5 CAPÍTULO 5

Artigo a ser enviado para publicação no periódico Clínica – International Journal of Brazilian Dentistry

Restaurações de resinas compostas em dentes posteriores – Controlando os efeitos da contração de polimerização

Composite resin restorations in posterior teeth – controlling the effects of polymerization shrinkage.

Aline Aredes Bicalho*

Adriano Fonseca Lima**

Silas Boaventura Júnior de Sousa***

Gisele Rodrigues da Silva****

Carlos José Soares****

* Doutoranda em Clínica Odontológica Integrada, Faculdade de Odontologia da Universidade Federal de Uberlândia.

**Especialista, Mestre e Doutor em Dentística. Professor do Curso de Pós-Graduação *stricto sensu* em Odontologia da Universidade Paulista - UNIP

*** Cirurgião Dentista graduado pela Faculdade de Odontologia da Universidade Federal de Uberlândia.

**** Professor de Dentística e Materiais Odontológicos, Faculdade de Odontologia da Universidade Federal de Uberlândia.

Autor de Correspondência:

Prof. Dr. Carlos José Soares

Área de Dentística e Materiais Odontológicos, Faculdade de Odontologia, Universidade Federal de Uberlândia – UFU.

Avenida Pará, n. 1720, Campus Umuarama - Bloco 4L-A, sala 4L-A42, Uberlândia, MG-Brasil: CEP;38405-902, Fone: +55 34 32182255 / Fax: +55 34 32182279

E-mail: carlosjsoares@umuarama.ufu.br

Restaurações de resinas compostas em dentes posteriores – Controlando os efeitos da contração de polimerização

RESUMO

A contração de polimerização da resina composta pode desenvolver tensões na interface dente/restauração e estrutura dental remanescente, resultando em deflexão de cúspide, sensibilidade pós-operatória e fenda marginal. Este artigo apresenta por meio da associação de evidência científica e relato de caso uma reflexão de como o clínico pode minimizar os efeitos da contração de resina composta em dentes posteriores. Ainda persistem dúvidas sobre resinas em dentes posteriores, que é um dos procedimentos mais prevalentes em saúde. A associação de estudos laboratoriais e simulação computacional por meio de elementos finitos podem auxiliar na solução de problemas clínicos constantes. A odontologia baseada em evidência que dá suporte à tomada de decisão é fundamental para o sucesso clínico destes procedimentos.

PALAVRAS CHAVES

Resinas compostas. Dentes posteriores. Contração de polimerização. Tensão. Deformação.

ABSTRACT

The polymerization shrinkage of composite resin is responsible for the stress in the tooth/restoration interface and into remaining tooth structure, causing cusp deflection, post-operative sensitivity and marginal gap. This study present the association of scientific evidence with case report the reflection how the clinicians can minimize the effects of the polymerization shrinkage in posterior teeth. Still remaing doubts about resins posterior restorations, which is one of the most prevalent health procedures. A combination of laboratory studies and computer simulation using finite elements can assist the clinicians to solve frequents problems. Dentistry based in evidence that supports the decision-making is critical to the clinical success of these restorative procedures.

KEYWORDS

Composite resins. Posterior teeth. Polymerization shrinkage. Stress. Strain.

SIGNIFICÂNCIA CLÍNICA

Ao realizar restaurações em dentes posteriores, controlar a contração de polimerização é fundamental para minimizar os efeitos imediatos como a sensibilidade pós-operatória, trincas em esmalte e formação de fendas marginais. Para alcançar estes benefícios, priorizar o uso de isolamento absoluto, optar por resina composta microhíbrida que associe boas propriedades mecânicas com reduzida contração; inserção incremental oblíqua com incrementos não menores que 2,0mm; aliado ao ajuste oclusal são ações que estão ao domínio do operador e que resultam em benefícios consideráveis para o sucesso clínico de resinas compostas em dentes posteriores.

INTRODUÇÃO

O volume de materiais restauradores comercializados no mercado odontológico mundial leva-se a inferir que mais de 500 milhões de restaurações diretas são realizadas em cada ano em todo o mundo. Destas, cerca de 261 milhões são restaurações diretas confeccionadas em resina composta.[1] As estimativas acima mencionados sugerem que a confecção de restaurações diretas em resina composta representa uma das intervenções em saúde humana mais prevalentes em todo o mundo. Muitas destas restaurações constituem substituições de antigas restaurações de amálgama ou mesmo de resina composta. A substituição prematura de restaurações de resina em dentes posterior se baseiam muitas vezes em razões que contradizem as evidências científicas.[2] O motivo mais frequente definido pelos clínicos para a substituição é a presença de cárie adjacentes às margens da restauração, denominada cárie secundária ou recorrente.[3,4] No entanto, a maioria dos profissionais confundem pigmentação marginal com presença de cárie marginal. Diante disso, pode-se deduzir que a maioria das restaurações são substituídas prematuramente.[5]

A resina composta tem sido largamente utilizada para restaurar dentes posteriores uma vez que possui baixo custo, proporciona conservação de estrutura dental sadia, fato possível devido à adesão aos substratos dentais,[6,7] resultando em recuperação do comportamento biomecânico de forma similar ao dente hígido.[8] Porém, a técnica necessária para a confecção de restaurações utilizando resina composta, assim como as propriedades do material podem acarretar efeitos como a sensibilidade pós-operatória, deflexão de cúspide, até trincas na estrutura dental remanescente e descoloração marginal.[9,10] Muitos autores associam essas falhas com tensões geradas durante a contração de polimerização.[11-13]

As propriedades mecânicas das resinas compostas usadas nos dentes posteriores devem atender aos princípios de resistência e adesão suficiente para suportar cargas mastigatórias.[14] Os compósitos resinosos são formados por uma fase inorgânica, composta por partículas de carga que auxiliam no aumento das propriedades mecânicas do material, e uma fase orgânica que é responsável pela redução volumétrica durante a polimerização, a contração de polimerização.[15] O mecanismo utilizado para criar novos compostos envolve modificações em componentes monoméricos e nas quantidades e tipos de cargas. Monômeros tais como bis-GMA (bisfenol A-glicidil metacrilato) e TEGDMA (trietilenoglicol dimetacrilato) podem apresentar até 12,5% de contração volumétrica, sendo que este valor pode ser reduzido quando é acrescentado componentes inorgânicos à matriz monomérica.[16] A contração de polimerização é ainda dependente da concentração da carga, das características de polimerização, do volume dos incrementos e do tamanho da cavidade.[14,17-20]

Durante o processo de polimerização das resinas compostas, duas etapas são importantes no que se relacionam com as tensões geradas na estrutura dental: a primeira, onde as tensões geradas são irrelevantes devido a capacidade de deformação do material (fase pré-gel), gerando relaxamento destas tensões; e outra em que o enrijecimento do material, caracterizado pela geração do módulo de elasticidade, representa a fonte de geração de tensões no substrato devido à contração do material (fase pós-gel).[21,22]

Diferentes técnicas de polimerização têm sido propostas para minimizar os efeitos da contração de polimerização preocupando-se ao mesmo tempo com as propriedades mecânicas da resina composta.[14,19,20] O uso de baixa intensidade seguido de maior intensidade de luz pode prolongar a fase inicial (pré-gel), e assim reduzir as tensões geradas durante a contração da resina composta.[23] Esta menor intensidade na contração está relacionada ao processo de polimerização que é extremamente dinâmico, conduzindo a maior flexibilidade dos monômeros, devido ao aumento no tempo da fase pré-gel, na qual a resina é mais viscoelástico, proporcionando maior relaxamento das cadeias em formação. [11,21]

Técnicas de inserção incremental têm sido frequentemente indicadas para resultar em adequadas propriedades mecânicas da resina composta em maiores profundidades da cavidade sem, no entanto gerar altos níveis de tensões de contração de polimerização.[19,20] Para atuar de forma sinérgica na redução dos efeitos colaterais indesejados da contração de polimerização e ainda minimizar os efeitos biológicos em cavidades profundas, uma camada intermediária entre a resina composta e a parede pulpar tem sido proposta.[24] Materiais ionoméricos convencionais ou modificados por resina tem sido recomendados como material intermediário.[25] Esta camada substitui parte do volume de resina composta, podendo reduzir consequentemente os efeitos colaterais da contração de polimerização. Em molares tratados endodonticamente o preenchimento da câmara pulpar pode facilitar o acesso aos canais frente à necessidade de retratamento endodôntico, como também reduzir as tensões e deflexões de cúspides causadas pela contração do compósito resinoso utilizado. [26]

As restaurações Classe II MOD são convencionalmente restauradas iniciando-se a inserção dos incrementos pelas caixas proximais, transformando-se desta forma a Classe II em uma Classe I, sendo posteriormente finalizada a restauração,[24,27] sendo que esta maneira de execução facilita da execução da escultura anatômica do dente.[24] Bicalho *et al.* (2013),[24] mostrou que o início da restauração pelas caixas proximais ou pela oclusal não modifica o padrão de distribuição de tensões. Porém na perspectiva de facilitar o procedimento técnico o início pelas proximais tende a ser mais benéfico. Dentro das incontáveis perguntas que permeiam a realidade do profissional frente a procedimentos restauradores diretos em dentes posteriores, a busca por evidências científicas que tragam ao clínico maior segurança é imperativa para o sucesso profissional. Portanto este trabalho tem por objetivo apresentar a associação entre dados relevantes de pesquisas laboratoriais e ensaios computacionais com o relato de caso clínico que visam minimizar as tensões de contração de polimerização de resinas compostas geradas em procedimentos restauradores em dentes posteriores.

RELATO DE CASO

O objetivo deste trabalho é descrever um caso clínico de técnica restauradora direta de resina composta para reduzir os efeitos deletérios da contração de polimerização em restauração classe II em molar inferior (Figura 1). O dente 36 apresentava restauração em amálgama fraturada, aliado à fratura de borda da estrutura dental e desadaptação marginal, levando à indicação da substituição. Sendo então indicada a restauração em resina composta. A restauração foi removida com ponta diamantada em alta rotação sob constante e abundante irrigação. Foi então realizado o isolamento absoluto (Figura 2), que facilita sobremaneira o controle de contaminação do campo operatório e a minimização das tensões de contração de polimerização pelo efeito da possível presença de maior umidade.(Bicalho et al., 2014) Foi então realizado condicionamento com ácido fosfórico (Scotchbond, 3M ESPE, St. Paul, MN, EUA) por 30 s apenas em esmalte (Figura 3), seguido da lavagem e secagem deste substrato com jato de ar. O sistema adesivo autocondicionante (ClearFill Protect Bond, Kuraray Medical, Osaka, Japan) foi aplicado, iniciando-se com a aplicação do *primer* por 20 segundos de forma ativa (Figura 4), leve jato de ar por 10 s para facilitar a volatilização do solvente contido neste, seguido da aplicação do adesivo em toda a cavidade (Figura 5). A fotoativação foi efetuada por 20 s, empregando luz halógena (Demetron LC, Kerr, Orange, CA, EUA). A resina composta nanoparticulada (Filtek Z350XT, 3M Espe, St. Paul, MN, USA) foi inserida inicialmente na região proximal, a fim de favorecer a escultura do dente a ser restaurado, em incrementos de 2mm de forma oblíqua (Figura 6 e 7), minimizando as tensões de contração (Figura 8). A fotoativação de cada incremento no modo de intensidade progressiva de luz, cuja luz inicia-se com baixa intensidade e aumenta gradualmente até atingir o máximo de energia que permanece pelo maior tempo de ativação a cada incremento. Esta técnica foi realizada afastando-se a ponta do aparelho fotoativador em 1cm por 5 s, finalizando com esta colocada o mais próximo possível do incremento realizado por 15 s (Figura 9). Em sequência, foram realizados os incrementos referentes à dentina (Z350XT A3D), esboçando o formato a ser finalizada a restauração. Esta etapa se faz importante para que não haja resina composta em locais onde devem ser encontrados sulcos principais e secundários, dificultando o estabelecimento da correta anatomia do elemento a ser restaurado. Deve ser enfatizado que os incrementos foram realizados de forma a não se tocarem e não unirem paredes opostas no momento da polimerização. Após o término dos incrementos referentes à dentina, foram realizados os incrementos relacionados à camada de esmalte (Z350XT A2E), para finalização da restauração, restabelecendo forma e função ao elemento em questão (Figura 10). Em seguida, o isolamento absoluto foi removido, e o ajuste oclusal realizado (Figura 11), o que minimiza a concentração de tensões nas margens das restaurações (Figura 12), seguido do polimento da restauração utilizando pontas abrasivas (Jiffy, Ultradent Products Inc., Salt Lake City, UT, USA) e pasta de polimento (Enamelize, Cosmedent Inc., Chicago, IL, USA), obtendo-se superfície lisa e brilhante (Figura 13).

DISCUSSÃO

A resina composta tem se mostrado o material restaurador ideal para recuperar estruturalmente dentes posteriores devido a ótimas propriedades mecânicas e integração adesiva à estrutura dental. Para viabilizar o uso em dentes posteriores a necessidade de adequada resistência à compressão e módulo de elasticidade são imperativos para o sucesso clínico. O módulo de elasticidade semelhante ao da dentina conduz à diminuição das tensões de contração de polimerização transferidas à estrutura dental e a interface dente-restauração.[14,19,20,22] O aumento da quantidade de carga na resina é um método que tem sido deduzido por muitos como sendo suficiente para reduzir a contração de polimerização, porém no caminho oposto faz com que o material tenha um aumento significativo em sua rigidez.[28]A maior rigidez resulta em menor capacidade de escoamento do material durante a polimerização o que acaba por gerar maiores tensões. Por outro lado o valor de módulo de elasticidade próximo ao da dentina é essencial para minimizar o desgaste na superfície oclusal e ainda resultar em adequada resistência do complexo dente restauração.[19,26]

Não há relação direta entre substituição de restaurações diretas e contração de polimerização. O que se pode inferir é que altas tensões de contração podem resultar em fendas marginais, que ao acumularem pigmentos podem mais tarde resultar em indicativo errôneo de necessidade de substituição de resinas em posteriores. Um acompanhamento clínico de 22 anos de restaurações de resina composta em dentes posteriores mostrou que estas podem apresentar pigmentação marginal, todavia este não é um indicativo principal para que as restaurações sejam substituídas. As mesmas podem apresentar-se funcionalmente adequadas, a não ser que seja evidenciada a presença de cárie recorrente através de exames complementares.[2] O estabelecimento de corretos e cientificamente embasados critérios para substituição de restaurações são modelos educacionais que devemos perseguir continuamente.

No presente relato de caso foi utilizado uma resina nanoparticulada que tem contração de polimerização relativamente baixa em relação a resinas convencionais.[14] por outro lado este material apresenta propriedades mecânicas adequadas para o uso em dentes posteriores. A técnica de inserção da resina é um fator importante no desenvolvimento das tensões geradas pela contração de polimerização.[14,19,20] Por muito tempo se propagou o conceito de que o uso de técnica incremental reduz as tensões de contração. Bicalho *et al.*, em dois artigos publicados em 2014,[19,20] demonstraram que a técnica de incremento único, ou "bulk" proporciona a formação de significativamente menores tensões de contração, menor deformação de cúspide em comparação à técnica incremental convencional. Porém tensão de contração não é a única propriedade esperada de um material restaurador adequado para dentes posteriores. A escolha da técnica deve basear-se na otimização de todo procedimento, como a capacidade de polimerização adequada da resina inserida, resultando em união satisfatória, sendo que a técnica de incremental oblíqua é capaz de promover estes requisitos.[19,20] A técnica de inserção oblíqua de incrementos tem sido demonstrada como mais eficiente na redução de tensões de contração do que técnicas de inserção horizontal.[14] Quanto ao volume de cada incremento, Bicalho *et al.* (2014)[19,20] compararam o efeito de diferentes volumes de resina nas tensões geradas na parede do preparo. Foram avaliados volumes de incrementos de 1,0mm, 2,0mm e incremento único, e os resultados demonstraram que a restauração em incremento único não resulta em adequadas propriedades mecânicas, e que o uso de incrementos de maior volume (2,0mm) gera menores tensões e deformação de cúspides com excelentes propriedades mecânicas.

O método de polimerização é uma estratégia viável para diminuir a contração de polimerização da resina composta. Quando baixa intensidade de luz é utilizada inicialmente, as tensões são reduzidas em percentual próximo a 30%. A definição de integridade marginal de materiais restauradores é fator importante para o desempenho em longo prazo nas margens das restaurações, principalmente quando estas estão próximas dos contatos oclusais. Para diminuir o risco de falha marginal, a verificação dos contatos oclusais antes e durante o preparo da cavidade é recomendado para evitar o contato oclusal na interface da restauração. A oclusão balanceada parece ser fator chave para minimizar intercorrências que interferem no sucesso de restaurações em dentes posteriores,[29,30] principalmente quando os contatos oclusais são determinados próximo a margem da restauração.[30]

Desta forma, a escolha do material adequado, juntamente com a habilidade necessária para a confecção dos procedimentos restauradores diretos, sempre aliada à decisões e práticas baseadas em evidências científicas, promovem a realização de procedimentos de sucesso.

CONCLUSÕES E ORIENTAÇÕES AO CLÍNICO

A contração de polimerização deve ser um desafio constante a ser superado pelas indústrias no que se refere ao desenvolvimento de novas resinas compostas, mas também deve ser considerado pelos clínicos com o objetivo de incorporar à sua pratica procedimentos que minimizem este efeito.

Alguns fatores podem ser definidos como alternativas para redução da geração de tensões resultantes de polimerização como:

- Preserve estrutura dental, reduzindo ao máximo possível a remoção de substrato sadio, pois maior volume de estrutura minimiza os efeitos das tensões resultantes da contração;
- Selecione uma resina composta que associe boas propriedades mecânicas, principalmente módulo de elasticidade próximo ao da dentina, com menor contração de polimerização;
- Utilize sempre que possível o isolamento absoluto para realizar procedimentos restauradores em dentes posteriores, pois este minimiza a ocorrência de contaminação e minimizar as tensões de contração de polimerização;
- Utilize inserção incremental com volume de 2,0mm, iniciando pelas caixas proximais em cavidades classe II;
- Ao polimerizar cada incremento, principalmente os que estão em contatos diretos com a estrutura remanescente, utilize intensidade progressiva de luz com fonte de luz que possui intensidade suficiente;
- Ao remover o isolamento defina um adequado ajuste oclusal restabelecendo a oclusão balanceada e evitando o contato oclusal na resina composta muito próximo às margens da cavidade.

REFERÊNCIAS

1. Zöchbauer H. Number of dental restorations worldwide. Market Re- search Ivoclar Vivadent 2011.
2. Da Rosa Rodolpho PA, Donassollo TA, Cenci MS, Loguércio AD, Moraes RR, Bronkhorst EM, Opdam NJ, Demarco FF. 22-Year clinical evaluation of the performance of two posterior composites with different filler characteristics. Dent Mater. 2011 Oct;27(10):955-63.
3. Mjör IA. The reasons for replacement and the age of failed restorations in general dental practice. Acta Odontol Scand 1997;55:58-63.
4. van de Sande FH, Opdam NJ, Rodolpho PA, Correa MB, Demarco FF, Cenci MS. Patient risk factors' influence on survival of posterior composites. J Dent Res. 2013 Jul;92(7 Suppl):78S-83S.
5. Heintze SD, Rousson V. Clinical effectiveness of direct class II restorations - a meta-analysis. J Adhes Dent. 2012 Aug;14(5):407-31.
6. Cavalcanti AN, Mitsui FH, Lima AF, Mathias P, Marchi GM (2010). Evaluation of dentin hardness and bond strength at different walls of class II preparations. *J Adhes Dent* 12(3)*:*183-188.
7. Lima AF, da Silva VB, Soares GP, Marchi GM, Baggio Aguiar FH, Lovadino JR (2012). Influence of previous acid etching on interface morphology and bond strength of self-etching adhesive to cavosurface enamel. *Eur J Dent* 6(1)*:*56-62.
8. Versluis A, Versluis-Tantbirojn D. Filling cavities or restoring teeth? J Tenn Dent Assoc. 2011 Spring;91(2):36-42;
9. Jensen ME, Chan DCN. Polymerization shrinkage and microleakage. In: Vanherle G, Smith DC, editors. Posterior composite resin dental restorative materials. Utrecht: Peter Szulc Publishing Company; 1985. p. 243–62.
10. Bausch JR, De Lange C, Davidson CL, Peters A, De Gee AJ. The clinical significance of the polymerization shrinkage of composite resin restorative materials. J Prosthet Dent 1982;48:59–67.
11. Tantbirojn D, Versluis A, Pintado MR, DeLong R, Douglas WH. Tooth deformation patterns in molars after composite restoration. Dental Materials. 2004; 20:535–542.
12. Takahashi H, address WJAF, Wegner K, Utterodt A, Komatsu M, Watsmann B, Balkenhol M. Factors influencing marginal cavity adaptation of nanofiller containing resin composite restorations. Dental Materials 2010; 26(12):1166-1175.
13. Tantbirojn D, Chongvisal S, Augustson DG, Versluis A. Hardness and postgel shrinkage of preheated composites. Quintessence International. 2011; 42:(3):51-59.

14. Soares CJ, Bicalho AA, Tantbirojn D, Versluis A. Polymerization shrinkage stresses in a premolar restored with different composite resins and different incremental techniques. J Adhes Dent. 2013 Aug;15(4):341-50.
15. Clifford SS, Roman-Alicea K, Tantbirojn D, Versluis A. Shrinkage and hardness of dental composites acquired with different curing light sources. Quintessence International. 2009;40:203–214.
16. Labella R, Lambrechts P, Van Meerbeek B, Vanherle G. Polymerization shrinkage and elasticity of flowable composites and filled adhesives. Dent Mater. 1999 Mar;15(2):128-37.
17. Ferracane JL. Developing a more complete understanding of stresses produced in dental composites during polymerization. *Dent Mater* 2005; 21: 36-42.
18. Petrovic LM, Atanackovic TM. A model for shrinkage strain in photopolymerization of dental composites. *Dent Mater* 2008; 24: 556-60.
19. Bicalho A, Pereira R, Zanatta R, Franco S, Tantbirojn D, Versluis A, Soares C. Incremental filling technique and composite material-part I: cuspal deformation, bond strength, and physical properties. Oper Dent. 2014 Mar-Apr;39(2):e71-82.
20. Bicalho A, Valdívia A, Barreto B, Tantbirojn D, Versluis A, Soares C. Incremental Filling Technique and Composite Material-Part II: Shrinkage and Shrinkage Stresses. Oper Dent. 2014 Mar-Apr;39(2):e83-92.
21. Versluis A, Tantbirojn D, Douglas WH. Distribution of transient properties during polymerization of a light-initiated restorative composite. Dental Materials. 2004;20:543–553.
22. Ruttermann S, Kruger S, Raab WH-M, Janda R. Polymerization shrinkage and hygroscopic expansion of contemporary posterior resin-based filling materials—A comparative study. Journal Dentistry. 2007;35:806-813.
23. Emami N, Soderholm KJM, Berglund LA. Effect of light power density variations on bulk curing properties of dental composites. Journal Dentistry. 2003;31:189–196.
24. Bicalho AA, Ferreira MS, Pereira RAS, Ruggiero JG, Versluis A, Soares CJ. Efeito do protocolo restaurador com resina composta na deformação de cúspide de molares. In: 30ª Reunião Anual da Sociedade Brasileira de Pesquisa Odontológica - SBPqO, 2013, Águas de Lindóia. Proceedings of the 30th SBPqO Annual Meeting, 2013. v. 27. p. 323-323.
25. Kwon OH, Kim DH, Park SH. The influence of elastic modulus of base material on the marginal adaptation of direct composite restoration. Oper Dent. 2010 Jul-Aug;35(4):441-7.
26. Pereira RAS, Bicalho AA, Franco SB, Tantbirojn D, Versluis A, Soares C. Effect of restorative protocol on cuspal strain and residual stress in endodontically treated molars. Oper Dent., 2014 in press.

27. Peutzfeldt A, Asmussen E. Determinants of in vitro gap formation of resin composites. *Journal of Dentistry* 2004 Feb; **32**(2):109-15.
28. Campodonico CE, Tantbirojn D, Olin PS, Versluis A. Cuspal deflection and depth of cure in resin-based composite restorations filled by using bulk, incremental and transtooth-illumination techniques. J Am Dent Assoc. 2011 Oct;142(10):1176-82.
29. Versluis A, Tantbirojn D. Relationship between shrinkage and stress. In: Daskalaki A (ed). Dental computing and applications: advanced techniques for clinical dentistry. Hershey, PA: IGI Global, 2009:45-64.
30. Bicalho A, Tantbirojn D, Versluis A, Soares C. Effect of occlusal loading and mechanical properties of resin composite on stress generated in posterior restorations. Am J Dent 2014, 27: in press

FIGURAS

Figura 1: Aspecto inicial do dente 46 com fratura de margem da restauração e manchamento dental periférico.

Figura 2: Preparo finalizado resumindo a remoção da restauração, com instalação de matriz parcial, estabilizada por grampo específico e cunha de madeira e isolamento do campo operatório.

Figura 3: Condicionamento ácido seletivo do esmalte do ângulo cavosuperficial para viabilizar maior integração de adesivo autocondicionante ao preparo.

Figura 4: Aplicação de primer do sistema adesivo autocondicionante utilizado para hibridização da restauração.

Figura 5: Aplicação de adesivo do sistema adesivo autocondicionante utilizado para hibridização da restauração.

Figura 6: Inserção de incremento oblíquo iniciando pela caixa proximal.

Figura 7: Inserção de incremento oblíquo reconstruindo crista marginal, resultando em cavidade similar a classe I.

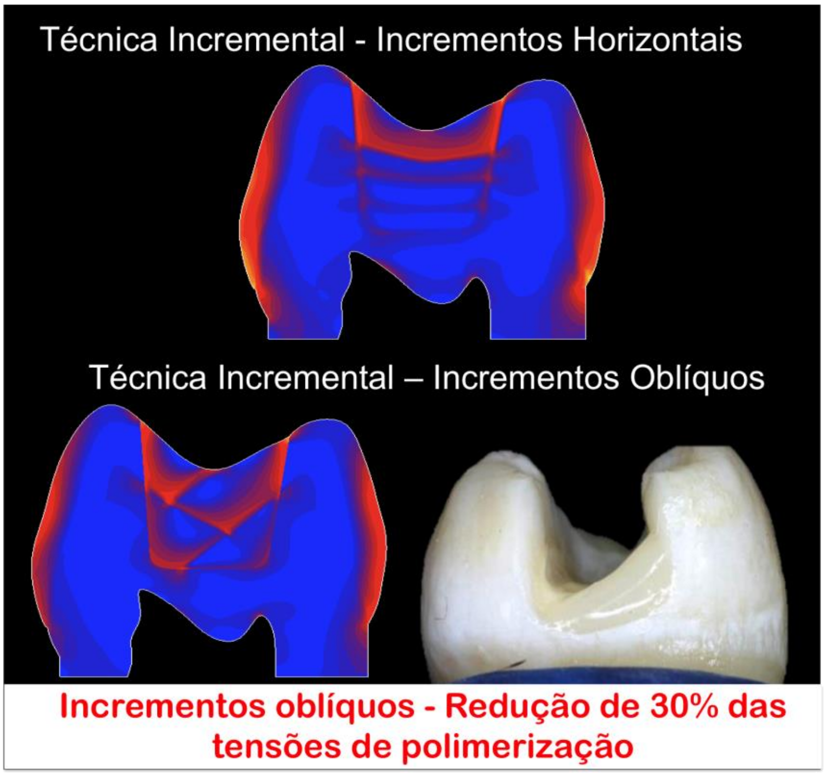

Figura 8: Imagem de modelo de elementos finitos mostrando que a técnica de inserção obliqua resulta em redução de 30% das tensões de contração de polimerização.

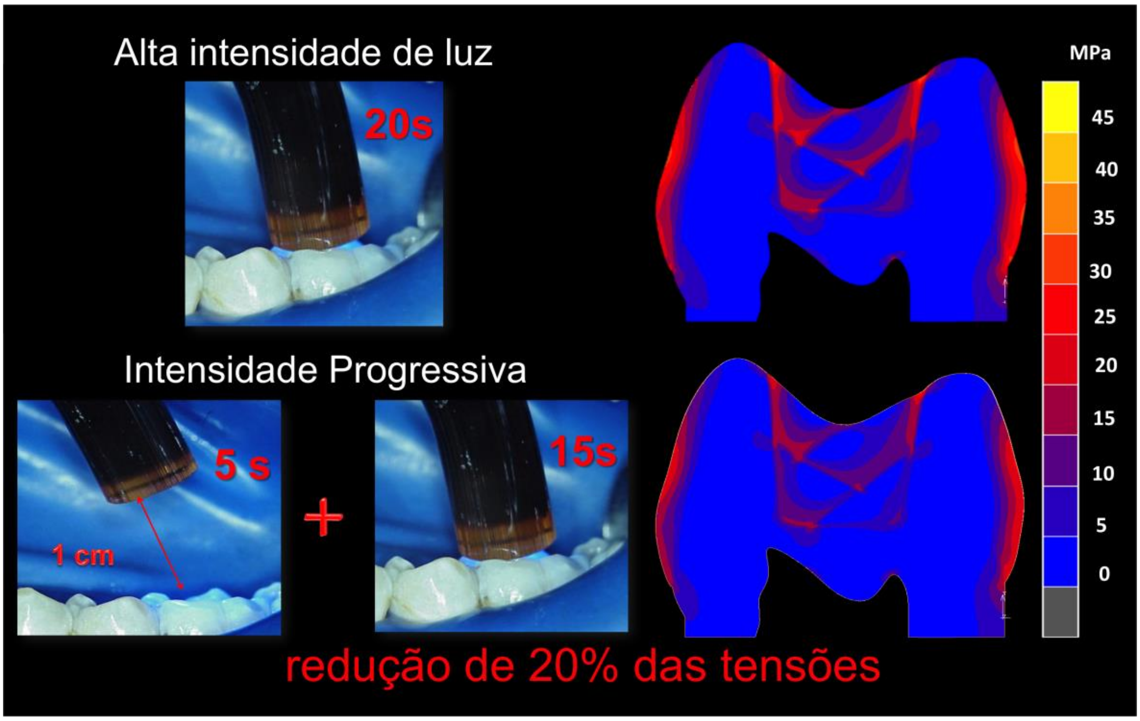

Figura 9: Sequência que ilustra por meio de modelo de elementos finitos de técnica de ativação com afastamento da fonte de luz por 1cm nos primeiros 5 segundos seguido da aproximação da fonte para resultar em alta intensidade de luz, demonstrando redução das tensões de contração de polimerização.

Figura 10: Inserção incremental concluída que contribui para recuperação mais facilitada da anatomia dental.

Figura 11: Checagem dos contatos oclusais determinando a necessidade de ajuste oclusal para distribuição equilibrada das forças oclusais.

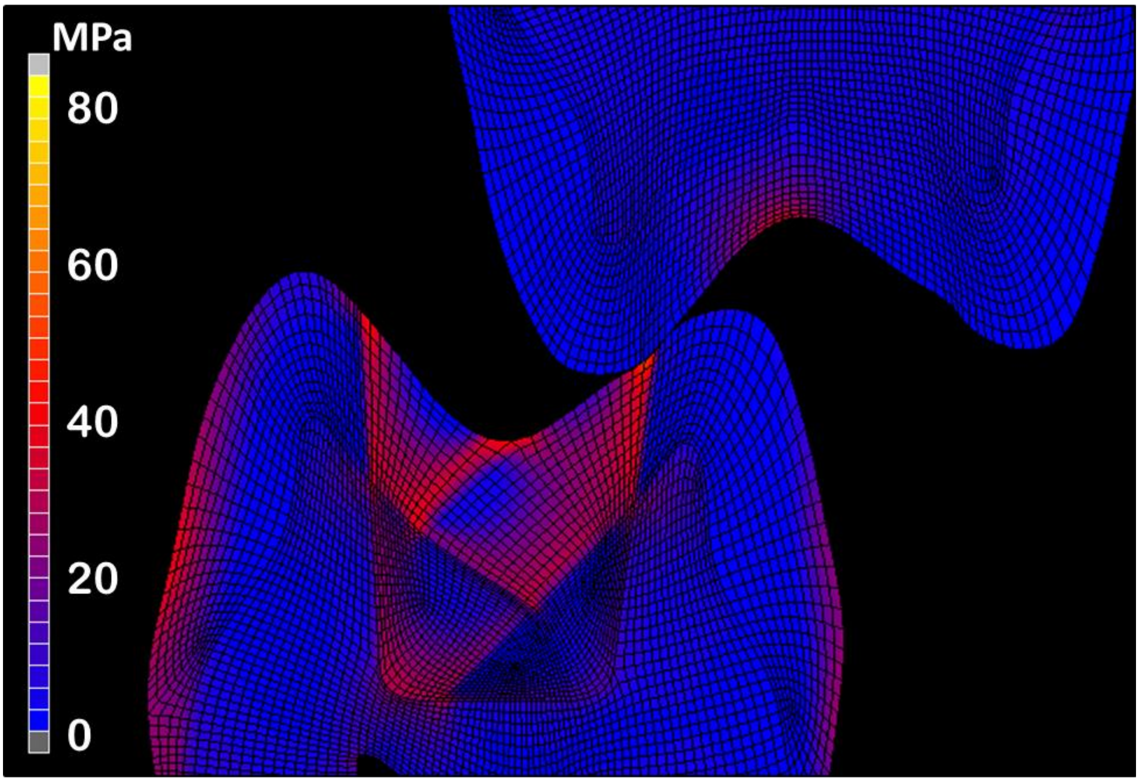

Figura 12: Simulação de contatos oclusais em dentes posteriores e atenuação das tensões com contatos mais equilibrados e mais distantes da margem dente/restauração.

Figura 13. Aspecto final da restauração.

CONSIDERAÇÕES FINAIS

4- CONSIDERAÇÕES FINAIS

A função primária dos dentes posteriores é o preparo do alimento, por meio do processo de mastigação para suprir as necessidades do organismo, caracterizando assim um processo tipicamente biomecânico. (Versluis *et al.;* 2009). Dentes posteriores são projetados para preparar e triturar os alimentos por meio de transferência de forças, a anatomia oclusal permite a manutenção da adequada função mastigatória e transmissão das tensões e deformações geradas pelas forças oclusais ao suporte radicular. Os contatos entre os dentes antagonistas devem ocorrer normalmente durante as atividades funcionais de um dente comprometido quando restaurado de forma direta ou indireta. Como naturalmente os dentes posteriores estão expostos a forças mecânicas de maiores intensidades, as tensões geradas são proporcionalmente maiores em comparação com os dentes anteriores. Com isso pode-se prever risco de falhas maiores, com consequente comprometimento das restaurações ou até mesmo resultando em perda dental.

Integridade marginal de restaurações diretas em resinas compostas é fator importante para o desempenho clínico em longo prazo, principalmente quando estas margens estão próximas dos contatos oclusais (Rodriguez *et al.,* 2011). Para diminuir o risco de falha marginal, verificação de contatos oclusais, antes e durante o preparo da cavidade é recomendado para evitar o contato oclusal na interface da restauração. O contato oclusal com o antagonista na margem da restauração deve ser evitado para melhor desempenho restaurador em dentes posteriores. Fica evidente nos achados deste estudo que o ajuste oclusal e a definição de contatos oclusais equilibrados são fatores aparentemente simples que repercutem diretamente no desempenho biomecânico destas restaurações.

Excelente integração adesiva e propriedades mecânicas são essenciais para o desempenho clínico ideal das restaurações diretas em dentes posteriores. Algumas condições de temperatura e umidade intraoral podem alterar o comportamento biomecânico dos materiais e do complexo restaurador. Desta forma a negligência de isolamento adequado do campo operatório parece ser condições clínicas que compromete diversos aspectos de restaurações adesivas em dentes posteriores. A contração de polimerização pode ser responsável pela sensibilidade pós-operatória e outras complicações (Versluis *et al*., 2011), tais como microtrincas e infiltração marginal. Assim o aumento da contração pós-gel, da deformação de cúspide e das tensões geradas frente ao aumento da umidade e temperatura torna-se prejudicial ao procedimento clínico e deve ser evitada sempre que possível. Por outro lado utilizar estes parâmetros em experimentos laboratoriais é imperativo para que se aproxime das condições vivenciadas na cavidade oral.

As resinas compostas estão sendo cada vez mais utilizadas nas restaurações de dentes posteriores e muito se especula no sentido de diminuir os efeitos da contração e polimerização. A colocação de um material de base, ou proteção do complexo dentinho-pulpar, com menor módulo elástico prévio à restauração de resina composta diminui a deformação de cúspide em molares classe II MOD. Com o uso de base protetora empregando ionômero de vidro modificado por resina, as cúspides deformam menos tanto no momento da restauração quando o dente é submetido à cargas oclusais normais (100N). Quando o dente é submetido à teste de carga compressiva até o momento da fratura, a presença da base torna-se insignificante, tendo em vista os altos níveis de tensões e deformações que as estruturas estão submetidas. Outro fator importante é a ordem de inserção dos incrementos dentro da cavidade. A literatura recomenda iniciar as restaurações classe II MOD pelas caixas proximais, determinando a modificação desta classe II para uma restauração classe I facilitando a técnica e a escultura da mesma (Deliperi *et al.,* 2012). Biomecanicamente esta ordem de inserção (caixas oclusais ou proximais) não apresenta nenhuma diferença significante em nenhum dos parâmetros avaliados. Neste estudo, a técnica de preenchimento não influenciou a deformação de cúspide em nenhum dos momentos, nem a resistência à fratura e padrão de fratura dos molares. Ao avaliar a adaptação de margens de restaurações em resina composta utilizando base de cimento ionômero de vidro modificado por resina ou alternando a ordem de inserção dos incrementos também não foi observada nenhuma diferença significativa. No entanto, nota-se que a margem mais crítica de uma restauração classe II é a margem gengival, sendo foco de falhas, fendas e infiltrações, independente da técnica utilizada. As propriedades dos materiais utilizados, resina composta e ionômero de vidro também não são afetadas pela técnica utilizada, o que determina a obtenção destas propriedades é a adequada polimerização garantida pela inserção incremental (Bicalho *et al.,* 2014 a, Bicalho *et al*., 2014b). A contração de polimerização dos compósitos gera tensões residuais que são transferidas para as estruturas dentais podendo causar falha no processo reabilitador e sensibilidade pós-operatória. Modelos de elementos finitos 3D mesmo que simplificados podem trazer importantes respostas sempre que correlacionados com dados experimentais. A presença de ionômero de vidro como material de base em restauração de resina composta classe II diminui de forma considerável as tensões de contração na parede pulpar do preparo cavitário. Isto permite inferir que menor sensibilidade pós-operatória ocorrerá em cavidades profundas. A ordem de inserção dos incrementos mostra pouca diferença na distribuição de tensões de contração, assim a inserção pelas proximais parece mais pertinente, pois tem a vantagem de facilitação da técnica e da escultura.

O uso de metodologias não destrutivas associadas a métodos computacionais como o método de elementos finitos associados a ensaios destrutivos colaboram de forma substancial para a compreensão dos problemas biomecânicos de dentes restaurados com compósitos. Contudo, os ensaios *in vitro* possuem limitações inerentes e insuperáveis que requerem de forma definitiva o delineamento de estudos clínicos prospectivos que avaliem estes parâmetros. Mas devido ao processo contínuo e progressivo de geração e transmissão do conhecimento com evidência científica este trabalho ressalta que o clínico deve estar atento as constantes inovações propostas pelas indústrias de materiais odontológicos e os pesquisadores abertos a buscar investigar parâmetros clínicos que pouco são suportados por evidências científicas.

CONCLUSÕES

5- CONCLUSÕES

Dentro das limitações deste estudo que envolveu 4 estudos laboratoriais e computacionais e um relato de caso clínico pode-se concluir-se que:

- ✓ Materiais com maiores valores de módulo elástico causam maiores tensões de contração.
- ✓ Contatos oclusais aumentam os níveis de tensões em dentes restaurados mesmo quando utilizados resinas composta de baixos valores de contração de polimerização.
- ✓ Contato oclusal localizado na margem da restauração de resina composta posterior aumentam as tensões geradas na interface.
- ✓ Contatos oclusais estáveis no centro da restauração resultaram em melhor distribuição de tensões.
- ✓ As condições do ambiente afetam significativamente a contração pós-gel, módulo de elasticidade, deformação de cúspide, resistência adesiva e tensões de contração em dentes restaurados com resinas compostas.
- ✓ A simulação da temperatura e umidade do ambiente bucal deve ser realizada nos testes de laboratório para avaliar a contração de polimerização, deformação de cúspide e tensões de contração.
- ✓ A ordem de preenchimento dos incrementos de resina composta não influenciou na deformação de cúspide, resistência à fratura, modo de fratura, adaptação marginal e tensões geradas de molares restaurados com resina composta.
- ✓ A deformação de cúspide e as tensões de contração diminuíram com a presença de Ionômero de vidro modificado por resina usado como material de base em restaurações de resinas em dentes posteriores.
- ✓ A resistência à fratura e modo de fratura não foram influenciados pela presença de material de base em molares restaurados com resina composta.
- ✓ A margem restauradora com maior desadaptação em molares classe II MOD é a margem gengival.

RERERÊNCIAS

6- REFERÊNCIAS

1. Bausch JR, de Lange K, Davidson CL, Peters A, de Gee AJ. Clinical significance of polymerization shrinkage of composite resins. J Prosthet Dent. 1982 Jul;48(1):59-67.

2. Bicalho AA, Pereira RD, Zanatta RF, Franco SD, Tantbirojn D, Versluis A, Soares CJ. Incremental filling technique and composite material--part I: cuspal deformation, bond strength, and physical properties. Oper Dent. 2014a Mar-Apr;39(2):E71-82.

3. Bicalho AA, Valdívia AD, Barreto BC, Tantbirojn D, Versluis A, Soares CJ. Incremental filling technique and composite material--part II: shrinkage and shrinkage stresses. Oper Dent. 2014b Mar-Apr;39(2):E83-92.

4. Boaro LC, Gonçalves F, Guimarães TC, Ferracane JL, Versluis A, Braga RR. Polymerization stress, shrinkage and elastic modulus of current low-shrinkage restorative composites. Dent Mater. 2010 Dec;26(12):1144-50.

5. Bryant RW. Direct posterior composite resin restorations: a review. 1. Factors influencing case selection. Aust Dent J. 1992 Apr;37(2):81-7.

6. Davidson CL, de Gee AJ, Feilzer A. The competition between the composite-dentin bond strength and the polymerization contraction stress. J Dent Res. 1984 Dec;63(12):1396-9.

7. Deliperi S. Functional and aesthetic guidelines for stress-reduced direct posterior composite restorations. Oper Dent. 2012 Jul-Aug;37(4):425-31.

8. El-Safty S, Silikas N, Watts DC. Temperature-dependence of creep behaviour of dental resin-composites. J Dent. 2013 Apr;41(4):287-96.

9. Feilzer AJ, De Gee AJ, Davidson CL. Quantitative determination of stress reduction by flow in composite restorations. Dent Mater. 1990 Jul;6(3):167-71.

10. Ferracane JL. Developing a more complete understanding of stresses produced in dental composites during polymerization. Dent Mater. 2005 Jan;21(1):36-42.

11. Ferracane JL. Resin composite--state of the art. Dent Mater. 2011 Jan;27(1):29-38.

12. Jensen ME, Chan DCN. Polymerization shrinkage and microleakage. In: Vanherle G, Smith DC (eds). Posterior composite resin dental restorative materials. Utrecht: Peter Szulc Publishing, 1985:243-262.

13. Kopperud SE, Tveit AB, Gaarden T, Sandvik L, Espelid I. Longevity of posterior dental restorations and reasons for failure. Eur J Oral Sci. 2012 Dec;120(6):539-48.
14. Kwon OH, Kim DH, Park SH. The influence of elastic modulus of base material on the marginal adaptation of direct composite restoration. Oper Dent. 2010 Jul-Aug;35(4):441-7.
15. Labella R, Lambrechts P, Van Meerbeek B, Vanherle G. Polymerization shrinkage and elasticity of flowable composites and filled adhesives. Dent Mater. 1999 Mar;15(2):128-37.
16. Mjör IA. Problems and benefits associated with restorative materials: side-effects and long-term cost. Adv Dent Res. 1992 Sep;6:7-16.
17. Petrovic LM, Atanackovic TM. A model for shrinkage strain in photo polymerization of dental composites. Dent Mater. 2008 Apr;24(4):556-60.
18. Peutzfeldt A, Asmussen E. Determinants of in vitro gap formation of resin composites. J Dent. 2004 Feb;32(2):109-15.
19. Rodriguez Tapia MT, Ardu S, Daeniker L, Krejci I. Evaluation of marginaladaptation, seal and resistance against fatigue cracks of different pit and fissure sealants under laboratory load. Am J Dent. 2011 Dec;24(6):367-71.
20. Sakaguchi RL, Sasik CT, Bunczak MA, Douglas WH. Strain gauge method for measuring polymerization contraction of composite restoratives. J Dent 1991;19:312-316.
21. Scariot R, Stadler AF, Assunção CM, Pintarelli TP, Ferreira Fde M. A map of Brazilian dental research in the last decade. Braz Oral Res. 2011 May-Jun;25(3):197-204.
22. Shah PK, Stansbury JW. Role of filler and functional group conversion in the evolution of properties in polymeric dental restoratives. Dent Mater. 2014 May;30(5):586-93.
23. Soares CJ, Bicalho AA, Tantbirojn D, Versluis A. Polymerization shrinkage stresses in a premolar restored with different composite resins and diferente incremental techniques. J Adhes Dent. 2013 Aug;15(4):341-50.
24. Versluis A, & Tantbirojn D (2009) Relationship between shrinkage and stress In: Daskalaki A (ed) Dental Computing and Applications: Advanced Techniques for Clinical Dentistry. Hershey, PA: IGI Global. 45-64.

25. Versluis A, Versluis-Tantbirojn D. Filling cavities or restoring teeth? J Tenn Dent Assoc. 2011 Spring;91(2):36-42; quiz 42-3.
26. Watts DC, Alnazzawi A. Temperature-dependent polymerization shrinkage stress kinetics of resin-composites. Dent Mater. 2014 Jun;30(6):654-60.
27. Watts DC, Cash AJ. Determination of polymerization shrinkage kinetics in visible-light-cured materials: methods development. Dent Mater. 1991 Oct;7(4):281-7.

ANEXOS

7 – ANEXOS

7.1 Parecer do Comitê de ética

Universidade Federal de Uberlândia
Pró-Reitoria de Pesquisa e Pós-Graduação
COMITÊ DE ÉTICA EM PESQUISA - CEP
Av. João Naves de Ávila, nº 2121 - Bloco 1A – sala 224 - Campus Santa Mônica - Uberlândia-MG –
CEP 38408-144 - FONE/FAX (34) 3239-4131; e-mail: cep@propp.ufu.br; www.comissoes.propp.ufu.br

ANÁLISE FINAL N° 117/12 DO RELATÓRIO FINAL PARA O PROTOCOLO REGISTRO CEP/UFU: 352/10

Projeto Pesquisa: "Efeito do material restaurador, da técnica de polimerização na integridade adesiva, deformação de cúspides e tensões geradas na restauração de cavidades classe II em molares com grande perda estrutural.".

Pesquisador Responsável: Carlos José Soares

De acordo com as atribuições definidas na Resolução CNS 196/96, o CEP manifesta-se pela aprovação do relatório final, recebido em 30/10/2012.

Situação: O relatório final não apresenta problemas de ética nas condutas de pesquisa com seres humanos, nos limites da redação e da metodologia apresentadas.

O CEP/UFU lembra que:
a- segundo a Resolução 196/96, o pesquisador deverá arquivar por 5 anos o relatório da pesquisa e os Termos de Consentimento Livre e Esclarecido, assinados pelo sujeito de pesquisa.
b- poderá, por escolha aleatória, visitar o pesquisador para conferência do relatório e documentação pertinente ao projeto.
c- a aprovação do protocolo de pesquisa pelo CEP/UFU dá-se em decorrência do atendimento a Resolução 196/96/CNS, não implicando na qualidade científica do mesmo.

SITUAÇÃO: RELATÓRIO FINAL APROVADO.

Uberlândia, 09 de novembro de 2012.

Profa. Dra. Sandra Terezinha de Farias Furtado
Coordenadora do CEP/UFU

Orientações ao pesquisador

(Para parecer Aprovado ou Aprovado com Recomendações)

- O sujeito da pesquisa tem a liberdade de recusar-se a participar ou de retirar seu consentimento em qualquer fase da pesquisa, sem penalização alguma e sem prejuízo ao seu cuidado (Res. CNS 196/96 - Item IV.1.f) e deve receber uma cópia do Termo de Consentimento Livre e Esclarecido, na íntegra, por ele assinado (Item IV.2.d).
- O pesquisador deve desenvolver a pesquisa conforme delineada no protocolo aprovado e descontinuar o estudo somente após análise das razões da descontinuidade pelo CEP que o aprovou (Res. CNS Item III.3.z), aguardando seu parecer, exceto quando perceber risco ou dano não previsto ao sujeito participante ou quando constatar a superioridade de regime oferecido a um dos grupos da pesquisa (Item V.3) que requeiram ação imediata.
- O CEP deve ser informado de todos os efeitos adversos ou fatos relevantes que alterem o curso normal do estudo (Res. CNS Item V.4). É papel do pesquisador assegurar medidas imediatas adequadas frente a evento adverso grave ocorrido (mesmo que tenha sido em outro centro) e enviar notificação ao CEP e à Agência Nacional de Vigilância Sanitária – ANVISA – junto com seu posicionamento.
- Eventuais modificações ou emendas ao protocolo devem ser apresentadas ao CEP de forma clara e sucinta, identificando a parte do protocolo a ser modificada e suas justificativas. Em caso de projetos do Grupo I ou II apresentados anteriormente à ANVISA, o pesquisador ou patrocinador deve enviá-las também à mesma, junto com o parecer aprovatório do CEP, para serem juntadas ao protocolo inicial (Res. 251/97, item III.2.e). O prazo para entrega de relatório é de 120 dias após o término da execução prevista no cronograma do projeto, conforme norma da Res. 196/96 CONEP.

7.2 Cartas de aceite e Normas dos Periódicos

7.2.1 Capítulo 1

Re: Effect of occlusal loading and mechanical properties of composite resin on stress generated in posterior restoration .

Dr. Soares:

I am pleased to inform you that your revised manuscript has been accepted for publication in the **American Journal of Dentistry.**

Before publication you will receive page proofs (galleys) for your approval.

Again, thank you for considering the **American Journal of Dentistry** for publication of your work.

Sincerely,

Franklin Garcia-Godoy, DDS, MS, PhD, PhD
Editor

Franklin Garcia-Godoy, DDS, MS, PhD, PhD
Editor, *American Journal of Dentistry*

: 1138 N. Germantown Parkway, #360
Cordova, TN 38018

: 901 752-1225 E-: godoy@amjdent.com

Information for Authors

The **American Journal of Dentistry** is published six times a year in February, April, June, August, October and December by *Mosher & Linder, Inc*.

The **AJD** invites submission of research manuscripts and reviews related to the clinical practice of dentistry. Manuscripts are considered for publication with the understanding that they have not been published elsewhere in any form or any language, are submitted solely to the **AJD**, and if accepted for publication in the **AJD**, they will not be published elsewhere in the same form or in any other language, without the consent of the Editor. Manuscripts are reviewed by at least two referees.

Statements and opinions expressed in the articles and communications herein are those of the author(s) and not necessarily those of the Editor, Managing Editor, Editorial Board members or publisher of the **American Journal of Dentistry**.

All correspondence from the Editorial Office will be made with the designated Corresponding Author unless otherwise specified in a letter by the authors.

Preparation of manuscripts. Papers should be written in proper American English, double spaced, with liberal margins, and **only submitted by E-mail to the Editor**, with the text and tables in Microsoft Word files and illustrations in JPEG image format.

Papers reporting results of original research should be divided into Introduction, Materials and Methods, Results, Discussion, Acknowledgements (if any), and References.

Clinical Research Papers. Need to follow the CONSORT Statement (Needleman I, *et al. Am J Dent* 2008;21: 7-12).

Disclosure statement. The *American Journal of Dentistry* is instituting a policy to disclose conflicts of interest, as well as sponsorship of studies published in the Journal. Please provide information regarding any conflict of interest relationships of all authors, or state that each author has no conflict.

Examples of common financial relationships include: employment, consultancies, stock ownership, honoraria, and paid expert testimony. You can read more about other potential conflict of interests and the general policy at: http://www.nlm.nih.gov/pubs/factsheets/supplements.html and http:// www.icmje.org/#conflicts

Copyright release. The following statement, signed by all authors, should accompany all manuscripts:

"All manuscript's copyright ownership is transferred from the author(s) of the article (title of article), to the American Journal of Dentistry in the event the work is published. The manuscript has not been published in any form or any language and is only submitted to the American Journal of Dentistry".

Title page should include the title of the manuscript, all authors' full names and degrees, affiliations to institution or private practice, designation and address of corresponding author, telephone and fax numbers and e-mail address.

Disclosure statement

Abstract page should follow the title page and only contain: the title of the manuscript, the abstract and the clinical significance sections. On the abstract page, the name(s) of the author(s) should not appear. The abstract should have the following sections: Purpose, Methods, and Results.

Clinical significance. As a separate sentence after the abstract, a short statement should highlight the clinical significance of the manuscript.

References. All references and only those cited in the text should appear in the list of references. They should be numbered consecutively as they appear in the text of the paper. Reference formatting programs should not be used.

When a paper cited has three or more authors, it should appear in the text thus: Gwinnett *et al.*[1] In the Reference section, article references must include the names and initials of all the authors, the full title of the paper, the abbreviated title of the journal, year of publication, the volume number, and first and last page numbers, *e.g.*:

Journals:

1. Thornton JB, Retief DH, Bradley EA. Marginal leakage of two glass ionomer cements: Ketac-Fil and Ketac-Silver. *Am J Dent* 1988; 1: 35-38.

Abstracts:

2. Alpeggiani M, Gagliani M, Re D. Operator influence using adhesive systems: One bottle *vs*. multi bottles. *J Dent Res* 1998;77: 942 (Abstr 2487).

Online abstracts:

3. Bayne SC, Wilder Jr AD, Perdigão J, Heymann HO, Swift EJ. 4-year wear and clinical performance of packable posterior composite. *J Dent Res* 2003:86 (Sp Is A): (Abstr 0036).

Papers in the course of publication should only be entered in the references if they have been accepted for publication by a journal and then given in the standard manner in the text and in the list of references with the journal title, accompanied by "In press," *e.g.*:

3. Crim GA, Abbott LJ. Effect of curing time on marginal sealing by four dentin bonding agents. *Am J Dent*, In press.

Book and monograph references should include author, title, city, publisher, year of publication, and page numbers, *e.g.*:

4. Malone WFP, Koth DL. *Tylman's theory and practice of fixed prosthodontics*. St. Louis: Ishiyaku Euro-America, 1989; 110-123.
5. Ripa LW, Finn SB. The care of injuries to the anterior teeth of children. In: Finn SB. *Clinical pedodontics*. 4th ed, Philadelphia: WB Saunders, 1973; 125.

Personal communications should only appear in paren-theses in the text and not in the list of references.

Illustrations. Illustrations should be numbered, provided with suitable legends, and kept to the minimum essential for proper presentation of the results. Color illustrations will be published at the authors' expense. Contact the Managing Editor at (954) 888-9101 or amjdent@amjdent.com.

Legends are required for all illustrations and should be typed as a group on a separate page. For photomicrographs, legends must specify original magnification and stain (if used).

Tables should be logically organized and should supplement the information provided in the text. Each table should be typed on a separate page with the number, title and footnotes. Tables should be kept to the minimum essential for proper presentation of the results.

Permissions from author and publisher must be obtained for the direct use of previously published material including text, photographs, drawings, etc. The original permission should be then included with the manuscript.

Reprints. For reprints contact the Business Office at (954) 888-9101 or amjdent@amjdent.com.

Address. All manuscripts should be sent to the Editor by e-mail only to: godoy@amjdent.com

6/09

7.2.2 Capítulo 2

DENTAL MATERIALS

Official Publication of the Academy of Dental Materials

AUTHOR INFORMATION PACK

TABLE OF CONTENTS

ISSN: 0109-5641

DESCRIPTION

Online submission and editorial system now available at http://ees.elsevier.com/dema

Dental Materials publishes original research, review articles, and short communications.

Academy of Dental Materials members click here to register for free access to Dental Materials online.

The principal aim of *Dental Materials* is to promote rapid communication of scientific information between academia, industry, and the dental practitioner. Original Manuscripts on clinical and laboratory research of basic and applied character which focus on the **properties** or **performance** of **dental materials** or the **reaction** of host tissues to materials are given priority publication. Other acceptable topics include application technology in **clinical dentistry** and dental laboratory technology.

Comprehensive reviews and editorial commentaries on pertinent subjects will be considered. Only manuscripts...

AUDIENCE

Dental research scientists, materials scientists, clinicians, students of dentistry, dental materials and equipment manufacturers.

IMPACT FACTOR

2012: 3.773 © Thomson Reuters Journal Citation Reports 2013

ABSTRACTING AND INDEXING

Aluminium Industry Abstracts
Ceramic Abstracts
Computer and Information Systems Abstract
Corrosion Abstracts
Current Contents
Current Contents Search
MEDLINE®
International Aerospace Abstracts
METADEX
Materials Science Citation Index
Dental Abstracts
Earthquake Engineering Abstracts
El Compendex Plus
Electronics and Communications Abstracts
Engineering Materials Abstracts
Science Citation Index
Scisearch
Solid State Abstracts
UnCover
TOXFILE
CSA Civil Engineering Abstracts
CSA Mechanical & Transportation Engineering Abstracts
BIOSIS Previews
SIIC Data Bases
Inside Conferences
Scopus
CSA Technology Research Database
CSA Advanced Polymers Abstracts
CSA Engineered Materials Abstracts
Materials Business File
ISI
Mechanical and Transport Engineer Abstract

EDITORIAL BOARD

Reinhard Hickel, Ludwig-Maximilians University, GERMANY

GUIDE FOR AUTHORS

Authors are requested to submit their original manuscript and figures via the online submission and editorial system for Dental Materials. Using this online system, authors may submit manuscripts and track their progress through the system to publication. Reviewers can download manuscripts and submit their opinions to the editor. Editors can manage the whole submission/review/revise/publish process. Please register at: http://ees.elsevier.com/dema.
Dental Materials now only accepts online submissions.
The Artwork Quality Control Tool is now available to users of the online submission system. To help authors submit high-quality artwork early in the process, this tool checks the submitted artwork and other file types against the artwork requirements outlined in the Artwork Instructions to Authors on http://www.elsevier.com/artworkinstructions. The Artwork Quality Control Tool automatically checks all artwork files when they are first uploaded. Each figure/file is checked only once, so further along in the process only new uploaded files will be checked.

Manuscripts
The journal is principally for publication of **Original Research Reports**, which should preferably investigate a defined hypothesis. Maximum length 6 journal pages (approximately 20 double-spaced typescript pages) including illustrations and tables.

Systematic Reviews will however be considered. Intending authors should communicate with the Editor beforehand, by email, outlining the proposed scope of the review. Maximum length 10 journal pages (approximately 33 double-spaced typescript pages) including figures and tables.

Three copies of the manuscript should be submitted: each accompanied by a set of illustrations. The requirements for submission are in accordance with the "Uniform Requirements for Manuscripts Submitted to Biomedical Journals", Annals of Internal Medicine, 1997,126, 36-47. All manuscripts must be written in American English. Authors are urged to write as concisely as possible.

The Editor and Publisher reserve the right to make minimal literary corrections for the sake of clarity. Authors for whom English is not the first language should have their manuscripts read by colleagues fluent in English. If extensive English corrections are needed, authors may be charged for the cost of editing. For additional reference, consult issues of Dental Materials published after January 1999 or the Council of Biology Editors Style Manual (1995 ed.).

All manuscripts should be accompanied by a **letter of transmittal**, signed by each author, and stating that the manuscript is not concurrently under consideration for publication in another journal, that all of the named authors were involved in the work leading to the publication of the paper, and that all the named authors have read the paper before it is submitted for publication.

Always keep a backup copy of the electronic file for reference and safety.

Manuscripts not conforming to the journal style will be returned. In addition, manuscripts which are not written in fluent English will be rejected automatically without refereeing.

For further guidance on electronic submission, please contact Author Services, Log-In Department, Elsevier Ltd, The Boulevard, Langford Lane, Kidlington, Oxford, OX5 1GB, UK. E-mail: authors@elsevier.co.uk, fax: +44 (0)1865 843905, tel: +44 (0)1865 843900.

Page charges
This journal has no page charges.

BEFORE YOU BEGIN

Ethics in publishing
For information on Ethics in publishing and Ethical guidelines for journal publication see http://www.elsevier.com/publishingethics and http://www.elsevier.com/journal-authors/ethics.

Human and animal rights
If the work involves the use of animal or human subjects, the author should ensure that the work described has been carried out in accordance with The Code of Ethics of the World Medical Association (Declaration of Helsinki) for experiments involving humans

http://www.wma.net/en/30publications/10policies/b3/index.html; EU Directive 2010/63/EU for animal experiments http://ec.europa.eu/environment/chemicals/lab_animals/legislation_en.htm; Uniform Requirements for manuscripts submitted to Biomedical journals http://www.icmje.org. Authors should include a statement in the manuscript that informed consent was obtained for experimentation with human subjects. The privacy rights of human subjects must always be observed.

Conflict of interest

All authors must disclose any financial and personal relationships with other people or organizations that could inappropriately influence (bias) their work. Examples of potential conflicts of interest include employment, consultancies, stock ownership, honoraria, paid expert testimony, patent applications/registrations, and grants or other funding. See also http://www.elsevier.com/conflictsofinterest. Further information and an example of a Conflict of Interest form can be found at: http://help.elsevier.com/app/answers/detail/a_id/286/p/7923.

Submission declaration

Submission of an article implies that the work described has not been published previously (except in the form of an abstract or as part of a published lecture or academic thesis or as an electronic preprint, see http://www.elsevier.com/postingpolicy), that it is not under consideration for publication elsewhere, that its publication is approved by all authors and tacitly or explicitly by the responsible authorities where the work was carried out, and that, if accepted, it will not be published elsewhere including electronically in the same form, in English or in any other language, without the written consent of the copyright-holder.

Authorship

All authors should have made substantial contributions to all of the following: (1) the conception and design of the study, or acquisition of data, or analysis and interpretation of data, (2) drafting the article or revising it critically for important intellectual content, (3) final approval of the version to be submitted.

Changes to authorship

This policy concerns the addition, deletion, or rearrangement of author names in the authorship of accepted manuscripts:

Before the accepted manuscript is published in an online issue: Requests to add or remove an author, or to rearrange the author names, must be sent to the Journal Manager from the corresponding author of the accepted manuscript and must include: (a) the reason the name should be added or removed, or the author names rearranged and (b) written confirmation (e-mail, fax, letter) from all authors that they agree with the addition, removal or rearrangement. In the case of addition or removal of authors, this includes confirmation from the author being added or removed. Requests that are not sent by the corresponding author will be forwarded by the Journal Manager to the corresponding author, who must follow the procedure as described above. Note that: (1) Journal Managers will inform the Journal Editors of any such requests and (2) publication of the accepted manuscript in an online issue is suspended until authorship has been agreed.

After the accepted manuscript is published in an online issue: Any requests to add, delete, or rearrange author names in an article published in an online issue will follow the same policies as noted above and result in a corrigendum.

Article transfer service

This journal is part of our Article Transfer Service. This means that if the Editor feels your article is more suitable in one of our other participating journals, then you may be asked to consider transferring the article to one of those. If you agree, your article will be transferred automatically on your behalf with no need to reformat. More information about this can be found here: http://www.elsevier.com/authors/article-transfer-service.

Copyright

Upon acceptance of an article, authors will be asked to complete a 'Journal Publishing Agreement' (for more information on this and copyright see http://www.elsevier.com/copyright). Acceptance of the agreement will ensure the widest possible dissemination of information. An e-mail will be sent to the corresponding author confirming receipt of the manuscript together with a 'Journal Publishing Agreement' form or a link to the online version of this agreement.

Subscribers may reproduce tables of contents or prepare lists of articles including abstracts for internal circulation within their institutions. Permission of the Publisher is required for resale or distribution outside the institution and for all other derivative works, including compilations and translations (please consult http://www.elsevier.com/permissions). If excerpts from other copyrighted works are included, the author(s) must obtain written permission from the copyright owners and credit the source(s) in the article. Elsevier has preprinted forms for use by authors in these cases: please consult http://www.elsevier.com/permissions.

Retained author rights
As an author you (or your employer or institution) retain certain rights; for details you are referred to: http://www.elsevier.com/authorsrights.

Role of the funding source
You are requested to identify who provided financial support for the conduct of the research and/or preparation of the article and to briefly describe the role of the sponsor(s), if any, in study design; in the collection, analysis and interpretation of data; in the writing of the report; and in the decision to submit the article for publication. If the funding source(s) had no such involvement then this should be stated.

Funding body agreements and policies
Elsevier has established agreements and developed policies to allow authors whose articles appear in journals published by Elsevier, to comply with potential manuscript archiving requirements as specified as conditions of their grant awards. To learn more about existing agreements and policies please visit http://www.elsevier.com/fundingbodies.

Language (usage and editing services)
Please write your text in good English (American or British usage is accepted, but not a mixture of these). Authors who feel their English language manuscript may require editing to eliminate possible grammatical or spelling errors and to conform to correct scientific English may wish to use the English Language Editing service available from Elsevier's WebShop (http://webshop.elsevier.com/languageediting/) or visit our customer support site (http://support.elsevier.com) for more information.

Informed consent and patient details
Studies on patients or volunteers require ethics committee approval and informed consent, which should be documented in the paper. Appropriate consents, permissions and releases must be obtained where an author wishes to include case details or other personal information or images of patients and any other individuals in an Elsevier publication. Written consents must be retained by the author and copies of the consents or evidence that such consents have been obtained must be provided to Elsevier on request. For more information, please review the *Elsevier Policy on the Use of Images or Personal Information of Patients or other Individuals*, http://www.elsevier.com/patient-consent-policy. Unless you have written permission from the patient (or, where applicable, the next of kin), the personal details of any patient included in any part of the article and in any supplementary materials (including all illustrations and videos) must be removed before submission.

Submission
Submission to this journal proceeds totally online and you will be guided stepwise through the creation and uploading of your files. The system automatically converts source files to a single PDF file of the article, which is used in the peer-review process. Please note that even though manuscript source files are converted to PDF files at submission for the review process, these source files are needed for further processing after acceptance. All correspondence, including notification of the Editor's decision and requests for revision, takes place by e-mail removing the need for a paper trail.

Submit your article
Please submit your article via http://ees.elsevier.com/dema/.

Referees
Please submit, with the manuscript, the names, addresses and e-mail addresses of three potential referees. Note that the editor retains the sole right to decide whether or not the suggested reviewers are used.

PREPARATION

Use of word processing software
It is important that the file be saved in the native format of the word processor used. The text should be in single-column format. Keep the layout of the text as simple as possible. Most formatting codes will be removed and replaced on processing the article. In particular, do not use the word processor's options to justify text or to hyphenate words. However, do use bold face, italics, subscripts,

superscripts etc. When preparing tables, if you are using a table grid, use only one grid for each individual table and not a grid for each row. If no grid is used, use tabs, not spaces, to align columns. The electronic text should be prepared in a way very similar to that of conventional manuscripts (see also the Guide to Publishing with Elsevier: http://www.elsevier.com/guidepublication). Note that source files of figures, tables and text graphics will be required whether or not you embed your figures in the text. See also the section on Electronic artwork.
To avoid unnecessary errors you are strongly advised to use the 'spell-check' and 'grammar-check' functions of your word processor.

Embedded math equations
If you are submitting an article prepared with Microsoft Word containing embedded math equations then please read this related support information (http://support.elsevier.com/app/answers/detail/a_id/302/).

Article structure

Subdivision - numbered sections
Divide your article into clearly defined and numbered sections. Subsections should be numbered 1.1 (then 1.1.1, 1.1.2, ...), 1.2, etc. (the abstract is not included in section numbering). Use this numbering also for internal cross-referencing: do not just refer to 'the text'. Any subsection may be given a brief heading. Each heading should appear on its own separate line.

Introduction
This must be presented in a structured format, covering the following subjects, although actual subheadings should not be included:
• succinct statements of the issue in question;
• the essence of existing knowledge and understanding pertinent to the issue (reference);
• the aims and objectives of the research being reported relating the research to dentistry, where not obvious.

Materials and methods
• describe the procedures and analytical techniques.
• only cite references to published methods.
• include at least general composition details and batch numbers for all materials.
• identify names and sources of all commercial products e.g.
"The composite (Silar, 3M Co., St. Paul, MN, USA)..."
"... an Au-Pd alloy (Estheticor Opal, Cendres et Metaux, Switzerland)."
• specify statistical significance test methods.

Results
• refer to appropriate tables and figures.
• refrain from subjective comments.
• make no reference to previous literature.
• report statistical findings.

Discussion
• explain and interpret data.
• state implications of the results, relate to composition.
• indicate limitations of findings.
• relate to other relevant research.

Conclusion (if included)
• must NOT repeat Results or Discussion
• must concisely state inference, significance, or consequences

Appendices
If there is more than one appendix, they should be identified as A, B, etc. Formulae and equations in appendices should be given separate numbering: Eq. (A.1), Eq. (A.2), etc.; in a subsequent appendix, Eq. (B.1) and so on. Similarly for tables and figures: Table A.1; Fig. A.1, etc.

Essential title page information

• ***Title.*** Concise and informative. Titles are often used in information-retrieval systems. Avoid abbreviations and formulae where possible.

• ***Author names and affiliations.*** Where the family name may be ambiguous (e.g., a double name), please indicate this clearly. Present the authors' affiliation addresses (where the actual work was done) below the names. Indicate all affiliations with a lower-case superscript letter immediately after the author's name and in front of the appropriate address. Provide the full postal address of each affiliation, including the country name and, if available, the e-mail address of each author.
• ***Corresponding author.*** Clearly indicate who will handle correspondence at all stages of refereeing and publication, also post-publication. **Ensure that phone numbers (with country and area code) are provided in addition to the e-mail address and the complete postal address. Contact details must be kept up to date by the corresponding author.**
• ***Present/permanent address.*** If an author has moved since the work described in the article was done, or was visiting at the time, a 'Present address' (or 'Permanent address') may be indicated as a footnote to that author's name. The address at which the author actually did the work must be retained as the main, affiliation address. Superscript Arabic numerals are used for such footnotes.

Abstract (structured format)

• 250 words or less.
• subheadings should appear in the text of the abstract as follows: Objectives, Methods, Results, Significance. (For Systematic Reviews: Objectives, Data, Sources, Study selection, Conclusions). The Results section may incorporate small tabulations of data, normally 3 rows maximum.

Graphical abstract

A Graphical abstract is optional and should summarize the contents of the article in a concise, pictorial form designed to capture the attention of a wide readership online. Authors must provide images that clearly represent the work described in the article. Graphical abstracts should be submitted as a separate file in the online submission system. Image size: Please provide an image with a minimum of 531 × 1328 pixels (h × w) or proportionally more. The image should be readable at a size of 5 × 13 cm using a regular screen resolution of 96 dpi. Preferred file types: TIFF, EPS, PDF or MS Office files. See http://www.elsevier.com/graphicalabstracts for examples.
Authors can make use of Elsevier's Illustration and Enhancement service to ensure the best presentation of their images also in accordance with all technical requirements: Illustration Service.

Highlights

Highlights are mandatory for this journal. They consist of a short collection of bullet points that convey the core findings of the article and should be submitted in a separate file in the online submission system. Please use 'Highlights' in the file name and include 3 to 5 bullet points (maximum 85 characters, including spaces, per bullet point). See http://www.elsevier.com/highlights for examples.

Highlights are mandatory for this journal. They consist of a short collection of bullet points that convey the core findings of the article and should be submitted in a separate file in the online submission system. Please use 'Highlights' in the file name and include 3 to 5 bullet points (maximum 85 characters, including spaces, per bullet point). See http://www.elsevier.com/highlights for examples.

Keywords

Up to 10 keywords should be supplied e.g. dental material, composite resin, adhesion.

Abbreviations

Define abbreviations that are not standard in this field in a footnote to be placed on the first page of the article. Such abbreviations that are unavoidable in the abstract must be defined at their first mention there, as well as in the footnote. Ensure consistency of abbreviations throughout the article.

Acknowledgements

Collate acknowledgements in a separate section at the end of the article before the references and do not, therefore, include them on the title page, as a footnote to the title or otherwise. List here those individuals who provided help during the research (e.g., providing language help, writing assistance or proof reading the article, etc.).

Units

Follow internationally accepted rules and conventions: use the international system of units (SI). If other units are mentioned, please give their equivalent in SI.

Math formulae

Present simple formulae in the line of normal text where possible and use the solidus (/) instead of a horizontal line for small fractional terms, e.g., X/Y. In principle, variables are to be presented in italics. Powers of e are often more conveniently denoted by exp. Number consecutively any equations that have to be displayed separately from the text (if referred to explicitly in the text).

Embedded math equations

If you are submitting an article prepared with Microsoft Word containing embedded math equations then please read this related support information (http://support.elsevier.com/app/answers/detail/a_id/302/).

Footnotes

Footnotes should be used sparingly. Number them consecutively throughout the article, using superscript Arabic numbers. Many wordprocessors build footnotes into the text, and this feature may be used. Should this not be the case, indicate the position of footnotes in the text and present the footnotes themselves separately at the end of the article. Do not include footnotes in the Reference list.

Table footnotes

Indicate each footnote in a table with a superscript lowercase letter.

Artwork

Electronic artwork

General points

• Make sure you use uniform lettering and sizing of your original artwork.
• Embed the used fonts if the application provides that option.
• Aim to use the following fonts in your illustrations: Arial, Courier, Times New Roman, Symbol, or use fonts that look similar.
• Number the illustrations according to their sequence in the text.
• Use a logical naming convention for your artwork files.
• Provide captions to illustrations separately.
• Size the illustrations close to the desired dimensions of the printed version.
• Submit each illustration as a separate file.

A detailed guide on electronic artwork is available on our website:
http://www.elsevier.com/artworkinstructions

You are urged to visit this site; some excerpts from the detailed information are given here.

Formats

If your electronic artwork is created in a Microsoft Office application (Word, PowerPoint, Excel) then please supply 'as is' in the native document format.

Regardless of the application used other than Microsoft Office, when your electronic artwork is finalized, please 'Save as' or convert the images to one of the following formats (note the resolution requirements for line drawings, halftones, and line/halftone combinations given below):

EPS (or PDF): Vector drawings, embed all used fonts.
TIFF (or JPEG): Color or grayscale photographs (halftones), keep to a minimum of 300 dpi.
TIFF (or JPEG): Bitmapped (pure black & white pixels) line drawings, keep to a minimum of 1000 dpi.
TIFF (or JPEG): Combinations bitmapped line/half-tone (color or grayscale), keep to a minimum of 500 dpi.

Please do not:

• Supply files that are optimized for screen use (e.g., GIF, BMP, PICT, WPG); these typically have a low number of pixels and limited set of colors;
• Supply files that are too low in resolution;
• Submit graphics that are disproportionately large for the content.

Color artwork

Please make sure that artwork files are in an acceptable format (TIFF (or JPEG), EPS (or PDF), or MS Office files) and with the correct resolution. If, together with your accepted article, you submit usable color figures then Elsevier will ensure, at no additional charge, that these figures will appear in color on the Web (e.g., ScienceDirect and other sites) regardless of whether or not these illustrations are reproduced in color in the printed version. **For color reproduction in print, you will receive information regarding the costs from Elsevier after receipt of your accepted article**. Please indicate your preference for color: in print or on the Web only. For further information on the preparation of electronic artwork, please see http://www.elsevier.com/artworkinstructions.

Please note: Because of technical complications which can arise by converting color figures to 'gray scale' (for the printed version should you not opt for color in print) please submit in addition usable black and white versions of all the color illustrations.

Illustration services

Elsevier's WebShop (http://webshop.elsevier.com/illustrationservices) offers Illustration Services to authors preparing to submit a manuscript but concerned about the quality of the images accompanying their article. Elsevier's expert illustrators can produce scientific, technical and medical-style images, as well as a full range of charts, tables and graphs. Image 'polishing' is also available, where our illustrators take your image(s) and improve them to a professional standard. Please visit the website to find out more.

Captions to tables and figures

• list together on a separate page.
• should be complete and understandable apart from the text.
• include key for symbols or abbreviations used in Figures.
• individual teeth should be identified using the FDI two-digit system.

Tables

Number tables consecutively in accordance with their appearance in the text. Place footnotes to tables below the table body and indicate them with superscript lowercase letters. Avoid vertical rules. Be sparing in the use of tables and ensure that the data presented in tables do not duplicate results described elsewhere in the article.

References

References

Must now be given **according to the following numeric system**:
Cite references in text in numerical order. Use square brackets: in-line, not superscript e.g. [23]. All references must be listed at the end of the paper, double-spaced, without indents. For example: 1. Moulin P, Picard B and Degrange M. Water resistance of resin-bonded joints with time related to alloy surface treatments. J Dent, 1999; 27:79-87. 2. Taylor DF, Bayne SC, Sturdevant JR and Wilder AD. Comparison of direct and indirect methods for analyzing wear of posterior composite restorations. Dent Mater, 1989; 5:157-160. Avoid referencing abstracts if possible. If unavoidable, reference as follows: 3. Demarest VA and Greener EH . Storage moduli and interaction parameters of experimental dental composites. J Dent Res, 1996; 67:221, Abstr. No. 868.

Citation in text

Please ensure that every reference cited in the text is also present in the reference list (and vice versa). Any references cited in the abstract must be given in full. Unpublished results and personal communications are not recommended in the reference list, but may be mentioned in the text. If these references are included in the reference list they should follow the standard reference style of the journal and should include a substitution of the publication date with either 'Unpublished results' or 'Personal communication'. Citation of a reference as 'in press' implies that the item has been accepted for publication.

Reference links

Increased discoverability of research and high quality peer review are ensured by online links to the sources cited. In order to allow us to create links to abstracting and indexing services, such as Scopus, CrossRef and PubMed, please ensure that data provided in the references are correct. Please note that incorrect surnames, journal/book titles, publication year and pagination may prevent link creation. When copying references, please be careful as they may already contain errors. Use of the DOI is encouraged.

Web references

As a minimum, the full URL should be given and the date when the reference was last accessed. Any further information, if known (DOI, author names, dates, reference to a source publication, etc.), should also be given. Web references can be listed separately (e.g., after the reference list) under a different heading if desired, or can be included in the reference list.

References in a special issue

Please ensure that the words 'this issue' are added to any references in the list (and any citations in the text) to other articles in the same Special Issue.

Reference style
Text: Indicate references by number(s) in square brackets in line with the text. The actual authors can be referred to, but the reference number(s) must always be given.
Example: '..... as demonstrated [3,6]. Barnaby and Jones [8] obtained a different result ....'
List: Number the references (numbers in square brackets) in the list in the order in which they appear in the text.
Examples:
Reference to a journal publication:
[1] J. van der Geer, J.A.J. Hanraads, R.A. Lupton, The art of writing a scientific article, J. Sci. Commun. 163 (2010) 51–59.
Reference to a book:
[2] W. Strunk Jr., E.B. White, The Elements of Style, fourth ed., Longman, New York, 2000.
Reference to a chapter in an edited book:
[3] G.R. Mettam, L.B. Adams, How to prepare an electronic version of your article, in: B.S. Jones, R.Z. Smith (Eds.), Introduction to the Electronic Age, E-Publishing Inc., New York, 2009, pp. 281–304.

Journal abbreviations source
Journal names should be abbreviated according to the List of Title Word Abbreviations: http://www.issn.org/services/online-services/access-to-the-ltwa/.

Video data
Elsevier accepts video material and animation sequences to support and enhance your scientific research. Authors who have video or animation files that they wish to submit with their article are strongly encouraged to include links to these within the body of the article. This can be done in the same way as a figure or table by referring to the video or animation content and noting in the body text where it should be placed. All submitted files should be properly labeled so that they directly relate to the video file's content. In order to ensure that your video or animation material is directly usable, please provide the files in one of our recommended file formats with a preferred maximum size of 50 MB. Video and animation files supplied will be published online in the electronic version of your article in Elsevier Web products, including ScienceDirect: http://www.sciencedirect.com. Please supply 'stills' with your files: you can choose any frame from the video or animation or make a separate image. These will be used instead of standard icons and will personalize the link to your video data. For more detailed instructions please visit our video instruction pages at http://www.elsevier.com/artworkinstructions. Note: since video and animation cannot be embedded in the print version of the journal, please provide text for both the electronic and the print version for the portions of the article that refer to this content.

AudioSlides
The journal encourages authors to create an AudioSlides presentation with their published article. AudioSlides are brief, webinar-style presentations that are shown next to the online article on ScienceDirect. This gives authors the opportunity to summarize their research in their own words and to help readers understand what the paper is about. More information and examples are available at http://www.elsevier.com/audioslides. Authors of this journal will automatically receive an invitation e-mail to create an AudioSlides presentation after acceptance of their paper.

Supplementary data
Elsevier accepts electronic supplementary material to support and enhance your scientific research. Supplementary files offer the author additional possibilities to publish supporting applications, high-resolution images, background datasets, sound clips and more. Supplementary files supplied will be published online alongside the electronic version of your article in Elsevier Web products, including ScienceDirect: http://www.sciencedirect.com. In order to ensure that your submitted material is directly usable, please provide the data in one of our recommended file formats. Authors should submit the material in electronic format together with the article and supply a concise and descriptive caption for each file. For more detailed instructions please visit our artwork instruction pages at http://www.elsevier.com/artworkinstructions.

Submission checklist
The following list will be useful during the final checking of an article prior to sending it to the journal for review. Please consult this Guide for Authors for further details of any item.
Ensure that the following items are present:
One author has been designated as the corresponding author with contact details:
• E-mail address

• Full postal address
• Phone numbers
All necessary files have been uploaded, and contain:
• Keywords
• All figure captions
• All tables (including title, description, footnotes)
Further considerations
• Manuscript has been 'spell-checked' and 'grammar-checked'
• References are in the correct format for this journal
• All references mentioned in the Reference list are cited in the text, and vice versa
• Permission has been obtained for use of copyrighted material from other sources (including the Web)
• Color figures are clearly marked as being intended for color reproduction on the Web (free of charge) and in print, or to be reproduced in color on the Web (free of charge) and in black-and-white in print
• If only color on the Web is required, black-and-white versions of the figures are also supplied for printing purposes
For any further information please visit our customer support site at http://support.elsevier.com.

AFTER ACCEPTANCE

Use of the Digital Object Identifier

The Digital Object Identifier (DOI) may be used to cite and link to electronic documents. The DOI consists of a unique alpha-numeric character string which is assigned to a document by the publisher upon the initial electronic publication. The assigned DOI never changes. Therefore, it is an ideal medium for citing a document, particularly 'Articles in press' because they have not yet received their full bibliographic information. Example of a correctly given DOI (in URL format; here an article in the journal *Physics Letters B*):
http://dx.doi.org/10.1016/j.physletb.2010.09.059
When you use a DOI to create links to documents on the web, the DOIs are guaranteed never to change.

Proofs

One set of page proofs (as PDF files) will be sent by e-mail to the corresponding author (if we do not have an e-mail address then paper proofs will be sent by post) or, a link will be provided in the e-mail so that authors can download the files themselves. Elsevier now provides authors with PDF proofs which can be annotated; for this you will need to download Adobe Reader version 9 (or higher) available free from http://get.adobe.com/reader. Instructions on how to annotate PDF files will accompany the proofs (also given online). The exact system requirements are given at the Adobe site: http://www.adobe.com/products/reader/tech-specs.html.
If you do not wish to use the PDF annotations function, you may list the corrections (including replies to the Query Form) and return them to Elsevier in an e-mail. Please list your corrections quoting line number. If, for any reason, this is not possible, then mark the corrections and any other comments (including replies to the Query Form) on a printout of your proof and return by fax, or scan the pages and e-mail, or by post. Please use this proof only for checking the typesetting, editing, completeness and correctness of the text, tables and figures. Significant changes to the article as accepted for publication will only be considered at this stage with permission from the Editor. We will do everything possible to get your article published quickly and accurately – please let us have all your corrections within 48 hours. It is important to ensure that all corrections are sent back to us in one communication: please check carefully before replying, as inclusion of any subsequent corrections cannot be guaranteed. Proofreading is solely your responsibility. Note that Elsevier may proceed with the publication of your article if no response is received.

Offprints

The corresponding author, at no cost, will be provided with a PDF file of the article via e-mail or, alternatively, 25 free paper offprints. The PDF file is a watermarked version of the published article and includes a cover sheet with the journal cover image and a disclaimer outlining the terms and conditions of use. For an extra charge, more paper offprints can be ordered via the offprint order form which is sent once the article is accepted for publication. Both corresponding and co-authors may order offprints at any time via Elsevier's WebShop (http://webshop.elsevier.com/myarticleservices/offprints). Authors requiring printed copies of multiple articles may use Elsevier WebShop's 'Create Your Own Book' service to collate multiple articles within a single cover (http://webshop.elsevier.com/myarticleservices/booklets).

AUTHOR INQUIRIES

For inquiries relating to the submission of articles (including electronic submission) please visit this journal's homepage. For detailed instructions on the preparation of electronic artwork, please visit http://www.elsevier.com/artworkinstructions. Contact details for questions arising after acceptance of an article, especially those relating to proofs, will be provided by the publisher. You can track accepted articles at http://www.elsevier.com/trackarticle. You can also check our Author FAQs at http://www.elsevier.com/authorFAQ and/or contact Customer Support via http://support.elsevier.com.

7.2.3 Capítulos 3 e 4

Links | Of Interest
Journal | Authors
Subscribe | Reviewers
Shopping Cart | Continuing Education

OPERATIVE DENTISTRY

INSTRUCTIONS TO AUTHORS

New Instructions as of 20 September 2008

Operative Dentistry requires electronic submission of all manuscripts. All submissions must be sent to Operative Dentistry using the Allen Track upload site. Your manuscript will only be considered officially submitted after it has been approved through our initial quality control check, and any problems have been fixed. You will have 6 days from when you start the process to submit and approve the manuscript. After the 6 day limit, if you have not finished the submission, your submission will be removed from the server. You are still able to submit the manuscript, but you must start from the beginning. Be prepared to submit the following manuscript files in your upload:

- A Laboratory or Clinical Research Manuscript file must include:
    - a title
    - a running (short) title
    - a clinical relevance statement
    - a concise summary (abstract)
    - introduction, methods & materials, results, discussion and conclusion
    - references (see Below)
    - The manuscript **MUST NOT** include any:
        - identifying information such as:
            - Authors
            - Acknowledgements
            - Correspondence information
        - Figures
        - Graphs
        - Tables
- An acknowledgement, disclaimer and/or recognition of support (if applicable) must in a separate file

and uploaded as supplemental material.
- All figures, illustrations, graphs and tables must also be provided as individual files. These should be high resolution images, which are used by the editor in the actual typesetting of your manuscript. Please refer to the instructions below for acceptable formats.
- All other manuscript types use this template, with the appropriate changes as listed below.

Complete the online form which includes complete author information and select the files you would like to send to Operative Dentistry. Manuscripts that do not meet our formatting and data requirements listed below will be sent back to the corresponding author for correction.

GENERAL INFORMATION

- All materials submitted for publication must be submitted exclusively to Operative Dentistry.
- The editor reserves the right to make literary corrections.
- Currently, color will be provided at no cost to the author if the editor deems it essential to the manuscript. However, we reserve the right to convert to gray scale if color does not contribute significantly to the quality and/or information content of the paper.
- The author(s) retain(s) the right to formally withdraw the paper from consideration and/or publication if they disagree with editorial decisions.
- International authors whose native language is not English must have their work reviewed by a native English speaker prior to submission.
- Spelling must conform to the American Heritage Dictionary of the English Language, and SI units for scientific measurement are preferred.
- While we do not currently have limitations on the length of manuscripts, we expect papers to be concise; Authors are also encouraged to be selective in their use of figures and tables, using only those that contribute significantly to the understanding of the research.
- Acknowledgement of receipt is sent automatically. If you do not receive such an acknowledgement, please contact us at editor@jopdent.org rather than resending your paper.
- **IMPORTANT:** Please add our e-mail address to your address book on your server to prevent transmission problems from spam and other filters. Also make sure that your server will accept larger file sizes. This is particularly important since we send page-proofs for review and correction as .pdf files.

REQUIREMENTS

- ## FOR ALL MANUSCRIPTS

1. **CORRESPONDING AUTHOR** must provide a WORKING / VALID e-mail address which will be used for all communication with the journal.
   NOTE: Corresponding authors MUST update their profile if their e-mail or postal address changes. If we cannot contact authors within seven days, their manuscript will be removed from our publication queue.

2. **AUTHOR INFORMATION** must include:
   - full name of all authors
   - complete mailing address for each author
   - degrees (e.g. DDS, DMD, PhD)
   - affiliation (e.g. Department of Dental Materials, School of Dentistry, University of

Michigan)

3. **MENTION OF COMMERCIAL PRODUCTS/EQUIPMENT** must include:
   - full name of product
   - full name of manufacturer
   - city, state and/or country of manufacturer

4. **MANUSCRIPTS AND TABLES** must be provided as Word files. Please limit size of tables to no more than one US letter sized page. (8 ½ " x 11")

5. **ILLUSTRATIONS, GRAPHS AND FIGURES** must be provided as TIFF or JPEG files with the following parameters
   - line art (and tables that are submitted as a graphic) must be sized at approximately 5" x 7" and have a resolution of 1200 dpi.
   - gray scale/black & white figures must have a minimum size of 3.5" x 5", and a maximum size of 5" x 7" and a minimum resolution of 300 dpi and a maximum of 400 dpi.
   - color figures must have a minimum size of 2.5" x 3.5", and a maximum size of 3.5" x 5" and a minimum resolution of 300 dpi and a maximum of 400 dpi.
   - color photographs must be sized at approximately 3.5" x 5" and have a resolution of 300 dpi.

• OTHER MANUSCRIPT TYPES

1. **CLINICAL TECHNIQUE/CASE STUDY MANUSCRIPTS** must include:
   - a running (short) title
   - purpose
   - description of technique
   - list of materials used
   - potential problems
   - summary of advantages and disadvantages
   - references (see below)

2. **LITERATURE AND BOOK REVIEW MANUSCRIPTS** must include:
   - a running (short) title
   - a clinical relevance statement based on the conclusions of the review
   - conclusions based on the literature review…without this, the review is just an exercise
   - references (see below)

• FOR REFERENCES

REFERENCES must be numbered (superscripted numbers) consecutively as they appear in the text and, where applicable, they should appear after punctuation.

The reference list should be arranged in numeric sequence at the end of the manuscript and should include:

1. Author(s) last name(s) and initial (ALL AUTHORS must be listed) followed by the date of publication in parentheses.

2. Full article title.
3. Full journal name in italics (no abbreviations), volume and issue numbers and first and last page numbers complete (i.e. 163-168 NOT attenuated 163-68).
4. Abstracts should be avoided when possible but, if used, must include the above plus the abstract number and page number.
5. Book chapters must include chapter title, book title in italics, editors' names (if appropriate), name of publisher and publishing address.
6. Websites may be used as references, but must include the date (day, month and year) accessed for the information.
7. Papers in the course of publication should only be entered in the references if they have been accepted for publication by a journal and then given in the standard manner with "In press" following the journal name.
8. **DO NOT** include unpublished data or personal communications in the reference list. Cite such references parenthetically in the text and include a date.

EXAMPLES OF REFERENCE STYLE

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

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

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

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

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

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

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

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

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

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

Manuscript upload site

7.2.4 Capítulo 5

editora ponto

Clínica
INTERNATIONAL JOURNAL OF BRAZILIAN DENTISTRY

A Revista N. 1 em Odontologia

NORMAS PARA PUBLICAÇÃO DE ARTIGOS

Please, read the Instructions for Authors at the site www.revistaclinica.com.br A revista Clínica - International Journal of Brazilian Dentistry é dirigida à classe odontológica e a profissionais de áreas afins. Destina-se à publicação de artigos de investigação científica, relatos de casos clínicos e de técnicas, e revisões da literatura de assuntos de significância clínica, com periodicidade trimestral. As normas, principalmente na parte de referência da revista, estão baseadas no Uniform Requirements for Manuscripts Submitted to Biomedical Journals: Writing and Editing for Biomedical Publication, do International Committee of Medical Journal Editors (Grupo de Vancouver). N Engl J Med. 1997;336:309-16. Essas normas foram atualizadas em outubro de 2004 e estão descritas no site http://www.icmje.org.

NORMAS GERAIS

1) Os manuscritos enviados para publicação deverão ser inéditos, não sendo permitida a sua apresentação simultânea a outros periódicos. Caso não sejam seguidas as normas da revista, o manuscrito será devolvido para as devidas adaptações. A revista Clínica reserva-se todos os direitos autorais do trabalho publicado, inclusive de versão e tradução, permitindo-se a sua posterior reprodução como transcrição, com a devida citação da fonte.
2) A revista Clínica reserva-se o direito de submeter todos os manuscritos à avaliação da Comissão Editorial, que decidirá pela aceitação ou não deles. No caso de aceitação, esta poderá estar sujeita às modificações solicitadas pelo Corpo Editorial.
3) Manuscritos não aceitos para publicação serão devolvidos com a devida notificação e, quando solicitada, com a justificativa. Os manuscritos aceitos não serão devolvidos.
4) Os prazos fixados para a eventual modificação do manuscrito serão informados e deverão ser rigorosamente respeitados. Sua não-observação acarretará no cancelamento da publicação do manuscrito.
5) Os conceitos emitidos nos artigos publicados bem como a exatidão das citações bibliográficas serão de responsabilidade exclusiva dos autores, não refletindo necessariamente a opinião do Corpo Editorial.
6) Os manuscritos deverão estar organizados sem numeração progressiva dos títulos e subtítulos, que devem se diferenciar pelo tamanho da fonte utilizada.
7) As datas de recebimento e de aceitação do manuscrito constarão no final deste, no momento da sua publicação.
8) A revista Clínica receberá para publicação manuscritos redigidos em português, inglês ou espanhol, entretanto, os artigos em língua estrangeira serão publicados em português.
9) No processo de avaliação dos manuscritos, os nomes dos autores permanecerão em sigilo para os avaliadores, e os nomes destes permanecerão em sigilo para aqueles. Os manuscritos serão avaliados por pares (duas pessoas) entre os consultores do Corpo Editorial.
10) Recomenda-se aos autores que mantenham em seus arquivos cópia integral dos originais, para o caso de extravio deles.
11) Manuscritos que envolvam pesquisa ou relato de experiência com seres humanos deverão estar de acordo com a Resolução nº 196/96 do Conselho Nacional de Saúde, ou com o constante na Declaração de Helsinki (1975 e revisada em 1983), devendo ter o consentimento por escrito do paciente e a aprovação da Comissão de Ética da Unidade (Instituição) em que o trabalho foi realizado. Quando for material ilustrativo, o paciente não deverá ser identificado, inclusive não devendo aparecer nomes ou iniciais. Para experimentos com animais, deverão ser seguidos os guias da Instituição dos Conselhos Nacionais de Pesquisa sobre uso e cuidados dos animais de laboratório.
12) Manuscritos deverão estar acompanhados das Declarações de Responsabilidade e de Transferência de Direitos Autorais, assinadas pelos autores.
13) A revista Clínica compromete-se a enviar ao endereço de correspondência do autor, a título de doação, um exemplar da edição em que seu trabalho foi publicado. Separatas e artigos em PDF são oferecidos a preço de mercado. Para mais informações, consulte nosso site: www.revistaclinica.com.br

CLASSIFICAÇÃO DOS MANUSCRITOS

Os manuscritos podem ser submetidos em três formatos:
a) Artigos de investigação científica: título em português e inglês (máximo de 12 palavras), nomes, titulação e filiação institucional dos autores, endereço completo do autor principal (apenas na folha de rosto), resumo (máximo de 10 linhas), palavras-chave, significância clínica (máximo de 10 linhas), introdução, material e métodos, resultados, discussão, conclusões, abstract (máximo de 10 linhas), keywords, referências, desenho esquemático do experimento, tabelas, gráficos, agradecimentos e legenda das figuras (caso houver);
b) Relato de casos clínicos e de técnicas: título em português e inglês (máximo de 12 palavras), nomes, titulação e filiação institucional dos autores, endereço completo do autor principal (apenas na folha de rosto), resumo (máximo de 10 linhas), palavras-chave, introdução, revisão da literatura, relato do caso, discussão, conclusões ou considerações finais, abstract (máximo de 10 linhas), keywords, referências, agradecimentos e legenda das figuras;
c) Revisão da literatura: título em português e inglês (máximo de 12 palavras), nomes, titulação e filiação institucional dos autores, endereço completo do autor principal (apenas na folha de rosto), resumo (máximo de 10 linhas), palavras-chave, significância clínica (máximo de 10 linhas), introdução, revisão da literatura, discussão, conclusão, abstract (máximo de 10 linhas), keywords, referências, agradecimentos e legenda das figuras (caso houver).

REFERÊNCIAS

As referências (estilo de Vancouver) deverão ser numeradas consecutivamente, na ordem em que aparecem no texto pela primeira vez, excluindo-se, conseqüentemente, o nome do autor no texto. Todos os autores citados no texto, nas tabelas e nas figuras deverão constar nas referências conforme a numeração progressiva deles no texto.

EXEMPLOS DE REFERÊNCIAS

De um a seis autores
Lodish H, Baltimore D, Berk A, Zipursky SL, Matsudaira P, Darnell J. Molecular cell biology. 3rd ed. New York: Scientific American; 1995.

Com mais de seis autore
Liebler M, Devigus A, Randall RC, Burke FJ, Pallesen U, Cerutti A, et al. Ethics of esthetic dentistry. Quintessence Int. 2004 Jun;35(6):456-65.

Livro
Marzola C. Técnica exodôntica. 3a ed. rev. ampl. São Paulo: Pancast; 2001.
Capítulo de livro

Soviero C, Garcia RS. Músculos da mímica facial. In: Oliveira MG, organizadora. Manual de anatomia da cabeça e do pescoço. 3a ed. Porto Alegre: EDIPURS; 1998. p. 66-73.

Sem indicação de autoria
Council on Drugs. List no. 52. New names. JAMA. 1966 Jul 18;197(3):210-1.

Instituição como autor
Conselho Nacional de Saúde(BR). Resolução no 196/96, de 10 de outubro de 1996. Dispõe sobre as diretrizes e normas regulamentares de pesquisa envolvendo seres humanos. Brasília: O Conselho; 1996.

Editor como autor
Murray JJ, editor. O uso correto de fluoretos na saúde pública. São Paulo: Santos;1992.

Trabalho em congresso
Lorenzetti J. A saúde no Brasil na década de 80 e perspectivas para os anos 90. In: Mendes NTC, coordenadora. Anais do 41º Congresso Brasileiro de Enfermagem; 1989 Set 2-7; Florianópolis, Brasil. Florianópolis: ABEn-Seção SC; 1989. p. 92-5.

Dissertação e tese
Tavares R. Avaliação da resistência de fundações de amalgama, através da tração de coroas totais metálicas [dissertação]. Florianópolis SC):Programa de Pós-Graduação em Odontologia/UFSC; 1988.

Documentos legais
Brasil. Portaria no 569, de 1 de junho de 2000. Institui o Programa de Humanização no Pré-natal e Nascimento. Diário Oficial da República Federativa do Brasil, 8 jun 2000. Seção 1.

Material não publicado
Tian D, Araki H, Stahl E, Bergelson J, Kreitman M. Signature of balancing selection in Arabidopsis. Proc Nath Acad Sci U S A. In press 2002.

Artigo padrão
Kidd EA. How 'clean' must a cavity be before restoration? Caries Res. 2004 May-Jun;38(3):305-13.

Artigo com número e suplemento
Fitzpatrick KC. Regulatory issues related to functional foods and natural health products in Canada: possible implications for manufacturers of conjugated linoleic acid. Am J Clin Nutr. 2004 Jun;79(6 Suppl):1217S-1220S.

Artigo sem número e com volume
Ostengo Mdel C, Elena Nader-Macias M. Hydroxylapatite beads as an experimental model to study the adhesion of lactic Acid bacteria from the oral cavity to hard tissues. Methods Mol Biol. 2004;268:447-52.

Artigo sem número e sem volume
Browell DA, Lennard TW. Inmunologic status of the cancer patient and the effects of blood transfusion on antitumor responses. Curr Opin Gen Surg. 1993:325-33.

Artigo indicado conforme o caso
Collins JG, Kirtland BC. Experimental periodontics retards hamster fetal growth [abstract]. J Dent Res. 1995;74:158.

Artigo de jornal
Tynan T. Medical improvements lower homicide rate:study sees drop in assault rate. The Washington Post. 2002 Aug 12; Sect. A:2 (col.4).

Material eletrônico
Abood S. Quality improvement initiative in nursing homes: the ANA acts in an advisory role. Am J Nurs [serial on the Internet]. 2002 Jun [cited 2002 Aug 12];102(6):[about 3 p.]. Available from: http://www.nursingworld.org/AJN/2002/june/wawatch.htm.
Foley KM, Gelband H, editors. Improving palliative care for cancer [monograph on the Internet]. Washington: National Academy Press; 2001[cited 2002 Jul 9]. Available from: http://www.nap.edu/books/0309074029/html/.
Anderson SC, Poulsen KB. Anderson's electronicatlas of hematology [CDROM]. Philadelphia: Lippincott Willians &Wilkins; 2002.

OBSERVAÇÕES ADICIONAIS

A referência comercial dos equipamentos, instrumentos e materiais citados deve ser composta respectivamente por modelo, marca e país fabricante, separados por vírgula e entre parênteses.
Nas citações diretas e indiretas deverá ser utilizado o sistema numérico. Quando apresentados por número seqüencial, colocar hífen; quando aleatório, colocar vírgula.
As citações indiretas (texto baseado na obra de um autor) deverão ser apresentadas no texto sem aspas e com o número correspondente da referência (autor) sobrescrito. Exemplo: Nossos resultados de[12] resistência de união ao esmalte estão de acordo com a literatura.[12]
As citações diretas (transcrição textual) deverão ser apresentadas no texto entre aspas indicando-se o número correspondente da referência e a pagina da citação, conforme exemplo: "Os resultados deste trabalho mostraram que os cimentos [...]".[12:127]
Os títulos das revistas serão abreviados conforme consulta no Index to Dental Literature ou nos sites: http://ibict.br e/ou http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?db=PubMed.
Colocar no máximo 4 descritores (palavras-chave identificando o conteúdo do manuscrito). Consultar a lista de Descritores em Ciências da Saúde (DECS) elaborada pela Bireme e disponível na internet no site: http://decs.bvs.br, ou Index to Dental Literature, e/ou Medical Subject Headings(MeSH) do Index Medicus no site: http: // www.ncbi.nlm.nih.gov/entrez/query.fcgi?db=mesh.
Notas de rodapé serão indicadas por asteriscos, mas devem ser evitadas ao máximo.
Evitar citar uma comunicação verbal; porém, se necessário, mencionar o nome da pessoa e data de comunicação entre parênteses no texto.
As ilustrações (fotografia e desenhos, com exceção das tabelas, gráficos e quadros) deverão ser designadas como figuras. Todas as figuras deverão ser fornecidas em slides originais, ou digitais com boa resolução (300dpi e tamanho mínimo de 3000 x 2000 pixels). Todas as figuras, tabelas, gráficos e quadros deverão estar com suas legendas e ser citados no texto e nas referências (quando extraídos de outra fonte). A Comissão Editorial reserva-se o direito de, em comum acordo com os autores, reduzir quando necessário o número de ilustrações. A montagem das tabelas deverá seguir as Normas Técnicas de Apresentação Tabular (IBGE, 1979). Não utilizar nas tabelas traços internos verticais e horizontais. As tabelas e os gráficos deverão ser fornecidos junto com o

disquete ou CD do artigo, no formato digital gerado por programas como Word, Excel, Corel e compatíveis. As fotografias deverão ser fornecidas em slides originais ou digitais com boa resolução (300dpi e tamanho mínimo de 3000 x 2000 pixels). É necessário também submeter 3 cópias coloridas (6 fotografias por folha) impressas em papel couché. No caso da submissão de slides, estes deverão vir em folhas de arquivo de slides, numerados, com as iniciais do primeiro autor e com o seu posicionamento (lado direito, esquerdo, superior e inferior) na moldura do slide.

APRESENTAÇÃO DOS MANUSCRITOS

Os artigos submetidos à revista deverão ser encaminhados em 3 cópias impressas, redigidos de acordo com a gramática oficial e digitados na fonte Times New Roman tamanho 12, em folhas de papel tamanho A4, com espaço duplo e margem de 3 cm em todos os lados, tinta preta e páginas numeradas no canto superior direito. O limite máximo para o tamanho do artigo será de 20 folhas. Deve-se encaminhar também cópia do documento utilizando-se o editor Word for Windows 98 ou editores compatíveis, em disquete 1.44 Mb ou CD.

Todos os artigos deverão ser enviados registrados, preferencialmente por Sedex, e encaminhados à:
Revista Clínica - International Journal of Brazilian Dentistry. Servidão Vila Kinczeski, 23, Centro, 88020-450, Florianópolis, Santa Catarina, Brasil.

CHECKLIST

- Declarações de Responsabilidade e de Transferência de Direitos Autorais assinada por todos os autores.
- Três cópias impressas incluindo figuras em papel couché.
- CD ou disquete contendo todo o manuscrito.
- Slides originais ou fotografias digitais gravadas em CD.

Clique aqui para fazer download da declaração

^Topo