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FORMAÇÃO DE FENDAS EM RESTAURAÇÕES DE COMPÓSITO:

TÉCNICAS DE AVALIAÇÃO, EFEITO DE MÉTODOS DE FOTOATIVAÇÃO E RELAÇÃO COM A RESISTÊNCIA DA UNIÃO

Tese apresentada à Faculdade de Odontologia de Piracicaba, da Universidade Estadual de Campinas, como parte dos requisitos para obtenção do título de Doutor em Materiais Dentários.

Orientador: Prof. Dr. Mário Alexandre Coelho Sinhoreti

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PROF. DR. MARIO FERNANDO DE GOES

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(José Arthur Giannotti)

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" Os verdadeiros sábios se dão a conhecer pelos bons princípios de seus atos, pela intocável moral de suas atitudes e pelo fato de servirem de exemplo dos ensinamentos que transmitem."
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" Uma vida sem amigo é uma vida sem sol. "
(Provérbio alemão)

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Segundo os psicólogos
e a experiência do dia a dia,
os motivos de alegria
costumam ser três:
O primeiro de todos é saber-se
amado por quem amamos.
O segundo, confiança no êxito
dos nossos empreendimentos.
O terceiro, satisfação pelo
dever cumprido

RESUMO

A formação de fendas em restaurações de compósito foi caracterizada neste estudo, abrangendo-se técnicas de avaliação, fatores modificadores e a relação com a resistência de união das restaurações à estrutura dental. No capítulo 1, objetivou-se validar a técnica do corante para avaliação das fendas através da comparação com a observação em Microscopia Eletrônica de Varredura (MEV). Vinte incisivos bovinos foram selecionados e desgastados até expor uma área plana em dentina, onde duas cavidades foram preparadas e restauradas com o compósito Filtek Z250 ou Filtek Flow. As amostras foram polidas e réplicas foram obtidas em resina epóxica. As réplicas foram observadas em MEV para determinar a porcentagem de fenda ao longo da margem cavitária. Na técnica do corante, Caries Detector (Kuraray) foi aplicado sobre as restaurações durante 5s. A imagem digital das restaurações coradas foi analisada com o *software* Image Tool para determinar a porcentagem de fendas. Os dados foram submetidos a ANOVA e teste de correlação de Pearson. Filtek Flow apresentou 35,54% e 33,52%, e Filtek Z250 26,68% e 29,11% de fendas, quando avaliadas em MEV e pela técnica do corante, respectivamente. Não houve diferença significativa entre os compósitos independente do método de avaliação, havendo forte correlação positiva (r=0,83) entre eles. Concluiu-se que a técnica do corante pode ser utilizada para avaliação das fendas com confiabilidade dos resultados. No capítulo 2, o efeito de métodos de fotoativação modulados na adaptação marginal e interna de restaurações confeccionadas com diferentes compósitos foi determinado. Sessenta terceiros molares foram selecionados, seccionados (2 fragmentos) e tiveram a superfície vestibular ou palatina ou lingual desgastada para expor uma área plana em esmalte, onde uma cavidade foi confeccionada. Os dentes foram distribuídos em 12 grupos (n=10), segundo o compósito restaurador (Filtek Z250, Herculite XRV e Heliomolar) e o método de fotoativação (Luz contínua; *Soft-Start; Pulse delay;* Luz intermitente). O teste de adaptação marginal (técnica do corante) foi conduzido da mesma maneira descrita anteriormente. Após, os espécimes foram seccionados dividindo a restauração em 4 fatias, que foram coradas e o mesmo procedimento de avaliação da adaptação marginal foi realizado para determinar a adaptação interna. Assim, pôde-se observar que todas as restaurações apresentaram perfeito selamento das margens externas. Considerando as fendas internas, os métodos modulados geraram redução significativa nas fendas quando comparados à luz contínua, independe do compósito empregado. Filtek Z250 apresentou a melhor adaptação interna, independente do método de fotoativação. A interação tipo de compósito e método de fotoativação não foi significativa. Conclui-se que os métodos de fotoativação modulados são eficientes na redução da formação de fendas internas e que podem ser indicados para a prática clínica, independente do compósito empregado. No capítulo 3, o objetivo foi relacionar a resistência da união à adaptação marginal e interna de restaurações fotoativadas por diferentes métodos. A resistência da união foi mensurada em cavidades tronco-cônicas confeccionadas em dentes bovinos através do teste *push-out* (Instron). A adaptação marginal e interna das restaurações foi verificada da mesma maneira descrita anteriormente. Em ambos os testes, as cavidades foram restauradas com o compósito Esthet-X, sendo as amostras distribuídas em 5 grupos (n=10), de acordo com o método de fotoativação: G1 – Luz contínua; G2 – Luz contínua baixa intensidade; G3 – *Soft-start*; G4 – Luz Intermitente; G5 – *Pulse Delay*. A dose de energia foi padronizada em 14J. Os dados foram submetidos a ANOVA e teste de Tukey. Considerando resistência da união, G5 (7,2 MPa) apresentou resultados significativamente melhores que G1 (4,6 MPa). G2, G3 e G4 tiveram médias intermediárias, não havendo diferenças significativas entre esses grupos e entre eles e G1 ou G5. Considerando adaptação marginal, não houve diferença significativa entre os grupos. Na adaptação interna (que incluía o substrato dentinário), o resultado foi inverso ao do teste de resistência de união, ou seja, G5 (2,8%) teve menor média de fendas que G1 (10,1%). Concluiu-se que a modulação da energia luminosa pode acarretar em aumento da resistência da união e redução na formação de fendas internas, havendo relação inversa entre resistência da união e formação de fendas internas.

Palavras – chave: formação de fendas, adaptação marginal, métodos de fotoativação, resistência de união, restaurações em compósito.

ABSTRACT

Gap formation in composite restorations has been characterized in this dissertation by way of evaluation techniques, modifying factors and the relationship between bond strength of the restorations and the dental structure. In Chapter 1 the objective was to compare the dye staining technique to Scanning Electron Microscopy (SEM) evaluation of gap formation in order to validate the dye technique. Twenty bovine incisors were selected and ground so as to expose a flat dentin area in which two circular cavities were prepared and restored using Filtek Z250 or Filtek Flow. The specimens were polished and replicas were obtained in epoxy resin. Replicas were observed in SEM to determine the percentage of gap formation in the margins of the restorations. In dye staining technique, the Caries Detector was applied on each restoration for 5 seconds. Digital images of the stained restorations were analyzed using Image Tool to determine gap percentage. Data were submitted to ANOVA and Pearson's correlation. Filtek Flow showed 35.54% and 33.52% of gap and Filtek Z250 showed 26.68% and 29.11%, when evaluated using SEM and Dye staining technique, respectively. There was no difference between the composites, regardless of the evaluation technique. There was a strong positive correlation (r=0.83) between the results obtained through the tested methods to assess marginal gap. This led to the conclusion that dye staining technique can be reliably employed to evaluate the gap formation in composite restorations. Chapter 2 aims at determining the effect of modulated photoactivation methods on gap formation of restorations using different composites. Sixty third molars were selected, sectioned (2 fragments) and ground so as to expose a flat enamel area in which a cavity was prepared. The specimens were distributed into twelve groups (n=10), according to the restorative composite (Filtek Z250, Herculite XRV, and Heliomolar) and the photoactivation method (Continuous Light, Soft-Start, Pulse Delay, and Intermittent Light) applied. Marginal adaptation test was conducted in the same way described before (dye staining technique). The specimens were then sectioned in 4 slices, all of which were stained, and the same evaluation procedure used to determine marginal adaptation was employed to evaluate internal gap formation. All restorations showed perfect sealing of the enamel outer margins. With regards to internal adaptation, modulated photoactivation methods showed a significant reduction on gap formation when compared under continuous light, regardless of the composite. Filtek Z250 showed the best internal adaptation, regardless of the photoactivation method.

The interaction between restorative composite and photoactivation method was not significant. The conclusion was that modulated photoactivation methods decrease the internal gap formation of composite restorations and should thus be encouraged on clinical practice, regardless of the type of composite. In Chapter 3, the aim was to evaluate the relationship between bond strength and marginal and internal adaptation of composite restorations photocured by different methods. Bond strength was measured in conical cavities prepared in bovine incisors using push-out test (Instron). Marginal and internal adaptation tests were conducted in the same way as before (dye staining technique). For both tests, cavities were filled with Esthet X resin composite. The specimens were distributed into 5 groups (n=10) according to photoactivation method: G1 – continuous light; G2 – low intensity continuous light; G3 – soft start; G4 – intermittent light; G5 – pulse delay. 14J was the standard energy dose. Data were submitted to ANOVA and Tukey`s test. Regarding bond strength, G5 (7.2 MPa) was statistically superior to G1 (4.6 MPa). G2, G3 and G4 showed intermediate mean values, which were not different from each other or from G1 or G5. Regarding marginal adaptation, there was no statistical difference among the groups. Internal adaptation results (that included dentin substrate) were the opposite of bond strength results. G5 (2.8%) showed a reduction on gap formation when compared to G1 (10.1%). In conclusion, it may be said that the modulated photocuring methods can increase bond strength while decreasing internal gap formation. An opposite relationship was observed regarding push-out bond strength and internal adaptation of composite restorations.

Key words: gap formation, marginal adaptation, photoactivation methods, bond strength, composite restorations.

SUMÁRIO

1. INTRODUÇÃO GERAL

Os compósitos resinosos vêm sendo aprimorados desde o início da década de 70, e desenvolveram-se de tal modo que atualmente apresentam diversas características vantajosas que propiciaram a ampliação de suas indicações na Odontologia. Tais características são: a capacidade de reproduzir esteticamente a estrutura dental perdida, a possibilidade de união com os substratos dentais (PASHLEY & CARVALHO, 1997), além de propriedades físicas e mecânicas satisfatórias que permitem sua aplicação em dentes anteriores e posteriores (PEUTZFELDT, 1997).

Entretanto, os compósitos têm como desvantagem inerente a contração de polimerização, decorrente de reações químicas na matriz orgânica do compósito (ASMUSSEN, 1975; DAVIDSON & FEIZER, 1997). Em função disto, diversas técnicas e materiais vêm sendo desenvolvidos com o intuito de reduzir ou mesmo eliminar a contração de polimerização (UNO & ASMUSSEN, 1991; PEUTZFELDT, 1997; SAKAGUCHI & BERGE, 1998).

Quando os compósitos polimerizam *in situ,* na cavidade dentária e, portanto, em condição restrita, ocorre o desenvolvimento de tensões na interface dente-restauração (FEILZER *ET AL.,* 1987). Se tais tensões forem superiores à resistência da união imposta pelo sistema adesivo, inevitavelmente formar-se-ão fendas, que representarão locais propícios para a instalação e proliferação bacteriana. Em condições específicas, a colonização bacteriana desses locais pode resultar em manchamento da interface, sensibilidade pós-operatória, cárie recorrente e inflamação pulpar, culminando no fracasso da restauração (COX, 1994). Diante da importância atribuída à formação de fendas nas restaurações de compósito, a avaliação, qualificação e mensuração dessas fendas têm sido amplamente realizada em estudos laboratoriais (LUTZ *ET AL.,* 1991; CIUCCHI *ET AL.,* 1997; MANHART *ET AL.,* 2001; YOSHIKAWA *ET AL.,* 2001; IRIE *ET AL.*, 2002; PEUTZFELDT & ASMUSSEN, 2004; ALONSO *ET AL.,* 2004; CORRER *ET AL.,* 2005; IWAMI *ET AL.,* 2005; ALONSO *ET AL.,* 2006). Na literatura, pode-se identificar vários métodos para se conduzir tal avaliação, dentre os quais pode-se citar: estudos de microinfiltração (com corantes, traçadores químicos e radioativos, bactérias, pressão de ar, etc)

(SHORTALL, 1982; PASHLEY, 1990; TAYLOR & LYNCH, 1992; RASKIN *ET AL.*, 2001), evidenciação de fendas por corantes (YOSHIKAWA *ET AL.,* 2001; ERNST *ET AL.,*2002 A; ERNST *ET AL.,*2002 B; ALONSO *ET AL.,* 2004; ALONSO *ET AL.,* 2006; CORRER *ET AL.,* 2005) e análise em Microscopia Eletrônica de varredura (MEV) (SAHAFI *ET AL.,* 2001; LIM *ET AL.*, 2002; PELIZ *ET AL.*, 2005; DUARTE *ET AL.,* 2005). Considera-se que a avaliação da adaptação das restaurações é melhor determinada pela Microscopia Eletrônica de Varredura, com o uso de réplicas, técnica considerada como "padrão ouro" para avaliação das fendas (SHORTALL, 1982, IWAMI *ET AL.,*2005). A evidenciação das fendas com o uso de corantes foi conduzida por ERNST *ET AL.* (2002 A e B) em cavidades classe II utilizando solução de azul de metileno a 2% durante 10s. A solução de propileno glicol e acido vermelho a 1% (Caries Detector) foi utilizada para detectar fendas por YOSHIKAWA *ET AL.,* 2001; ALONSO *ET AL.,* 2004; ALONSO *ET AL.,* 2006; CORRER *ET AL.,* 2005 . Trata-se de um método mais simples pois detecta fendas ao longo das margens das restaurações com a utilização de corantes por um curto período de tempo (5 a 10 s). O curto período de aplicação do corante permite que sua penetração ocorra por capilaridade apenas nas fendas formadas, previnindo a difusão do corante para dentro da camada de adesivo. Maiores períodos de aplicação poderiam acarretar em nanoinfiltração, atrapalhando a avaliação da formação de fendas. Apesar da facilidade de aplicação desta técnica, algumas dúvidas a respeito de sua eficácia ainda persistem, principalmente devido ao menor aumento utilizado na avaliação das restaurações.

Todavia, apesar da contração de polimerização ser a causa, as tensões por ela geradas são consideradas o mecanismo responsável pelos problemas de união na prática clínica (DAVIDSON & FEILZER, 1997). Dessa maneira, uma vez que a contração de polimerização é uma característica inerente de cada compósito e função direta do seu grau de conversão (ASMUSSEN, 1975), a tensão de contração incidente na interface dente-compósito deve ser encarada como fator a ser reduzido para a manutenção de uma boa integridade marginal das restaurações. DAVIDSON & DE GEE, em 1984, observaram que parte considerável das tensões de contração pode ser compensada pelo acomodamento das cadeias poliméricas durante a cura, o que foi definido pelos autores como escoamento.

Dessa maneira, vários métodos para reduzir as tensões de contração e, por conseqüência, melhorar a qualidade de adaptação das restaurações em compósito foram sugeridos, entre eles estão a redução do volume de compósito aplicado e redução do fator de configuração cavitária de cada incremento (FEILZER *ET AL.,* 1987; DAVIDSON *ET AL.,* 1984; FEILZER *ET AL.,* 1990); o aumento da capacidade de escoamento e flexibilidade dos materiais restauradores (FEILZER *ET AL.,* 1990; UNTERBRINK & MUESSNER, 1995); alteração na formulação dos compósitos (WATTS & HINDI, 1999; PEUTZFELDT, 1997); a inserção criteriosa do compósito na cavidade através da técnica incremental (LUTZ *ET AL.,* 1991); a utilização de materiais com baixo módulo de elasticidade como forradores resilientes (KEMP-SCHOLTE & DAVIDSON, 1990; SAKAGUCHI & BERGE, 1998; UNTERBRINK & LIEBENBERG, 1999), além do uso de técnicas alternativas para a fotoativação de compósitos (KORAN & KÜRSCHNER, 1998; ERNST *ET AL.,* 2000; BOUSCHLICHER *ET AL.,* 2000).

As técnicas alternativas de fotoativação buscam alterar a cinética de polimerização pela modulação da emissão de luz durante a fotoativação dos compósitos (ERNST *ET AL.,* 2000) e, com isso, podem reduzir as tensões que incidem na interface dente-restauração durante a polimerização dos compósitos. Esta modulação pode ser realizada através de fotoativação *soft-start* (dupla intensidade luminosa) pela técnica *pulse delay* ou por luz pulsátil, utilizando aparelhos com lâmpada halógena.

A possibilidade de alteração da cinética de contração está diretamente relacionada à composição da matriz resinosa do compósito, bem como à quantidade e tipo de fotoiniciadores empregados. Compósitos com grande quantidade de fotoiniciadores e monômeros com alto peso molecular, cuja polimerização processa-se rapidamente, tendem a apresentar maior dificuldade em responder adequadamente à modulação da intensidade luminosa[1].

O método *soft-start* consiste na irradiação inicial do compósito com baixa intensidade de luz (o que pode possibilitar a redução da contração de

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polimerização pós-gel e das tensões por ela induzidas), seguida pela exposição à alta intensidade (o que garante grau de conversão adequado) (SAKAGUCHI & BERGE, 1998; SILIKAS *ET AL.,* 2000). Como demonstrado por UNO & ASMUSSEN (1991) e YOSHIKAWA *ET AL* (2001), o método de fotoativação por dupla intensidade pode melhorar a adaptação marginal de compósitos resinosos às paredes cavitárias pela redução da tensão de contração.

O método *pulse delay* é semelhante ao método de fotoativação por dupla intensidade de luz, uma vez que também utiliza ativação inicial com baixa intensidade de luz e complementação com alta intensidade. A diferença é que no método *pulse delay* há um intervalo entre as emissões. Tal intervalo pode permitir maior acomodamento das cadeias poliméricas reduzindo a tensão que incide na interface dente restauração e podendo, portanto, melhorar a adaptação interfacial das restaurações em compósito.

O método pulsátil utiliza luz intermitente para a fotoativação dos compósitos. No período em que a luz está apagada e o compósito não está sendo irradiado, há possibilidade de redução das tensões geradas pela contração de polimerização, como ocorre no método de ativação por dupla intensidade luminosa (OBICI *ET AL*, 2002). A redução destas tensões ocorre devido ao prolongamento do período visco-elástico, o que garante ao compósito maior capacidade de escoamento (MEHL, 1997) e pode permitir melhor adaptação marginal às restaurações ativadas por tal método.

Assim, em vista do problema exposto a respeito da contração de polimerização e da formação de fendas, observa-se a necessidade de pesquisas com o intuito de avaliar as características das restaurações, objetivando a produção de restaurações clinicamente aceitáveis com melhor qualidade marginal, com possível prolongamento de sua longevidade.

Dessa forma, essa tese foi dividida em três artigos[2] que estão contemplados nos capítulos 1, 2 e 3, cujos objetivos foram:

1) O objetivo do primeiro estudo foi determinar a formação de fendas marginais utilizando a técnica do corante para evidenciação das fendas e comparar este método com a avaliação da formação de fendas através da análise em Microscopia Eletrônica de Varredura, para validar o método com uso do corante;

2) No segundo estudo, o objetivo foi verificar os efeitos de diferentes técnicas de fotoativação na adaptação marginal superficial e interna de restaurações confeccionadas com compósitos odontológicos realizadas em dentes permanentes;

3) O objetivo do terceiro estudo foi avaliar a relação entre a formação de fendas marginais e internas e a resistência de união de restaurações em compósito determinada através do teste *push-out*. A influência dos métodos de fotoativação modulados na adaptação marginal e interna e resistência de união também foi determinada.

[2] Este trabalho foi realizado no formato alternativo, com base na deliberação da Comissão Central de Pós-Graduação (CCPG) da Universidade de Campinas (UNICAMP) nº 001/98.

2. CAPÍTULOS

2.1. Capítulo 1

Dye staining gap test: an alternative method for assessing marginal gap formation in composite restorations – Validating the method

Methods for evaluation of marginal gaps

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ABSTRACT

Objective: The aim of this study was to evaluate and compare marginal adaptation of composite restorations assessed by a dye staining method and by a SEM analysis. **Materials and methods:** Twenty bovine incisors were selected and ground flat to expose dentin. Two cylindrical cavities were prepared on the central area of flattened surfaces. Single Bond adhesive system was applied according to the manufactures' instructions and the cavities were filled with Filtek Z250 or Filtek Flow. The specimens were polished and replicas were obtained in epoxy resin. The replicas were observed by SEM for marginal quality/quantity evaluation. Then, Caries Detector was applied on each specimen for 5s to verify marginal adaptation through dye staining of the formed gaps on the outer margins. Images of the stained gaps were transferred to a computer measurement program to determine gap length. The length of the gap was expressed as the percentage of total length of the margins observed. Data were submitted to two-way ANOVA and Pearson correlation. **Results**: Filtek Flow showed 36% and 34% and Filtek Z250 27% and 29% of gap in the margins, when evaluated by SEM analysis and by dye staining test, respectively. There was no difference between the composites, regardless the evaluation technique. There was a strong positive correlation (r=0.83) between the results obtained with the tested methods to assess marginal gap. **Conclusion:** The method of dye staining the gaps can be used to evaluate the gap formation in composite restorations with good reliability.

KEY WORDS: composite restoration, dye, gap, marginal adaptation, SEM.

INTRODUCTION

Composite restorative materials undergo significant volumetric shrinkage when polymerized. The shrinkage that accompanies the polymerization of resin composites generates stress at the tooth-restoration interface and may lead to marginal gap formation [1].

The dimensional stability of the tooth/restoration interface is challenged from the very beginning of the polymerization reaction. The polymerization stress inside and around the restoration can be relieved rapidly by the deformation of the cavity walls around the restorative materials [2] by plastic flow, or over longer periods of time, by water sorption of the material [3]. It can also be reduced by different rupture mechanisms, cohesive inside the material or tooth, or adhesive at the interface. Adhesive failures open margins at the periphery of the restorations [4].

The main determinant factors that determine shrinkage stress, and consequently, gap formation in composite restorations are the polymerization shrinkage level [5,6], the elastic modulus, and the flow capacity of the composite [5]. Other factors that also regulate the gap formation are the configuration factor of the cavity in which the composite is inserted, and the bond strength of the resin composite to the cavity walls [6].

The marginal gap formation does not necessarily correspond to microleakage. However, it is accepted that the detectable marginal gap would lead to interfacial microleakage [7]. *In vitro* microleakage measurements have not been accepted as predictive of restoration failure. Some researchers believe that in vitro microleakage studies overestimate the amount of leakage that will occur clinically, since the molecular size and molecular weight of the tracers are smaller than bacteria or endotoxines that would be responsible for pathosis and secondary caries [8]. The criticism leveled at microleakage studies also include the necessity of destroying the specimen each time a dye assessment is made and difficulties in interpreting staining patterns. The presence of gaps is considered to be more reliable, once it is considered as the first sign of restoration failure [8]. It can be clinically evidenced by marginal staining [9]. Thus, the identification of marginal gaps could enable easier prognosis of the longevity of the composite restorations.

Within the limitations of laboratory studies, quantitative marginal analysis by Scanning Electron Microscopy (SEM) has proven to be an exact and reliable assessment method for the evaluation of the marginal adaptation of adhesive restorations [10]. In contrast to microleakage studies, it is a truly quantitative method that assesses the entire circumference of the tooth-restoration interface. It is also a non-destructive method, allowing marginal qualities to be assessed before and after exposure of the specimens to aging procedures, such as thermal and mechanical loading [8,10]. This evaluation technique suffered because it may be difficult to distinguish experimental gaps vs. specimen damage artifacts formed as a result of sectioning or dehydration, heat, and vacuum required for SEM imaging. However, these latter problems can be overcome to some extent by utilizing replicas [8].

Some SEM studies evaluate the gap width [5,6,11] but the presence or absence of marginal gaps is more relevant than the gap width. The formed gap, regardless the width, is an open door to oral fluids, capable to degrade the dentin-composite interface. It is more reliable to evaluate the marginal gap length along the restorations margins. Reduced gap length could result in reduced length of the margins that are submitted to degradation by oral fluids or penetration of bacteria.

A dye staining gap test was conducted by Ernst et al [12,13] in class II preparations using 2% methylene blue dye solution for 10 s. A 1% red propylene glycol acid solution to detect marginal gap was used by Yoshikawa et al. [14], Alonso et al. [15], Correr et al. [16]. This is a simple method to assess marginal gap formation by dye staining the gaps using reduced dye penetration time (5 s). This short time period of dye penetration allows only a penetration due to capillary action and prevents a diffusion of the dye into the adhesive layer. Longer dye penetration periods would allow a particular look at nano-leakages and not only to marginal gap, but this seems to be only possible in the comparison of adhesives with the same solvent and therefore, with the same solubility [12,13].

However, there is some concern about the accuracy of this evaluation due to the limited magnification used in the evaluation of the results.

Considering that, the aim of this study was to evaluate the marginal gap formation using a dye staining method and compare it to the SEM evaluation, as a gold standard. The hypothesis tested was that there is no difference between the methods for assessing marginal gap formation in composite restorations.

MATERIAL AND METHOD

For this study, it was selected a hybrid composite (Filtek Z250, shade A3, batch # 3AM, 3M/ESPE, St Paul, MN, EUA), a flowable composite (Filtek Flow, shade A3, batch # 1BA, 3M/ESPE, St Paul, MN, EUA) and an adhesive system (Adper Single Bond, batch # 3HR, 3M/ESPE, St Paul, MN, EUA).

Specimen preparation

Twenty bovine incisors were selected, cleaned, and stored in a 0.5% chloramine T solution at 4ºC for no more than a week. The roots were sectioned off 1 mm under the cement enamel junction using a double-face diamond saw (KG Sorensen, São Paulo, SP, Brazil). The buccal surface was ground on a water-cooled mechanical polisher (Metaserv 2000, Buehler, UK LTD, Lake Bluff, IL 60044 - USA) using 80-, 180-, 320-, and 600-grid silicon carbide (SiC) abrasive paper (Carbimet Disc Set, #305178180, Buehler, UK LTD, Lake Bluff, IL 60044 - USA) in order to expose a flat dentin area of at least 8 mm. These teeth were observed in a stereomicroscope (Zeiss, Manaus, AM, Brazil), at 25x magnification, to verify if the enamel has been completely removed.

Two cylindrical cavities (1.8 mm diameter x 2 mm deep) were prepared on the flattened surface, using a cylindrical diamond tip # 2294 (KG Sorensen, São Paulo, SP, Brazil), mounted in a high-speed hand piece (Kavo, Joinville, SC, Brazil), under constant cooling with air-water. The diamond tips were replaced after every 10th preparation.

Internal cavity walls had a 90º angle to the dentin surface plan, while the internal cavity angles were rounded with the diamond used. The cavities had an internal area of 13.87 mm^2 and a free surface area of 2.54 mm^2. The C factor of the cavity was 5.4 and the volume of composite inserted into the cavity was 5.08 mm^3. During the preparation of the cavities, if any pulp exposure was noted at the axial wall, the specimen was discarded.

Restorative procedure

Each specimen was restored using the Single Bond adhesive system (SB), applied in accordance with the manufacturer's instructions: the cavity was etched with 35 % phosphoric acid (H_3PO_4) gel for 15 s, rinsed for 10 s and blot-dried. The adhesive system was applied twice with a five-second interval in between, dried carefully with air to remove the solvent, approximately 15 s (observing a glossy surface), and light cured for 10 s, using the photocuring unit Elipar Tri-light (3M/ESPE) with power density of 800 mW/cm^2.

The cavities were restored using a hybrid composite (Filtek Z250) or a flowable composite (Filtek Flow). The composites were inserted in a single increment and photoactivated for 20 s using the photocuring unit Elipar Tri-light.

After the light curing procedures, the specimens were stored in distilled water at 37°C for 24 hours. The restorations were then finished with 600- and 1200- grid SiC paper under water, and polished with 1 and 0.5 μm diamond paste using a polish cloth under water and ultrasonically cleaning for 30 minutes between the steps of the finishing procedures.

Evaluation of marginal adaptation by SEM

Impressions of the restorations were taken with a low-viscosity polyvinyl siloxane material (Aquasil, Dentsply DeTrey, Konstanz, Germany) and the impressions were poured with epoxy resin (Buehler, Lake Buff, IL, USA). Afterwards, they were gold-sputter coated (Balzers-SCD 050 Sputter Coater, Liechtenstein) and observed by SEM (JEOL, JSM-5600LV, Scanning Electron Microscope, Japan) for evaluation, measurement and classification of the cavity margins. The measurements and classification were made with 200x magnification directly on the microscope monitor, using a multi-point measuring device, observing the entire cavity perimeter in approximately 20 sections [17].

The measurements were recorded and classified in steps of 50 to 150 μm, according to morphologically-defined parameters:

- Perfect margin: defined as a continuous, gap-free transition between filling and tooth substrate (Figure 1A).
- Marginal gap: observed as a gap formation and loss of interfacial adhesion (Figure 1B).

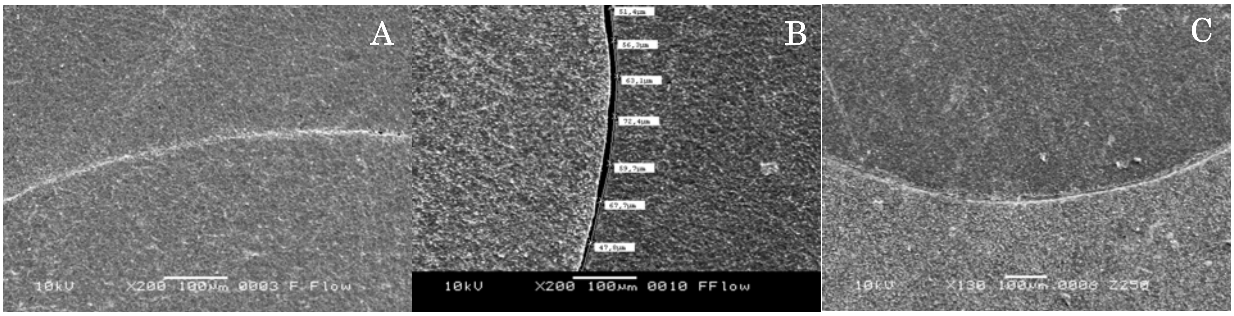

Figure 1. SEM analysis. A – Perfect sealing of the margin; B – Marginal gap measured using a multi-point measuring device of Scanning Electron Microscope; C – Marginal irregularity.

This classification was defined by Kemp Scholte & Davidson [18].

Marginal gap formation was calculate and expressed as percentage of the cavity perimeter of each specimen.

Evaluation of marginal adaptation by dye staining gap test

In order to determine the marginal adaptation at the surface, by a staining technique, a 1.0% acid red propylene glycol solution (Caries Detector, Kuraray Co., Osaka, Japan) was applied at the restoration margins for 5 s [14,15,16]. The specimens were then rinsed in tap water and gently dried. This technique stained the gaps so they could easily be quantified. The cavity margins were evaluated using a stereomicroscope LEICA MZ6 (Leica Microsystems Ltd. Heerbrugg, Switzerland) at x 16 magnification. A digital image of each specimen was obtained at this stage (Figure 2A). The digital image was obtained using a video camera attached to the stereomicroscope and associated to a computer using Pinnacle 9.0 software. The length of dye stained gaps along the cavity margins was measured (µm) from the images using the UTHSCSA Image tool software version 2.0 (alpha 2 – September 1997), developed by the Department of Dental Diagnostic Science at the University of Texas Health Science Center (San Antonio, Texas 78210). The length of the gap formed was calculated as a percentage of the entire margin length.

Statistical analysis

Data of marginal gap formation using the SEM evaluation and the dye staining test were subjected to two-way ANOVA at 5% significance in order to compare the marginal gaps among the groups. Correlation between the results of the tested evaluation methods was obtained by the Pearson Correlation.

RESULTS

Filtek Flow showed 36(±27)% and 34(±25)% and Filtek Z250 27(±26)% and 29(±27)% of gap in the margins, when evaluated by SEM analysis and by dye staining test, respectively. There was no difference in the marginal gap formation between the resin composites, regardless of the evaluation method. Futher, the evaluation method did not influence the results, because there was no difference between the methods, regardless of the resin composite used.

The validation of the dye staining gap test was verified by the concordance between the results of the two methods. There was a strong positive correlation between the methods (SEM analysis using replicas and dye staining gap test). The Pearson Correlation Coefficient was 0.83. The linear correlation is shown in Figure 2.

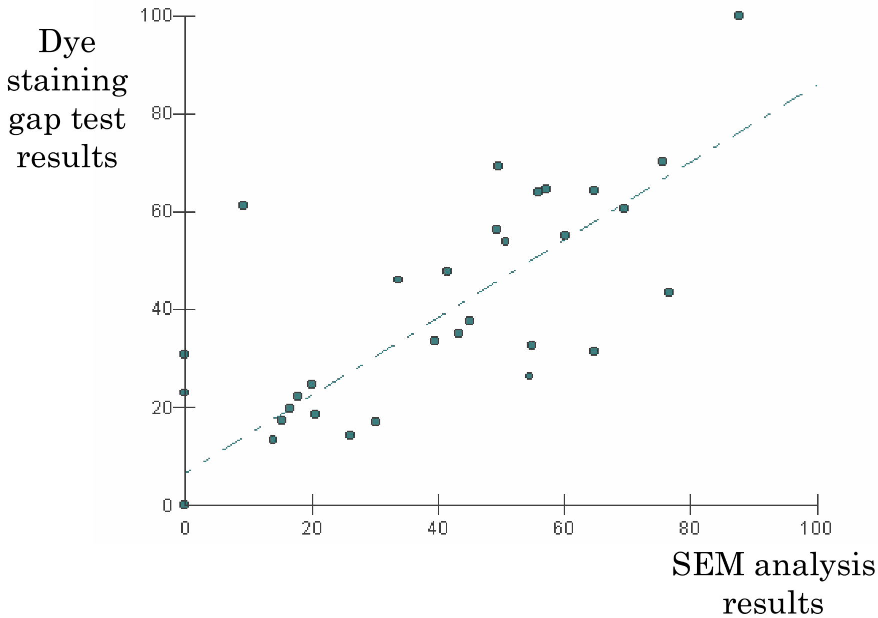

Figure 2. Scatterplot of results of Dye staining test and SEM analysis. Significant correlation was observed (r = 0.83, p<0.001).

DISCUSSION

The work hypothesis was accepted. Marginal adaptation can be evaluated using the dye staining method or the SEM analysis. There is no difference between the results of gap formation observed in these two tests.

An important factor to be considered in the evaluation of marginal gap using any technique is to define exactly what will be considered gap.

In SEM analysis, the gap was considered loss of interfacial adhesion (Figure 1A) due to polymerization shrinkage. This analysis allows distinguishing marginal gaps from marginal irregularities (Figure 1C) or tooth fractures. SEM analysis was conducted in very high magnification (from 37x to 1000x). Doubtful areas can be evaluated in higher magnification, making the evaluation more accurate.

In the SEM evaluation, a counterbalancing relationship of marginal gap and dentin fracture was observed, which demonstrates that the stress due to shrinkage can be relieved when occur marginal gap formations or fractures of the surrounding dentin. In the images of the dyed restorations, the dentin fracture could no be distinguished from the marginal gap formation. The image is not as clear as the SEM photomicrographs. In figures 3A and 3B, a comparison between the restoration images obtained in the Dye Staining test (Figure 3A) and in SEM analysis (Figure 3B) can be done. The SEM image is clearer than the dye staining image.

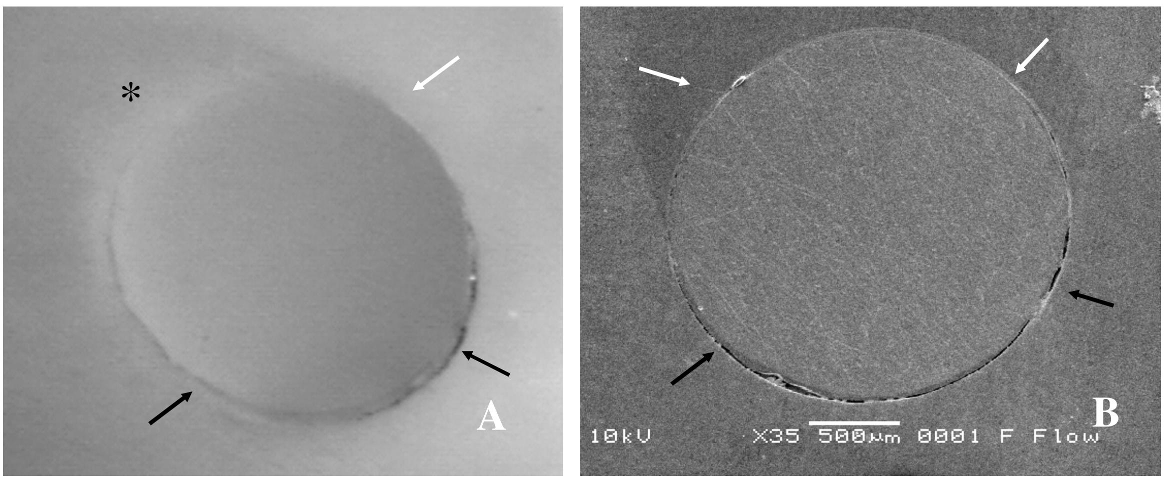

Figure 3 – Images of the perimeter of the restorations. A – Image from dye staining gap test; B – Image from SEM analysis. Black arrows indicate marginal gap and white arrows indicate marginal sealing. Staining of the surrounding dentin is indicated by (*). A common finding in marginal adaptation study is the semi-circumferential gap.

In dye staining gap test, it was decided that all parts of the margin into which the dye had penetrated to turn it dark would be considered a shrinkage gap (Figure 3A). Staining of the surrounding dentin was distinguished from gaps because it was a more diffuse staining (Figure 3A). However, this differentiation is difficult to carry out in a rigorous way and dye staining gap test needs a trained evaluator. In addition, in cases when the restorations margins became only slightly stained, it was considered marginal irregularity, and not a gap. Consequently, only a trained evaluator could reliably estimate the marginal gaps. Marginal irregularity was not included in the analysis of this study because it could not be surely distinguished in the staining gap test. Therefore, the irregularities were considered as a perfect seal in both evaluation methods. However, dye staining test is of easier and faster execution than the SEM analysis because there is no need of scanning electron microscope, or impression and casting procedures.

In dye staining gap test a digital image can be obtained using the video camera attached to a stereomicroscope and associated to a computer using Pinnacle 9.0 software, as in this study, or using a high resolution scanner with 1200 dpi. Less resolution could reduce the quality of the image and turn more difficult the visualization and interpretation of the gaps.

Both methodologies can be adapted to evaluate internal gap formation. In the dye staining gap test, the specimens must be sectioned and the dye applied in the internal margins of the restorations. This method was used by Yoshikawa et al. [14] and Correr et al. [16]. For SEM analysis, the specimen must be sectioned and a replica confectioned from the section.

Marginal adaptation test, regardless the method used, shows high variability data, what is revealed by the high standard deviation observed in all groups. It seams to be a characteristic of this test, especially on dentin substrate, since other studies have also showed the same pattern [14,15,16]. The high variability could be associated with the bonding process, which is influenced by many variables. Within the same group, specimens without gaps and specimens with almost 100% of gaps were found.

In this study, two different types, a flowable and a hybrid, composite were selected. There was no statistical difference between them, regardless the evaluation method used.

Polymerization shrinkage of composites restorations may induce mechanical stresses on tooth structure via bond to enamel and dentin. The magnitude of the polymerization stress depends on the material's composition, stiffness and flowability of the composite, rate of polymerization, the volume of the material to be polymerized, and the geometry of the restorations [19]. The volumetric shrinkage and the elastic modulus have effects on the total stress on tooth structure: the higher the volumetric shrinkage or the higher the elastic modulus, the higher the stress . High polymerization shrinkage could explain why the flowable composite, although it has low elastic modulus, showed restorations with similar marginal gap formation when compared to the restorations using the hybrid composite [20].

Based on the results, dye staining of gaps can be used to assess marginal gap formation with results similar to those found in the SEM analysis.

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Modulated photoactivation methods – effect on marginal and internal gap formation of restorations using different restorative composites

Modulated photoactivation methods on gap formation

Manuscrito aceito para publicação no periódico Journal of Biomedical Materials Research – Part B Applied Biomaterials

ABSTRACT

Objective: This study evaluated the effect of modulated photoactivation methods on gap formation of restorations using different composites. **Methods:** Sixty human third-molars were selected, sectioned (2 fragments) and ground to expose a flat enamel area. A cavity (5 mm long x 2 mm wide x 2 mm deep – C Factor: 3.8 – outer margins in enamel and inner margins in dentin) was prepared on the central area of flattened surface, Single Bond adhesive system was applied according to manufacturers instructions. The specimens were assigned into twelve groups (n=10), according to the restorative composite (Filtek Z250, Herculite XRV, and Heliomolar) and the photoactivation method (Continuous Light-CL; Soft-Start-SS; Pulse Delay-PD; and Intermittent Light-IL). Outer margins were stained using Caries Detector, observed under stereomicroscope, and images were transferred to a computer measurement program. Then, the specimens were sectioned in slices and the internal gaps were assigned using the same method. The length of gaps was expressed as percentage of total length of the margins. Data (internal adaptation) were submitted to ANOVA and Tukey's test. **Results**: All restorations showed perfect seal of the enamel outer margins. Modulated photoactivation methods (SS, PD, and IL) showed a significant reduction on internal gap formation when compared with CL, regardless the composite. Filtek Z250 showed the best internal adaptation, regardless the photoactivation method. **Conclusion:** Modulated photoactivation methods decrease the internal gap formation of composite restorations, and should be encouraged on clinical practice.

KEY WORDS: Composites, photoactivation methods, gap formation

INTRODUCTION

Shrinkage stress in composite restorations is the result of polymerization contraction taking place under confinement that is produced by bonding to cavity walls.[1] Shrinkage stress can generate marginal and internal discontinuity.[2]

Considering the difficulty to avoid gap formation in composite restorations, the use of compensatory mechanisms has been proposed in order to minimize the stress generated by polymerization shrinkage. Therefore, alternative photoactivation methods have been tested.[3-6]

Alternative photoactivation methods intend to modify the polymerization kinetics by the modulation of the power density during the photoactivation of the composites.[3] The objective is to decrease the intensity of stress at tooth /restoration interface. Soft-start, pulse delay and intermittent light are modulated photoactivation methods.

The soft-start method employs an initial light activation at low irradiance followed by a second at a higher irradiance that is typically equivalent to that used in the continuous method. The second irradiation provides to the material sufficient radiant exposure.[1] Yoshikawa *et al.*[6] demonstrated the soft-start photoactivation can increase the adaptation of the resin composites to cavity walls, reducing the shrinkage stress.

The pulse delay photoactivation method is similar to soft-start technique; since a reduced irradiance is applied during the first seconds of light activation, switching to high power density for the remaining curing time. The major difference is the lag period in pulse delay technique. The initial low energy density is enough to allow the start of the polymerization reaction of the composite. In the lag period the polymerization process is slow. At the last stage, a final exposure to high power density guarantees similar physical and mechanical properties to the composite polymerized using continuous light method.[7-9] Lim *et al.* [10] and Witzel *et al.*[11] showed that pulse delay can decrease the intensity of polymerization stress.

The intermittent light photoactivation method was initially reported by Obici *et al.*[5] This method consists of the light activation of the composite in cycles of light on and light off. It was demonstrated that the intermittent light can effectively reduce the polymerization shrinkage.[5] The light-off period could modify the polymerization kinetics of the composite reducing or modifying the distribution of stress, what could reduce the gap formation in composite restorations.[4]

Different formulations of resin composite may behave differently during the light activation using modulated methods. High concentration of initiators, low concentration of inhibitor and high molecular size of the monomer system seems to increase the polymerization rate, what could increase the shrinkage stress of the composites.[11] A study evaluating the effect of low curing rates on shrinkage stress development of three commercial materials found stress reductions between 19 and 30%.[10]

Consequently, it is important to evaluate the effect of modulated photoactivation methods on different composite formulations to ensure the efficiency of such methods.

The aim of this study was to verify the effect of the photoactivation methods on marginal and internal adaptation of composite restorations. The tested hypothesis is that the modulated photoactivation methods will reduce the marginal and internal gap formation in composite restorations.

MATERIALS AND METHODS

For this study were selected three restorative composites on shade A3 and an adhesive bonding system. The materials used in this study are described in Table 1.

Table 1 – Technical profiles and manufacturers of the materials evaluated

Material	Category	Composition	Manufacturer
Filtek Z250	Restorative composite	Bis-GMA; Bis-EMA; UDMA; Inorganic filler – Zircon/silica (60 vol. %); Photo initiator	3M Dental Products, St. Paul, MN 55144, USA
Herculite XRV	Restorative composite	BisGMA/TEGDMA, barium glass filler (50 vol.%), photo initiator, and pigments	Kerr Corporation, Orange, CA 92867, USA
Heliomolar	Restorative composite	Bis-GMA, UDMA and decandiol dimethacrylate, highly-dispersed silicon dioxide, ytterbium trifluoride and copolymer (46 vol.%), catalysts, stabilizers, and pigments	Ivoclair Vivadent, Schaan, Liechtenstein
Adper Single Bond	Adhesive system	Etchant: 35% Phosphoric acid; Adhesive: Aqueous solution of HEMA and polyalkenoic acid copolymer Bis-GMA, photointiator	3M Dental Products, St. Paul, MN 55144, USA

Bis GMA: Bisphenol A-glycidylmethacrylate
Bis EMA: Ethoxylated bisphenol A dimethacrylate
UDMA: Urethane dimethacrylate
TEGDMA: Triethylene glycol dimethacrylate
HEMA: Hydroxyethyl methacrylate

Specimen preparation

Sixty sound human third-molars from patients with age of 18 to 40 years old, extracted for clinical reasons were selected. The teeth were cleaned and stored in a 0.5% Chloramine T solution at 4^{o}C for no more than a month. After removing the roots 1 mm below the cement-enamel junction, the crowns were sectioned in a mesio-distal direction using an ISOMET 1000 machine (Buehler, UK LTD, Lake Bluff, IL 60044 - USA), resulting in a hundred-twenty fragments (buccal or lingual/palatine fragments). The enamel surface of fragments was ground on a water-cooled mechanical polisher (Metaserv 2000, Buehler, UK LTD, Lake Bluff, IL 60044 - USA) using 320-, 400- and 600-grit silicon carbide (SiC) abrasive paper (Carbimet Disc Set, #305178180, Buehler, UK LTD, Lake Bluff, IL 60044 - USA) in order to expose a flat enamel area of at least 6 mm in diameter. The specimens were observed in a stereomicroscope (Carl Zeiss, Manaus, AM, Brazil), at x 25 magnification, to verify if the enamel had remained on the surface.

Cavities (5 mm long x 2 mm wide x 2 mm deep – C Factor: 3.8 - Volume of composite inserted into the cavity: 20 mm^3) were prepared on the central area of the flattened enamel surfaces. These cavities were made using a cylindrical diamond (# 2143; KG Sorensen Indústria e Comércio Ltda, São Paulo, SP, Brazil), mounted in a high-speed hand piece (Kavo, Joinville, SC, Brazil), under constant air-water cooling. To achieve a uniform cavity size, the handpiece was mounted in a cavity standardization device. The diamonds were replaced after every 10^{th} preparation.

Internal cavity walls had a 90^{o} angle to the enamel surface plan, while the internal cavity angles were rounded with the diamond used.

The specimens were randomly assigned into twelve groups (n=10), according to the restorative composite and the photoactivation method (Table 2).

The Single Bond adhesive system was applied in accordance to the manufacturer's instructions: the cavity was etched with 35 % phosphoric acid gel for 15 s, rinsed for 10 s. The water excess was removed using absorbent paper, resulting in a glossy surface (wet technique). The adhesive system was applied twice with a five-second interval in between, dried carefully with air to remove the solvent, approximately during 5 s (observing a glossy surface), and light cured for 10 s with continuous light at 600 mW/cm^2, using the light-curing unit Degulux Soft Start (Degussa-Hülls, Hanau, Germany). The restorative composites were bulk inserted into the cavities and photocured according to the photoactivation methods (Table 2).

The curing unit used in this study to the light-curing of the restorative composites was an experimental curing unit developed in Dental Materials Department, Piracicaba Dental School, UNICAMP. The experimental curing unit was assembled from a commercial curing unit (Degulux Soft Start – Degussa-

Hülls, Hanau, Germany) that uses halogen light. This unit was adapted to an electric circuit that allows a cyclic irradiation (the time of the cycle can be adjusted) or continuous irradiation with power density of 600 mW/cm^2 (when the electric circuit is turned off).

Table 2 – Description of the photoactivation methods.

Photoactivation Method *	Irradiance and Time exposure
Continuous Light (CL)	600 mW/cm^2 during 20 s for Filtek Z250 and during 40 s for Herculite XRV and Heliomolar
Soft-Start † (SS)	150 mW/cm^2 during 10s + 600mW/cm^2 during 18s for Filtek Z250 during 38s for Herculite XRV and Heliomolar
Pulse Delay † (PD)	150 mW/cm^2 during 5s + 3 min light off + 700mW/cm^2 during 19s for Filtek Z250 and during 39s for Herculite XRV and Heliomolar
Intermittent Light (IL)	600mW/cm^2 (3s light on + 3s light off) during 48s for Filtek Z250 and during 96s for Herculite XRV and Heliomolar

* The energy dose applied for all groups was 12 J/cm^2 for Filtek Z250, and 24 J/cm^2 for Heliomolar and Herculite XRV. The curing unit used in this study was Degulux Soft Start (Degussa-Hülls, Hanau, German) adapted to an electric circuit, that can emit intermittent light when it is turned on.
† The reduction of the power density in these groups was obtained using a standard separator.

Afterwards, the specimens were stored in distilled water at 37°C for 24 h and then finished and polished in a water-cooled mechanical polisher (Metaserv 2000, Buehler, UK LTD, Lake Bluff, IL 60044 - USA), using 600- and 1200- grid SiC sandpaper (Carbimet Disc Set, #305178180, Buehler, UK LTD, Lake Bluff, IL 60044 - USA).

Marginal and internal adaptation evaluation

In order to determine the marginal adaptation at the surface, a 1.0 % acid red propylene glycol solution (Caries Detector, Kuraray Co., Osaka, Japan) was applied at the restoration margins for 5 s. This technique has been employed to evaluate gap formation, not microleakage. [4,6,12,13,14] As concluded by Alonso *et al* [12], the gap formation observed using the dye staining technique with Caries Detector is comparable to the gap formation observed in scanning electron microscopy, confirming the efficacy of methodology used in this study to evaluate gap formation.

After the dye staining, the specimens were then rinsed in tap water and gently blown dry. This technique stained the gaps, so they could easily be quantified. The cavity margins were evaluated using a stereomicroscope LEICA MZ6 (Leica Microsystems Ltd. Heerbrugg, Switzerland) at x 16 magnification. A digital image of each specimen was obtained at this stage, using a video camera attached to the stereomicroscope and associated to a computer using Pinnacle 9.0 software. The length of dye stained gaps along the cavity margins was measured (µm) from the images using the University of Texas Health Science Center of San Antonio (UTHSCSA) Image tool software version 2.0 (alpha 2 – September 1997), developed by the Department of Dental Diagnostic Science at the University of Texas Health Science Center (San Antonio, Texas, USA). The length of the marginal gap formed was calculated as a percentage of the entire margin length.

On the second part of this study, after the evaluation of the marginal adaptation at the surface, the restorations were cut in cervical-occlusal direction, in slices (1 mm thick), using an ISOMET 1000 machine (Buehler, UK LTD, Lake Bluff, IL, USA), to obtain 3 slices of each restoration. On these slices Caries Detector was applied to stain the internal gaps and the same procedures described previously were accomplished for the evaluation of the internal adaptation of the composite restorations. The percentage of internal gap of each slice was considered to obtain a mean of each specimen. The obtained data (internal adaptation) were transformed (arc-sen x/100) and submitted to ANOVA (two way analysis) and Tukey’s tests at 5 % significance.

RESULTS

Perfect seal of outer enamel margins was observed in all groups.

Concerning the internal adaptation, ANOVA test detected a statistically significant difference among the groups. The factors restorative material and photoactivation technique were individually significant ($p<0.05$). The interaction between restorative materials and photoactivation methods were not significant ($p>0.05$), what means that all composites showed similar behavior in face of the photoactivation methods. The results, according to the Tukey´s test, are listed in Figures 1 and 2.

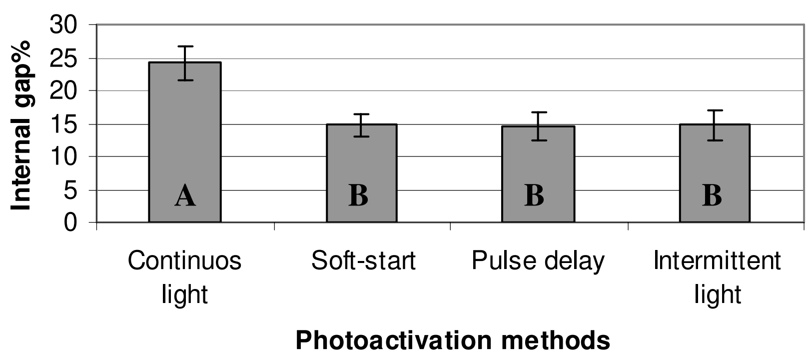

Figure 1. Percentage of internal gaps comparing different photoactivation methods, regardless of the restorative composite. Vertical bars indicate Standard Deviation. Different letters indicate statistical differences.

The influence of photoactivation methods on internal gap formation is demonstrated in Figure 1. Continuous light caused the highest level of internal gaps on the restorations. Modulated photoactivation methods (soft-start, pulse delay, and, intermittent light) showed a significant reduction on internal gap formation when compared with continuous light method, regardless the restorative composite. There was no significant difference among soft-start, pulse delay, and, intermittent light groups.

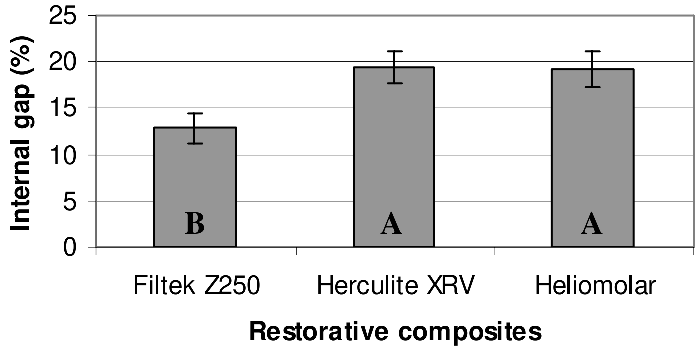

Figure 2. Percentage of internal gaps comparing different restorative composites, regardless of the photoactivation method. Vertical bars indicate Standard Deviation. Different letters indicate statistical differences.

Figure 2 shows that the restorations filled with Filtek Z250 showed a significant reduction on internal gap formation when compared to the restorations filled with Herculite XRV and Heliomolar, regardless the photoactivation method. There was no significant difference between the restorations filled with Herculite XRV and Heliomolar.

DISCUSSION

In this study, all restorations showed perfect seal of the outer enamel margins regardless the photoactivation technique or the material employed. The marginal adaptation was not affected by high stress situations, as light curing using continuous light of high power density.

Cavities with only enamel outer margins were selected in order to render homogeneous distribution of the shrinkage stress [13]. Cavities with outer margins partially located in enamel and partially located in dentin show the tendency to produce asymmetric stress, harming the bonding to dentin. In addition, in this study, the tooth/restoration interface was not submitted to any other kind of stress unless the shrinkage stress. Therefore, the effects of the modulated photoactivation methods could be evaluated without the interference of other factors that also could cause or increase gap formation.

No effect of the photoactivation methods or the material employed on marginal adaptation was observed. The main point in marginal adaptation seems to be the efficacy of the adhesive bonding system, what is revealed by a high-quality of the bond between tooth structure and resin composite.[16]

Conversely to the perfect marginal seal of all restorations, the evaluation of the internal adaptation showed the presence of gaps in most of the cavities. The internal margins were mainly located in dentin. Flaws in dentin bonding has already been extensively documented.[17-19]

The internal gaps were specially situated at the pulpal wall and axiopulpal angles, which are stress concentration regions, and a problematic zone for the composite application.[13] The presence of gaps at the pulpal wall and axiopulpal angles could cause fluid flow in the dentin tubules, resulting in a typical post-operative sensitivity.[20]

In contrast to the lack of statistical difference among the photoactivation methods in the outer enamel surface, a significant reduction in the internal gap formation was observed for the modulated photoactivation methods, regardless the type of composite (all composites showed similar behavior in face of the modulation of the power density during photoactivation). In the internal part of the restoration, shrinkage stress is in general released by gap formation,[20] and, when the stress is reduced, the adaptation to internal walls can be increased. The tested hypothesis was partially accepted; modulated photoactivation methods reduced the internal gap formation in composite restorations and no effect on marginal adaptation was observed. The reduction on internal gap formation seems to be result of the reduction of shrinkage stress using soft-start, intermittent light and pulse delay technique.[21]

Reduction on gap formation using modulated photoactivation methods was reported in previous studies.[4,5] However, these studies have not used the same energy dose when compared modulated photoactivation methods to continuous light. Alterations in energy dose can alter degree of conversion, and, consequently, volumetric shrinkage, shrinkage stress, gap formation, and mechanical properties since all these parameters are related. In this study, the same energy dose was used for all the photoactivation methods, within the same composite (12 J for Filtek Z250 and 24 J for Herculite XRV and Heliomolar). The selection of the energy dose of each composite was based on manufactures instructions, and supported by Calheiros *et al.*[22] Previous studies [23,24] have found a statistical equivalence in the degree of conversion for different photoactivation protocols for the combinations of exposure time and irradiance within the same total dose. Therefore, it can be concluded that the reduction on gap formation is consequence of the modulation of the power density.

Using intermittent light, the photoactivation is developed in cycles, inserting intervals of light on and light off.[4,5,21] As a result, the periods of light absence broaden the viscous-elastic stage of the composite, promoting lower stress generation, what had as ultimate consequence the reduction in internal gap formation. Regarding the intermittent light, it is important to point out that the calculus of the energy dose considered the energy loss during each cycle.[4] The energy loss occurs because, in each cycle, when the light turns on, it takes 0.7 s to reach 600 mW/cm^2, consequently during this period the energy is reduced. Full power density (600 mW/cm^2) is applied to the composite only during 1.3 s in each light cycle, as described by Alonso *et al.*[4]

Soft-start technique has also improved the internal adaptation. Such results could be related to the increased ability of the composite to flow. This phenomenon is caused by the slower formation of polymer network and cross-links, which supply favorable conditions to the adaptation of molecules within the polymeric chain that has been developed. Ernst *et al.*[3] found that the soft-start polymerization can significantly reduce polymerization stress.

The pulse delay photoactivation method is a variation of the soft-start technique. According to Lim *et al.*[10] the pulse delay photoactivation method provides a reduction of polymerization contraction stress in dental composites, without significant reduction on degree of conversion. They have also stated that the initial power density of 150 mW/cm^2 is too high to significantly reduce the shrinkage stress. In this study, however, even using 150 mW/cm^2 during 5 s, the internal gap formation has decreased significantly. Such results could be related to the reduction on shrinkage stress due to slower curing rate. The introduction of a delay into the early portion of the light-curing routine may prolong the low modulus phase, allowing the stress development to be relieved by polymer flow and deformation[1], while maximizing both degree of conversion and shrinkage that occurred before the composite became predominantly rigid, elastic solid.

Conversely to modulated methods, in continuous high intensity method, the fast reaction rate virtually eliminates the time allowed for viscous flow, and it is estimated that the polymer matrix become 'rigid' within few seconds after a relatively low degree of conversion.[25] As a result, stress begins to build-up almost immediately after polymerization is triggered and nearly all of the shrinkage occurs after the polymer matrix has reached a significant level of rigidity. Consequently, the stress imposed to cavity walls is higher, culminating in gap formation in order to release this stress.

Comparing the different restorative composites, a significant reduction on internal gap formation was observed when Filtek Z250 was compared to Herculite XRV and Heliomolar. Filtek Z250 shows a high inorganic loading (60% in volume) and a monomer system based high molecular weight monomers (BisGMA, BisEMA, UDMA). In addition, the practical elimination of the diluent monomer TEGDMA contributes to the reduction of volumetric shrinkage. The formulation of the Filtek Z250 composite results in a final shrinkage of 2.2%, according to manufacturer's information. It was certainly an important point for the best internal adaptation. At this point, it could be speculated that the energy dose delivered to Filtek Z250 was lower than that delivered to Herculite XRV and Heliomolar, and it could result in a less cured composite, with lower degree of conversion. However, Filtek Z250 shows a high concentration of photo-initiators and high molecular weight oligomers, resulting in a significant conversion after 20 seconds of light exposure,[23] different from the other composites. However, it should be considered that the higher energy dose delivered to Herculite XRV and Heliomolar could increase the degree of conversion and the polymerization shrinkage. Also, more energy induced more thermal energy and more thermal expansion, what could have resulted in more thermal shrinkage when the material cools down to room temperature, resulting in higher gap formation for Herculite XRV and Heliomolar.

In conclusion, the tested hypothesis was partially validated by the results. In spite of the lack of statistical difference among the photoactivation methods in the marginal adaptation test, the internal gap formation was significantly reduced by the modulated methods. It remains to be seen if these advantages could associate the modulated curing methods with significantly higher longevity and better clinical performance of composite restorations.

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2.3. Capítulo 3

Relationship between bond strength and marginal and internal adaptation of composite restorations photocured by different methods

Bond strength and gap formation of restorations

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ABSTRACT

Objective: This study evaluated the relationship between bond strength and marginal and internal restoration adaptation of composite restorations photocured using different methods with a quartz-tungsten-halogen light. **Material and methods:** A push-out test was performed to evaluate bond strength of conical restorations in 50 bovine incisors. To evaluate marginal (external) and internal restoration adaptation, 50 circular all-enamel margin preparations were made in bovine incisors. For both tests, the preparations were filled with Esthet•X resin composite. Specimens were distributed into 5 groups (n=10), according to photoactivation method: G1 – Continuous light 700; G2 – Continuous light 150; G3 – Soft-start; G4 – Intermittent light; and G5 – Pulse delay. The energy density for each method was standardized: 14J/cm². Caries Detector® (Kuraray) was placed into restoration margins for detection of marginal adaptation. The percentage of interfaces present as gaps was determined using digital images. Specimens were then sectioned, stained, and the internal adaptation was recorded in a similar manner. Data were submitted to ANOVA and the Tukey HSD test, pre-set α=0.05. **Results:** Regarding bond strength, G5 (7.2MPa ± 1.3) was significantly greater (p=0.00280) than G1 (4.6MPa ± 1.5). G2, G3, and G4 showed equivalent, intermediate strength values. No significant difference was found among marginal adaptation of all groups (p=0.16911). Internal adaptation results were the inverse of strength results: G5 (2.8% ± 4.9) showed significantly less (p=0.00979) gap formation compared to G1 (10.1% ± 6.2). **Conclusion:** Some modulated photocuring methods can increase bond strength while decreasing internal gap formation. An inverse relationship was found between push-out bond strength and internal adaptation. Marginal adaptation was not affected by any photoactivation method.

KEY WORDS: Bond strength, composites, gap formation, stepped polymerization.

INTRODUCTION

Light cured resin composites have become the material of choice to directly restore anterior and posterior teeth. However, these materials undergo significant volumetric shrinkage when polymerized [1]. *In vitro* measurements of composite polymerization range from 1.9% to 6% [2]. Placement and bonding of composites into preparations induces development of mechanical stress inside the material as well as at the bonded interface. [3] Stress is also transmitted via bonded interfaces to tooth structures [3]. The rapid conversion rate in light cured composites quickly induces increase in composite stiffness, causing high shrinkage stresses at the bonded interface [4]. This stress may disrupt bonding between the composite and the preparation walls, or may even cause cohesive failure of either the restorative material or the surrounding tooth tissue [3,4]. This stress development is the main cause of marginal failure and subsequent leakage in resin composite restorations [5].

Compensatory curing methods to counteract stress development have been proposed. Minimizing stress may potentially reduce gap formation [1,5-7]. These alternative photoactivation methods (modulated polymerization) have been shown beneficial effects [7-12]. Reduction in curing rate results in slower development of composite stiffness, allowing the material to flow instead of become rigid, thus reducing shrinkage stress [9,11,13]. Previous studies [1,14] have shown that marginal adaptation of composites can be improved by light curing using a low power density. Conversely, high light intensity is necessary to achieve deep and maximal polymerization of the material [15]. Therefore, modulated photoactivation methods, such as soft-start, intermittent light, and pulse-delay have been proposed [7-12].

Resin composites photocured using the soft-start technique demonstrate substantially lower viscosity increase, allowing more material flow during the earlier stages of curing, while keeping the total exposure time reasonably short [7,10]. Soft-start photoactivation has been shown to provide better cavo-surface marginal adaptation of composite restorations [7]. This photoactivation method affects shrinkage, surface hardness, and residual monomer concentration in a similar manner as conventional, continuous higher intensity photoactivation, as long as the total energy dose is the same [8,13].

The intermittent light photoactivation method consists of cyclic application of light on-and-off periods (a continuous pulse). This method has been shown to effectively reduce polymerization shrinkage. The light-off period may modify polymerization kinetics by reducing or modifying the distribution of stress [16].

The pulse-delay photoactivation method is a combination of low energy density application followed by a lag period (delay) before a final high power density exposure is provided [17,18]. The initial, low energy density provides enough light to allow the polymerization reaction to start. During the delay period, the polymerization process is slow, because no new radicals are forming, and the reaction progresses as a result of the “dark cure” reaction [19]. At the last stage, a final light exposure to high power density ensures maximal composite cure, thus providing similar physical and mechanical properties to the restoration as if it was cured using a continuous light exposure method [17].

The ultimate goal of a composite restoration is to ensure the biomechanical integrity of the tooth: this goal implies achieving and maintaining proper function over time. Such result also is derived from satisfactory marginal and internal restoration/tooth adaptation. The presence of gaps is considered the first sign of restoration failure, and can be clinically demonstrated by marginal staining. Thus, identification of early marginal changes could determine the prognosis for longevity of composite restorations.

The presence of internal gaps between the material and tooth structure causes fluid flow in the dentin tubules, resulting in a typical post-operative sensitivity. It is very important to enhance the adhesion between dentin and resin composite because such improved bond strength not only could prevent post-operative sensitivity, but also could lead to better restoration retention.

The relationship between bond strength and gap formation is a controvert issue in the literature [20]. Intuitively, it seems that when bond strength is increased, the ability of the material to withstand those forces that might stress the interface and disrupt the adaptation of restorative material to the cavity walls would be enhanced. However, several studies [6,21-23] showed absence of relationship between higher bond strength and improved marginal seal or decreased microleakage levels. The lack of relationship between improved bond strength and reduced gap formation is explained on basis on bond maturation [20]. Most of bond strength tests use preparations with C factor about 0.2, compared to the C factor of 3 to 5 in typical Class V, I, or II cavity preparations [24,25]. Therefore, the increased polymerization shrinkage stress encountered in cavity preparations could cause bond disruption that might not occur in the bond strength specimen. Also, polymerization shrinkage forces will occur very rapidly and stress the bond before it has the opportunity to mature [26], causing bond disruption that will result in early gap formation [20].

The purpose of this research was to evaluate the influence of alternative (modulated) photoactivation techniques (continuous low power, soft-start, intermittent light, and pulse-delay) on marginal and internal adaptation of resin composite restorations and on bond strength of composite restorations using push-out test when each treatment, as well as the control, received the same total energy density dose. In control group, the specimens were subjected to conventional intensity and continuous light. It was hypothesized that the alternative methods would significantly reduce marginal and internal gap formation and increase bond strength values relative to the control. It was further hypothesized that there would be an inverse relationship between push-out bond strength values and marginal and internal gap formation.

MATERIAL AND METHODS

Marginal and internal adaptation

Fifty bovine incisors were selected and cleaned immediately after the extraction. They were stored in a 0.5% aqueous solution of Chloramine T (Mallinckrodt Baker Brazil, 04795-100, São Paulo, Brazil) at 4^{o}C for no more than a week to avoid bacterial growing. After removing the root portion 1mm below the cemento-enamel junction, the buccal tooth surface was ground to provide at least a 6 mm diameter flat area using a water-cooled mechanical polisher (Minimet

1000, Buehler Co., UK LTD, Lake Bluff, IL, USA) using 320-, 400- and 600-grit silicon carbide (SiC) abrasive paper (Carbimet Disc Set, #305178180, Buehler, UK LTD, Lake Bluff, IL, USA). The teeth were examined under a stereomicroscope (Zeiss, Manaus, AM, Brazil) at 25X to verify that only enamel was present on the surface.

Preparations (4 mm diameter x 1.5 mm deep) were prepared in the central area of the flattened surfaces using a round tip diamond bur (# 3053; KG Sorensen, São Paulo, SP, Brazil), mounted in a high-speed hand piece (Kavo, Joinville, SC, Brazil), under constant air-water cooling. The burs were replaced after every 10th preparation.

Internal preparation walls were 90^{o} to the enamel surface plane, while the internal line angles were rounded using the diamond end. The C-factor of the preparation was calculated to be 2.5 and the volume of composite inserted into the cavity was 18.84 mm^3. The specimen was discarded if any pulp exposure was noted at the axial wall during preparation.

An adhesive system (Single Bond, lot# 4KF, 3M/ESPE Dental Products, St. Paul, MN, USA) was applied in accordance with manufacturer's instructions. Preparation walls were etched with 35% phosphoric acid (H_3PO_4) gel (lot # 4CB, 3M/ESPE Dental Products, St. Paul, MN, USA) for 15s, rinsed for 10s, and blotted dry using absorbent paper. The adhesive system was applied twice with a five-second interval in between, dried carefully for 15s with air to remove solvent, and light cured for 10s using a quartz-tungsten-halogen light curing unit (XL 2500, 3M/ESPE Dental Products, St. Paul, MN, USA). The power density of the light was measured using a hand-held curing radiometer model 100 (Demetron Research Corp., Danbury, CT, USA) and found to be 700 mW/cm^2. Power density readings were performed throughout the experiment to ensure proper light performance. A commercial hybrid composite (Esthet-X, shade A3, lot # 0308112, Dentsply De Trey, Konstanz, Germany) was inserted in a single increment, and a Mylar strip was placed over the composite. A microscope slide was used to force the composite into the preparation and to extrude the excess of the material. Then, the slide was removed and light-curing tip placed against the Mylar strip. The teeth were randomly assigned into five groups (n=10), according to the photoactivation method, and exposure duration was adjusted to provide equivalent energy density dosages among treatments: 14 J/cm^2 (Table I).

Table I – Description of the photoactivation methods.

Photoactivation Method *	**Light Curing Unit**	**Power density and Exposure duration**
Continuous Light 700	XL 2500, 3M-ESPE	700mW/cm^2 during 20s
Continuous Light 150	XL 2500, 3M-ESPE †	150mW/cm^2 during 94s
Soft-Start	XL 2500, 3M-ESPE †	150mW/cm^2 for 10s + 700mW/cm^2 for 18s
Pulse- Delay	XL 2500, 3M-ESPE †	150mW/cm^2 for 5s + 3 min with light off + 700mW/cm^2 for 19s
Intermittent Light	Optilux 150, Demetron, adapted ‡	600mW/cm^2 (2s light on + 2s light off) for 56s

* The energy density dose applied for all groups was 14 J/cm^2.

† The reduction of the power density in these groups was obtained using a standard separator.

‡ This photoactivation method used an experimental curing unit developed in Dental Materials Department, Piracicaba Dental School, UNICAMP. The unit was assembled from a commercial curing unit (Optilux 150 – Demetron) that uses a halogen light. This unit was modified electronically to provide cyclic, pulsed irradiation (2s light on and 2s light off).

The intermittent light photoactivation method used an experimental curing unit developed in Dental Materials Department, Piracicaba Dental School, UNICAMP. The unit was assembled from a commercial curing unit (Optilux 150 – Demetron) that uses a halogen light. This unit was modified electronically to provide cyclic, pulsed irradiation (2s light on and 2s light off). [9,16]

The other photoactivation methods were conducted using the curing unit XL2500 (3M/ESPE). The power density of 150 mW/cm^2 used in the soft-start and pulse delay photoactivation methods was obtained using a standard separator (black acrylic cylinder of 1.2 cm in height and 1.0 cm in diameter).

After light curing, specimens were stored in distilled water at 37°C for 24h and then finished and polished under running water using 600- and 1200- grid SiC sandpaper.

In order to determine surface marginal adaptation, a 1.0% acid red propylene glycol solution (Caries Detector®, Kuraray Co., Osaka, Japan) was applied at the restoration margins for 5s [7,9]. Specimens were then rinsed in tap water and gently blown dry. This technique stained any gaps so they could easily be quantified. Margins were evaluated using a stereomicroscope (MZ6, Leica Microsystems Ltd. Heerbrugg, Switzerland) at 16X. A digital image of each specimen was obtained. The accumulated length of dye-stained gaps along the restoration margins was measured (µm) from the images using software developed by the Department of Dental Diagnostic Science at the University of Texas Health Science Center (San Antonio, Texas 78210) (v2.0 – September 1997),. The length of the gap formed was calculated as a percentage of the entire margin length.

After the evaluation of surface marginal adaptation, the restorations were cut into 1 mm-thick sections in a bucco-lingual direction using a water-cooled saw (ISOMET 1000, Buehler, UK LTD, Lake Bluff, IL, USA), to obtain 2 slices of each restoration. The Caries Detector® solution was applied to the internal restoration margins to identify interfacial gaps in a similar manner as that described above for marginal adaptation.

Marginal adaptation data were transformed (arc sen$\sqrt{x/100}$) due to the abnormal distribution of the data and submitted to ANOVA (pre-determined significance level of 5%) Internal adaptation data were submitted to ANOVA and the Tukey HDS post-hoc test at a pre-determined significance level of 5%.

Push-out bond strength

Fifty bovine incisors were selected and cleaned immediately after the extraction. They were stored in a 0.5% aqueous solution of Chloramine T at 4^{o}C for no more than one week. The crowns were cut off at the cement-enamel junction using a double-faced diamond disk (KG Sorensen, São Paulo, SP, Brazil) (Figure 1A).

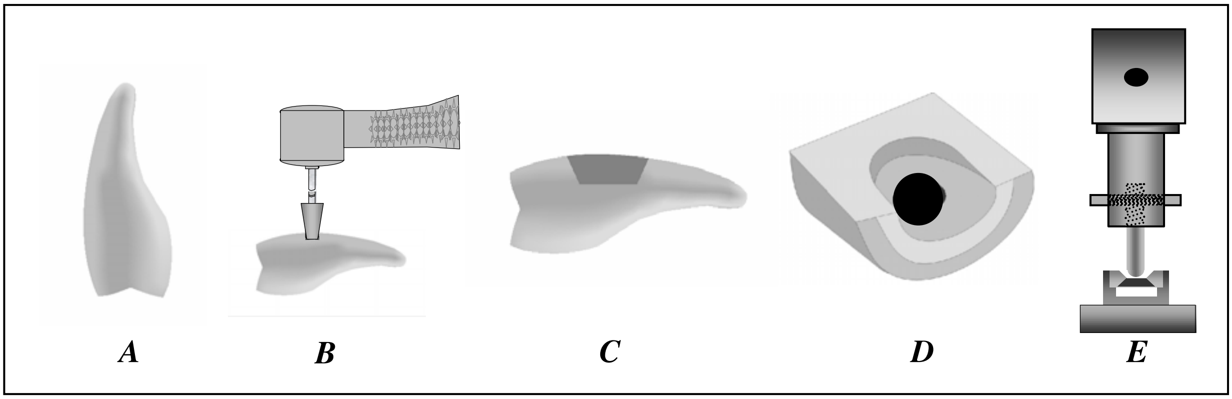

Figure 1. Schematic representation of the "push-out" test: ***A.*** Tooth crown; ***B.*** Preparation made using a specialized appliance; ***C.*** Lateral view of the restored specimen (2.0 mm in height, facial diameter 5.0 mm, and lingual diameter 4.0 mm); ***D.*** Selective removal of the lingual surface to expose of the axial wall the restoration; ***E.*** Lateral view of the specimen showing the direction of specimen push-out.

Conical preparations (top diameter of 5.0 mm, bottom diameter of 4.0 mm, and 2.0 mm in height Figure 1C) were prepared in the buccal surface of each tooth using a diamond tipped bur (#3131; KG Sorensen, São Paulo, SP, Brazil), mounted in a high-speed hand piece (Kavo, Joinville, SC, Brazil), under constant air-water cooling in a standard cavity preparation appliance (Figure 1B). The diamond burs were replaced after every 10th preparation. The C-factor of the preparation was calculated to be 2.2 and the volume of composite inserted into the cavity was 31.87 mm^3.

The similar restorative procedure was performed as described above for the marginal and internal adaptation tests, using an adhesive system (Single Bond, lot # 4KF, 3M/ESPE Dental Products, St. Paul, MN, USA) in accordance with the manufacturer's instructions. A commercial hybrid composite (Esthet•X, shade A3, lot # 0308112, Dentsply De Trey, Konstanz, Germany) was placed in a single increment (Figure 1C). The specimens were randomly assigned into five groups (n=10), according to photoactivation method and exposure duration (Table I).

After applying the light curing procedures, specimens were stored in distilled water at 37°C for 24h and then finished (Sof-Lex, 3M/ESPE Dental Products, St. Paul, MN, USA) on the enamel surface to remove excessive material.

A diamond tip bur (3017HL, Fava Metalúrgica, São Paulo, SP, Brazil) was used to selectively remove the lingual face of the crown, with the goal to expose the bottom (axial) surface of the restoration. The mesial and distal crown segments on the lingual surface were preserved to reinforce the specimen (Figure 1D).

A push-out bond strength test was performed. An acrylic device with a central hole was attached to the base of a universal testing machine (Instron, model 4411, Buckinghamshire, England). The central hole was used to control specimen positioning with the restoration bottom side up (smaller diameter of the preparation). A round stainless steel tip (2 mm diameter) was attached to the upper, movable member of the testing machine (Figure 1E). This tip applied a compressive force at a rate of 0.5 mm/min on the exposed, bottom (axial) surface of the restoration to force the restoration out in a facial direction. The results were recorded in units of force, and converted into units of stress (MPa) by dividing by the remaining, conical specimen bonded area.

After the test, the fractured specimens were examined under a stereomicroscope at 40X (Carl Zeiss, Manaus, AM, Brazil) and classified as to the characteristic of failure: cohesive failure in composite, cohesive failure in dentin, adhesive failure, or mixed. Bond strength values were subjected to ANOVA and Tukey's HSD post-hoc test at a pre-determined significance level of 0.05.

RESULTS

Experimental results and their statistical comparisons are presented in Figure 2. None of the photoactivation methods provided a totally intact margin: all methods demonstrated marginal gap formation. None of these values were significantly different, however. Thus, photoactivation method had no significant influence on marginal adaptation.

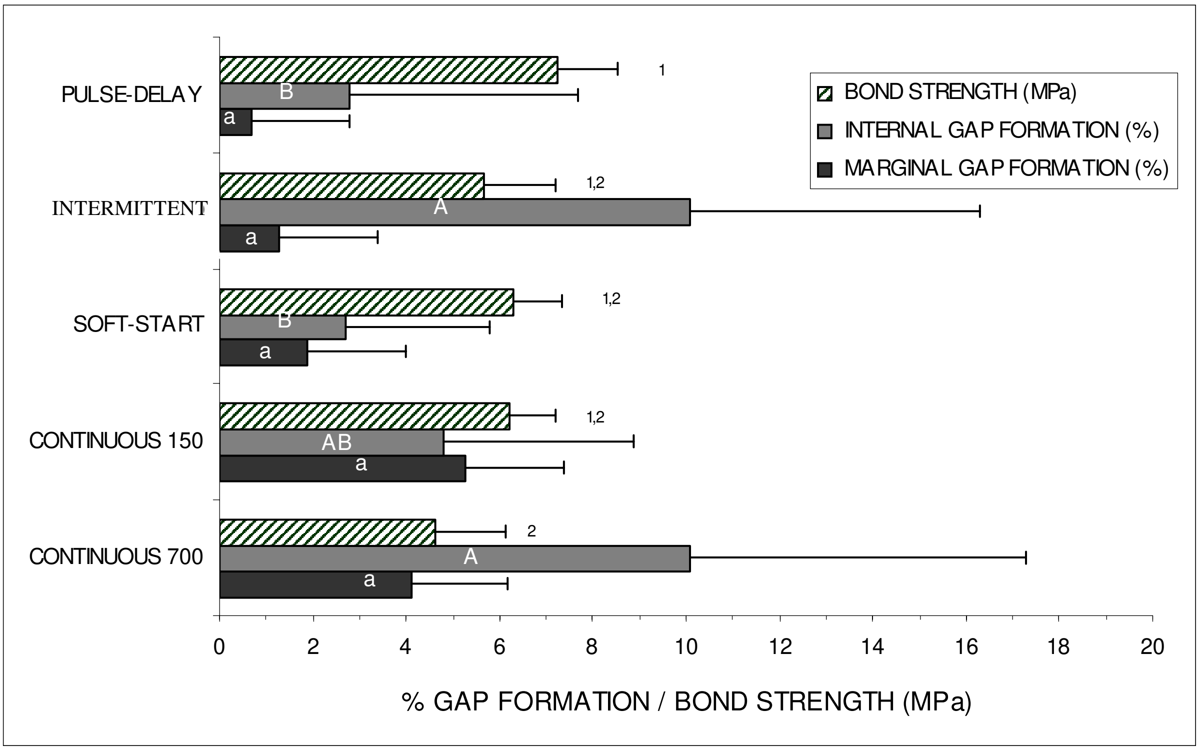

Figure 2. Results of parameter studies (mean (SD), horizontal bar +1 = standard deviation). Bars for parameter results containing similar codes (small case letter, upper case letter, or number) are not statistically different within that parameter

Significant differences among curing methods were noted for internal adaptation. Pulse-delay and the soft-start methods resulted in the least gap formation. The highest internal gap formation values were found when using continuous light 700 and the intermittent light techniques, that were equivalent. Specimens exposed to the low power, continuous method showed gap formations not significantly different from either of the two extremes just mentioned.

The pulse-delay method showed the highest push-out strength value (7.3 ±1.3 MPa) (Figure 2). This method, however was also not different from those seen using soft-start (6.3 ±1.1 MPa), continuous low power density (7.3 ±1.3 MPa), or pulsed light (5.7 ±1.6 MPa). Continuous exposure using 700 mW/cm^2 resulted in the lowest strength value (4.6 ±1.5 MPa), but was not different from the previous mentioned three methods. From this Figure, it can also be seen that there is an inverse relationship between internal adaptation values and push-out bond strength.

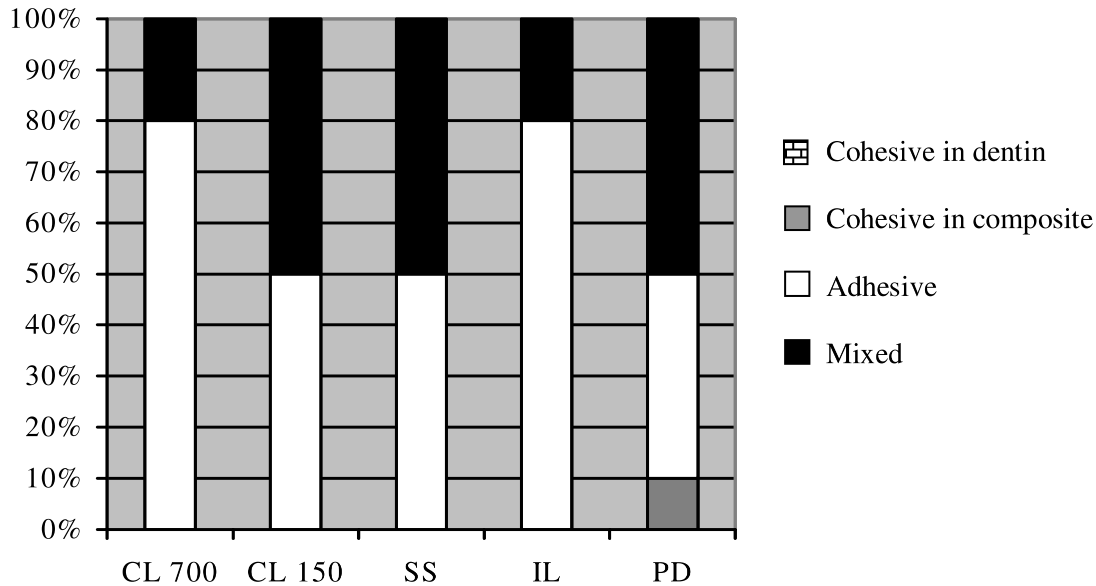

Figure 3. Percentage of failure mode in push-out bond strength test.

Observed failure mode proportions are show in Figure 3. For Continuous light 700 and Intermittent light, adhesive failure was the most observed mode (80%). In the Continuous light 150, Soft-start, and Pulse-delay groups, 50% of failure mode was mixed failure.

DISCUSSION

It is important to emphasize that each photocuring method used was adjusted to provide equivalent total energy to the composite: 14J/cm^2. Thus, assuming equivalent and maximal conversion with each method, differences seen among the test parameters would reflect the rate and method that the curing light was applied, which would affect the rate of polymerization, the onset of vitrification, and thus, the rate at which stress development occurred.

The push-out bond strength test is usually used to evaluate endodontic cements in the radicular canal space [27,28]. However, in the present study, this test was adapted to evaluate strength of restorative composites in a simulated Class I preparation. The advantage of using this test was that the bond strength can be evaluated in a high C-factor environment, and all the bonded area was submitted to mechanical force at the same time. The higher the C-factor, the higher the generated stress, considering the same volume of the contracting composite [3]. The C-factor used in the push-out test in the present study was 2.2 (a high stress condition).

An inverse relationship was observed between push-out bond strength and internal gap formation. The higher the bond strength, the lower was the internal gap formation (Figure 2). This condition arises because internal gap formation allow stress concentration on the interfacial defects and also lessens the total area that is bonded, and thus the lower is the force required to dislodge the restoration. Also, both gap formation and bond strength are affected by stress generation during the polymerization process. Because photoactivation method can affect shrinkage stress generation [11,30], and consequently, the internal gap formation, the resulting bond strength will be.

It is interesting to note that the photocuring method most used clinically (Continuous light 700 photoactivation method) resulted in the lowest bond strength and the highest gap formation. Using this method, composite may undergo an immediate and rapid polymerization reaction, solidifying very quickly. Because of the high power density used, the initial exposure phase induces to fast stress generation at composite/dentin interface. The stress orientation to the adhesive interface during a rapid polymerization rate reduces the probability of bond preservation, and thus internal gap formation. This assumption was confirmed by the high gap formation value of internal adaptation resulting from the Continuous light 700 group: 10.1%. Therefore, a lower force is necessary to eject specimens in this group during the push-out test. In addition, the predominant failure mode of this group was adhesive in nature (50%). This finding emphasizes weakening of the bond due to internal gaps.

The continuous, lower power density group (Continuous light 150) showed no significant difference from the higher power density, continuous light group, either with respect to marginal and internal adaptation, or in push-out bond strength values. However, the Continuous light 150 group presented predominately a mixed failure mode. The reduced power density (150mW/cm^2) could have enabled reduction of polymerization rate [1,14], resulting in slower stress development, increasing the probability of bond preservation. The internal gap formation for this group was 4.8%.

Intermittent light photoactivation is developed in cycles of intervals of light-on and light-off [9,16,30]. Theoretically, periods of light absence would extend the visco-elastic stage (vitrification) of the composite, resulting in reduced stress generation. Some studies [9,16,30] have pointed out the benefits of intermittent light on the photoactivation of composite. However, in these studies [9,16,30], the energy dose applied was lower than that of the other photoactivation methods. Reduction of energy dose leads to decreased shrinkage, and consequently, reduced shrinkage stress. The intermittent light method demonstrated similar bond strength, marginal and internal adaptation values as those obtained for the Continuous light 700 group. However, there was no significant difference between this group and any of the other modulated photoactivation methods. Therefore, it can be stated that the light off period was not long enough to cause a significant stress release and better results may have been obtained with a longer duration of light off. Other strobing durations should be evaluated in order to validate this concept.

Use of the soft-start technique had no effect on marginal adaptation. Other studies have also show no improvement in marginal adaptation when this polymerization method was used [31-33]. It has been claimed that the optimum combination of dentin bonding and resin composite is more important than is the irradiation method with respect to marginal adaptation [32,33]. However, in the present study, the evaluation of internal gap formation revealed that the soft start technique did improve this parameter. This finding may be attributed to the increased ability of composite to flow when polymerized at a reduced rate. It should be considered that at the bottom of the cavity the irradiance is reduced due to the scattering phenomena . Thus, development of the polymer network and cross-link formation is reduced, which then may allow the material to relieve stress through pre-vitrification plastic deformation, resulting in enhanced internal marginal adaptation [16]. Ernst *et al.* [34] found that soft-start polymerization can significantly reduce polymerization stress.

The soft-start technique showed intermediate value of push-out bond strength, which was not statistically different from the other photoactivation methods. The debonded specimens from this group presented predominantly the mixed failure, indicating partial preservation of the composite/dentin interface. This predominance of failure mode also correlates with what one would expect from the better internal marginal adaptation that was also observed.

The Pulse-delay photoactivation method is a variation of the soft-start technique. The pulse-delay method provides a reduction of polymerization contraction stress without a significant reduction on degree of conversion. This method has also been found to reduce marginal gap formation. At the present study, however, no significant difference was noted in marginal adaptation among all the experimental photocuring groups. Despite of the absence of statistical differences, the marginal gap formation of the restorations cured using the pulse-delay method was the lowest (0.7%).

It has been stated that an initial power density of 150 mW/cm^2 is too high to significantly reduce polymerization shrinkage stress [11]. In the present study, however, even using 150 mW/cm^2 for 5s resulted in a lowering of internal gap formation and a significant increase bond strength. This result was attributed to reduction in shrinkage stress due to the slower curing rate.

A 3 minute interval of light-off was selected as a delay between the two steps for pulse-delay method in the present study. The objective of this extended light-off time was to allow the radicals that had been formed during the initial exposure to grow as a result of the “dark cure” phenomenon [19]. During this phase, no new radicals are formed, and further polymerization is the result of chain propagation of already existing structures. This growth occurs quite slowly, and is expected to slow the rate of further polymer growth while the material is still in a pre-vitrified state prior to the second exposure which results in a great increase in the polymerization rate and rapid rise in modulus. Shrinkage prior to the acquisition of substantial modulus (vitrification) can be compensated for by molecular rearrangement of polymer chains (flow). Thus, introduction of the delay into the early portion of the light-curing routine may prolong the early low modulus phase, allowing the stress development to be relieved by polymer flow and deformation [11]. This situation was confirmed in this work, as the bond strength of this group was 7.3 MPa, statistically greater than that of the continuous light 700 group. The predominant failure mode of the pulse-delay group was mixed, due to the partial preservation of the adhesive interface. In addition, fractures specimens from the Pulse-Delay group were the only ones to demonstrate a cohesive failure. The pulse-delay group also showed a significant reduction in internal gap formation (2.8%) when compared to the Continuous light 700 group (control).

Additionally, it is important to point out some limitations of this study. The use of bovine teeth implies in caution on the interpretation of the results. However, the major problem of using bovine teeth occurs when different interactions between bonding systems and tooth substrate are compared. In this study, the interaction bonding system/tooth substrate was standardized, since the same bonding system and the same tooth location was used for all groups. The objective of this study was to evaluate the composite behavior under confinement face of the different photoactivation methods. In addition, the use of bovine incisors is supported by several authors [35-37].

Based on the results of the present study, the first hypothesis tested, that the alternative methods would significantly reduce marginal and internal gap formation and increase bond strength values relative to the control, must be only partially accepted. Modulated photoactivation methods demonstrated reduced internal gap formation and increased bond strength with respect to use of the common, contemporary continuous exposure (control).

The second hypothesis tested, that there would be an inverse relationship between push-out bond strength values and marginal and internal gap formation must also be partially accepted. Marginal adaptation was not affected by the any of the photoactivation methods and could not be related to bond strength or to internal gap formation. There was, however, an inverse relationship between bond strength and internal gap formation. This relationship could be confirmed in this study because both gap formation and bond strength were evaluated in high C factor cavity preparations. Consequently, the polymerization shrinkage stress caused bond disruption, decreasing the bond strength values and increasing the internal gap formation, especially in continuous light 700 group, in which the shrinkage stress is higher.

Based on the results found in this research, the clinical application of modulated photoactivation methods should be encouraged. Although *in vitro* evidence suggests that use of these modulated techniques may offer significant clinical advantages, *in vivo* studies would be performed to validate these assumptions.

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3. CONSIDERAÇÕES GERAIS

A obtenção de restaurações perfeitamente adaptadas às paredes cavitárias é o intuito do tratamento restaurador, principalmente quando se trata de restaurações adesivas. Entretanto, em várias situações ocorre a formação de fendas na interface dente/restauração. A origem destas fendas está relacionada a três fatores principais: a tensão de contração do compósito (DAVIDSON & FEILZER, 1997), tensões externas relacionadas à fadiga mecânica (DA CUNHA MELO *ET AL.*, 1997) e alterações de temperatura (MOMOI *ET AL.*, 1990), além de falhas durante o processo adesivo (MARSHALL *ET AL.*, 1997). Nos estudos apresentados nesta tese, o foco de avaliação foi a tensão de contração, por isso, as amostras não foram sujeitas a nenhum tipo de tensão externa e o procedimento adesivo foi padronizado, de forma que foram avaliadas exclusivamente as fendas provenientes da contração de polimerização.

Considerando essas fendas, pode-se classificá-las em dois tipos: as fendas diretamente ligadas ao meio externo, as quais foram referidas como fendas marginais e as fendas não ligadas diretamente ao meio externo, as quais foram tratadas por fendas internas.

As fendas marginais representam vias de entrada para a instalação bacteriana na interface dente-restauração, mais do que isso, também permitem o livre acesso dos fluidos bucais nessa região, o que certamente favorece à degradação da interface em longo prazo. Essas fendas são consideradas o primeiro sinal de falha na restauração, sendo clinicamente identificadas por descoloração marginal (MJÖR & TOFFENETTI, 2000).

As fendas internas provocam desequilíbrio hidrodinâmico na interface, causando sensibilidade pós-operatória típica devido à movimentação de fluidos na dentina e, com isso, excitação dos nociceptores presentes na polpa dental (DOWELL & ADDY, 1983; WEST, 2006). Além disso, essas fendas também são locais propícios para crescimento bacteriano, correspondendo a focos de enfraquecimento e degradação da união compósito-estrutura dental (DIETSCHI *ET AL.*, 1993; PEUTZFELDT & ASMUSSEN, 2004).

Nos capítulos 2 e 3, pode-se constatar que a formação de fendas internas é muito mais evidente que a formação de fendas marginais, fato relacionado a dois fatores principais: a baixa resistência de união à dentina e as altas tensões provenientes da contração de polimerização que ocorrem nas partes mais profundas das restaurações, especialmente nos ângulos internos e parede pulpar.

Através dos estudos apresentados nesta tese, nota-se que a adaptação marginal externa tem como fator determinante a resistência imposta pelo sistema de união. Quando a resistência é alta, como normalmente ocorre nas paredes de esmalte, pouca (Capítulo 3) ou nenhuma (Capítulo 2) fenda forma-se. Entretanto, quando a resistência de união diminui, a formação de fendas é maior, como normalmente ocorre nas cavidades com margens externas situadas em dentina (Capítulo 1). Outro fator que deve ser apontado, é que a formação de fendas nas paredes externas também pode ser abrandada pela liberação das tensões de contração pela parede livre.

Como citado anteriormente, a avaliação da formação de fendas nas restaurações de compósito tem se mostrado de grande importância e, por isso, diversas pesquisas tem sido realizadas (LUTZ *ET AL.,* 1991; CIUCCHI *ET AL.,* 1997; MANHART *ET AL.,* 2001; YOSHIKAWA *ET AL.,* 2001; IRIE *ET AL.*, 2002; PEUTZFELDT & ASMUSSEN, 2004; ALONSO *ET AL.,* 2004; CORRER *ET AL.,* 2005; IWAMI *ET AL.,* 2005; ALONSO *ET AL.,* 2006). Dentre as varias formas de avaliação da formação de fendas [estudos de microinfiltração - com corantes, traçadores químicos e radioativos, bactérias, pressão de ar, etc (SHORTALL, 1982; PASHLEY, 1990; TAYLOR & LYNCH, 1992; RASKIN *ET AL.*, 2001); evidenciação de fendas por corantes (YOSHIKAWA *ET AL.,* 2001; ALONSO *ET AL.,* 2004; ALONSO *ET AL.,* 2006; CORRER *ET AL.,* 2005) e análise em MEV (SAHAFI *ET AL.,* 2001; LIM *ET AL.*, 2002; PELIZ *ET AL.*, 2005; DUARTE *ET AL.,* 2005)], considera-se que a avaliação da adaptação das restaurações é melhor determinada pela avaliação em MEV, técnica considerada como "padrão ouro" para avaliação das fendas (SHORTALL, 1982, IWAMI *ET AL.,*2005). No capítulo 1, pode-se comprovar que a técnica do corante também pode ser usada na determinação das fendas, pois houve forte correlação positiva entre os resultados obtidos nos dois testes. O coeficiente de correlação de Pearson foi 0,83, um coeficiente considerado alto.

Nesse ponto, cabe ressaltar que na literatura uma grande discussão tem sido feita acerca da relevância desses estudos *in vitro* (SODERHOLM, 1991; ROULET, 1994; RASKIN *ET AL.,* 2001; SARRETT, 2005). Isso porque os desafios aos quais as restaurações estão submetidas clinicamente são multifatoriais, interagem mutuamente e ainda não existe um completo entendimento desses fatores e da magnitude de seus efeitos para predizer o desempenho das restaurações. Adicionalmente, a simulação exata das condições orais é muito difícil de ser realizada em estudos *in vitro*. Entretanto, estudos laboratoriais são essenciais ao entendimento, desenvolvimento e evolução de todos os aspectos da Odontologia. Nesses estudos pode-se conseguir um ambiente onde se padroniza técnicas, elimina-se variáveis e apontam-se problemas específicos de um modo que seria impossível de se realizar em um estudo clínico. Contudo, deve-se ter em mente que não se pode fazer uma extrapolação direta dos resultados obtidos em testes laboratoriais para a aplicação clínica. Determinar a relevância dos estudos laboratoriais para predizer o desempenho clínico de restaurações não é uma tarefa simples. Inicialmente, nos estudos relacionadas à microinfiltração e formação de fendas havia uma idéia simplista e errônea de que a simples formação de fendas marginais acarretaria em microinfiltração, e que a presença de microinfiltração levaria a restauração ao fracasso pela ocorrência de cárie recorrente. Mas nenhuma correlação forte pôde ser estabelecida entre cárie recorrente e fenda marginal ou microinfiltração (KIDD *ET AL.* 1994; KIDD & BEIGHTON, 1996; MJÖR, 1998 E 2005; SARRETT, 2005). O processo de desenvolvimento de cárie recorrente é multifatorial e fatores relacionados ao hospedeiro (que determinam o risco de cárie) são muito mais importantes na formação de cárie recorrente que as condições locais da restauração (KIDD *ET AL.* 1994; KIDD & BEIGHTON, 1996; MJÖR, 1998 E 2005).

Entretanto, pode-se considerar que a presença de fendas em restaurações de pacientes de alto risco para cárie dental (dieta acidogênica, controle de placa inadequado, baixa capacidade tampão da saliva) certamente facilitará o desenvolvimento de lesões recorrentes, uma vez que as fendas serão locais propícios para a instalação e proliferação bacteriana. Reconhece-se ainda, que a presença de fenda facilita o manchamento da interface pela degradação acelerada de seus componentes e, considerando a estética das restaurações em compósito, o manchamento interfacial já pode ser considerado como uma falha (ALANI & TOH, 1997; HILTON, 2002). Nesse ponto reside a importância do teste de adaptação marginal. Assim, pode-se afirmar que a avaliação da qualidade interfacial das restaurações, mesmo em estudos laboratoriais, pode nos auxiliar na seleção de técnicas e materiais com o intuito de melhorar a aplicação clínica dos compósitos restauradores.

No Capítulo 1 foi comprovada a eficácia do método do corante em determinar as fendas, de modo similar ao padrão ouro MEV. E assim, pode-se justificar o uso desta metodologia nos capítulos subseqüentes desta tese.

Ainda considerando fatores relacionados à metodologia, pode-se ressaltar que para cada trabalho houve cuidado com a padronização dos grupos e eliminação de variáveis que pudessem interferir com os resultados. Assim, o mesmo agente de união (Single Bond) foi utilizado em todos os casos. Essa padronização foi feita pois observou-se, em estudos preliminares, que a resistência de união imposta pelo sistema de união tem importância fundamental no mecanismo de formação de fendas, especialmente no que tange às fendas marginais. Para distribuição dos grupos, nos capítulos 2 e 3 foi realizado sorteio aleatório após a confecção das cavidades. Em todos os casos, para padronizar o tamanho das cavidades, uma máquina padronizadora de preparos foi utilizada.

A seleção do tipo de cavidade a ser utilizado nos estudos foi bastante criteriosa. As cavidades utilizadas nos estudos 2 e 3 apresentavam alto fator C, margens externas completamente localizadas em esmalte e a parte interna localizada em dentina. Cavidades com alto fator C foram selecionadas por gerar tensão de contração alta, o que representa uma situação limite, de alto desafio para a manutenção da integridade interfacial. Esta condição foi eleita para que os métodos de redução de tensão fossem expostos à alta tensão. Conjeturamos que se determinado método fosse favorável nesta condição, seria também em qualquer outra situação. Ainda considerando o tipo de cavidade, pode-se ressaltar que, em todos os estudos, as cavidades foram confeccionadas com apenas um tipo de substrato na margem superficial, para que se evitasse a ocorrência de tensões assimétricas que favorecem a ocorrência de fendas em determinado local da margem (como é o caso de cavidades com margens superficiais parcialmente localizadas em esmalte e parcialmente localizadas em dentina). No capítulo 1, as margens eram localizadas totalmente em dentina, onde a ocorrência de fendas é mais comum, para que se pudessem analisar os métodos de avaliação. Nos capítulos 2 e 3, as cavidades apresentavam margens externas situadas em esmalte e margens internas em dentina, desse modo, o comportamento de formação de fendas pôde ser observado nos dois tipos de substrato dental.

Um outro aspecto que cabe discussão refere-se à utilização de dentes bovinos no capítulo 3. Esse tipo de substrato vem sofrendo críticas quanto a sua utilização em estudos de adesão. Entretanto, pode-se considerar que o maior problema da utilização de dentes bovinos ocorre quando diferentes interações entre sistemas de união e o substrato dental são comparadas. Nesse estudo, essa interação foi padronizada pelo uso do mesmo sistema de união e da mesma localização da cavidade em todos os grupos, pois o objetivo do estudo foi comparar o comportamento do compósito polimerizado em confinamento frente aos diferentes métodos de fotoativação. Adicionalmente, a literatura fundamenta o uso desse substrato. Estudos histoquímicos e de comparação anatômica revelaram que os dentes dos mamíferos são essencialmente similares (LEICESTER, 1949; FUJITA, 1957; SUGA *ET AL*, 1971). NAKAMICHI *ET AL.* (1983) consideraram esmalte e dentina superficial bovina como sendo adequados para uso em testes de resistência de união. O maior problema ocorre na utilização de dentina profunda ou radicular, onde as falhas de adesão são mais freqüentes, como observado por SCHILKE *ET AL* (1999). Nestas regiões, os túbulos apresentam maior diâmetro e o conteúdo mineral é menor. Mas, esses tipos de dentina não foram utilizados neste estudo, já que as cavidades envolveram apenas dentina coronária superficial e média. SCHILKE *ET AL* (2000) compararam dentina humana e bovina em relação ao número e diâmetro de túbulos utilizando análise em MEV e demonstraram que as camadas superficiais de dentina de molares humanos e incisivos bovinos eram correspondentes, não havendo diferenças significativas no número de túbulos por mm^2 nem no diâmetro tubular. Os resultados desse estudo (SCHILKE *ET AL,* 2000) sustentam a viabilidade do uso de dentina coronária de incisivos bovinos como substituto da dentina humana em testes de adesão.

Entretanto, alguns autores apresentaram contra-indicações ao uso de dentes bovinos em testes que envolvam corantes. RETIEF *ET AL.*(1990) condenaram o uso de dentes bovinos em testes de microinfiltração envolvendo a penetração de corante; entretanto, a microinfiltração foi determinada através de espectrofotometria da concentração do corante. Essa avaliação não leva em consideração a permeabilidade do dente ao corante. Nossa experiência em estudos com corante (microinfiltração ou teste de adaptação) demonstra que a penetração de corante é maior na dentina bovina que na dentina humana, pois a dentina bovina parece ser mais permeável. Todavia, esta condição não interferiu nos resultados deste estudo, uma vez que observou-se a evidenciação das fendas pelo corante e não a concentração de corante no dente ou na interface dente/restauração. Estas observações obtêm suporte no estudo de REEVES *ET AL.* (1995). Esses autores compararam dentes humanos e bovinos através de teste de microinfiltração, avaliando os espécimes por sistema de escores e não houve diferença significativa no comportamento de microinfiltração das restaurações confeccionadas tanto em dentes humanos quanto em dentes bovinos.

Uma vez fundamentada a metodologia empregada nos capítulos desta tese, passa-se à discussão do fator em estudo nos capítulos 2 e 3, os métodos de fotoativação alternativos.

No capítulo 2, o efeito dos métodos de fotoativação alternativos na formação de fendas de restaurações confeccionadas com diferentes compósitos foi avaliado. Neste estudo pôde-se observar o perfeito selamento das margens externas, situadas em esmalte, em todos os grupos, inclusive aquele no qual a tensão de contração é mais acentuada (luz contínua). Observou-se também que a utilização dos métodos de fotoativação modulados (*Soft start, Pulse delay* e Luz pulsátil) acarretou em redução significativa da formação de fendas internas quando comparados ao método convencional de luz contínua, independente do tipo de compósito utilizado. Assim, pode-se constatar que a eficácia da modulação da intensidade luminosa durante a polimerização não é limitada a um tipo particular de compósito, e independe de fatores relacionados à composição do material para funcionar. Pode-se conjeturar que as velocidades de polimerização e de desenvolvimento de tensão são determinadas pela intensidade luminosa, e que a redução dessa intensidade nos instantes iniciais da polimerização e/ou a presença de intervalos de ausência de luz são capazes alterar a cinética de polimerização e contração acarretando em maior liberação de tensão e redução na formação de fendas nas restaurações fotoativadas por tais métodos.

Ainda considerando os métodos de fotoativação modulados, cabe salientar que o houve divergência nos resultados obtidos pelo método pulsátil nos capítulos 2 e 3. No capítulo 3, este método não foi capaz de reduzir significativamente as fendas internas quando comparado ao método convencional de luz contínua. Por isso, foi apontada a hipótese de que a duração do período de ausência de luz (2 s) teria sido insuficiente para reduzir a tensão de contração a ponto de causar redução significativa nas fendas internas. Tal hipótese foi confirmada no capítulo 2, no qual um ciclo com período de ausência de luz de 3 s foi testado e houve efetiva redução na formação de fendas internas.

Em todas as avaliações pôde-se observar menor formação de fendas internas quando o método *pulse delay* foi aplicado, embora não tenha havido diferença significativa entre os métodos modulados. A introdução do intervalo de 3 minutos durante a fotoativação provavelmente permitiu maior liberação de tensão e, com isso, melhor acomodamento do compósito às paredes cavitárias, reduzindo as fendas internas e aumentando a resistência de união.

No capítulo 3, buscou-se estabelecer uma relação entre formação de fendas e resistência de união. Em estudos preliminares, observou-se o aumento da resistência de união da restauração ao teste *push out* quando as restaurações foram fotoativadas através da técnica modulada, especialmente o método *pulse delay*. Foi observado também que este aumento na resistência ocorria em função da redução da formação de fendas na interface de união. Diante disso, desenvolveu-se este estudo para comprovar a veracidade dessa hipótese. E, realmente comprovou-se que a modulação da intensidade luminosa aumenta a resistência de união pela redução na formação de fendas internas, o que pode ser traduzido como preservação da interface de união entre a restauração e o substrato dental.

A relação entre resistência de união e formação de fendas nunca tinha sido estabelecida antes, apesar da tentativa de diversos autores (PRATI *ET AL.* 1990; FORTIN *ET AL.*, 1994; ATEYAH & ELHEJAZI, 2004; ATASH *ET AL*, 2005; CENCI *ET AL.*, 2005). Avaliando esses estudos, pôde-se notar que os mesmos falharam em obter essa relação porque a determinação da resistência de união era sempre realizada em superfícies planas, desconsiderando a condição de confinamento do compósito durante a polimerização em uma cavidade, especialmente em cavidades com alto fator C. Neste estudo, esta relação pôde ser estabelecida em função do teste utilizado para determinar a resistência de união (teste *push out*). Neste teste, a resistência de união da restauração toda é determinada e, dessa forma, a presença de fendas reduziu significativamente a resistência de união observada.

Ainda cabe salientar que no capítulo 3, a metodologia empregada para se determinar a resistência de união da restauração foi adaptada para tal fim. O teste *push out* é usualmente aplicado na determinação da resistência de união de cimentos endodônticos ao conduto radicular. Já a avaliação de uma restauração coronária nunca tinha sido realizada antes utilizando tal teste.

Em síntese, esta tese contribuiu para o estabelecimento de uma metodologia alternativa e eficaz para avaliação da formação de fendas em restaurações de compósito, além de apresentar uma nova maneira de se determinar a resistência de união das restaurações como um todo. Além disso, as diversas vantagens da aplicação de métodos modulados para a fotoativação de compósitos foram demonstradas, possibilitando o encorajamento da aplicação clínica destes métodos como alternativas para melhorar a qualidade interfacial das restaurações de compósito.

4. CONCLUSÕES GERAIS

Baseado nos resultados encontrados nos três estudos, pôde-se concluir que:

- A avaliação das fendas em restaurações de compósito pode ser feita através da técnica do corante com confiabilidade de resultados, uma vez que os resultados encontrados através desta técnica foram similares àqueles encontrados através da avaliação em microscopia eletrônica de varredura, a técnica considerada “padrão ouro” na literatura.
- A adaptação marginal das restaurações em compósito não é influenciada por fatores modificadores como as técnicas de fotoativação. As maiores influências são exercidas pelo substrato da margem (esmalte ou dentina).
- A formação de fendas internas pode ser significativamente reduzida pela modulação da intensidade luminosa durante a fotoativação (métodos *soft start, pulse delay* e luz intermitente).
- Os métodos de fotoativação modulados são capazes de reduzir a formação de fendas internas independente do compósito empregado.
- A utilização dos métodos modulados pode aumentar a resistência de união da restauração como um todo, pela redução da formação de fendas internas.
- Existe relação inversa entre resistência de união e formação de fendas internas, ou seja, quanto maior é a resistência de união, menor é a formação de fendas internas.

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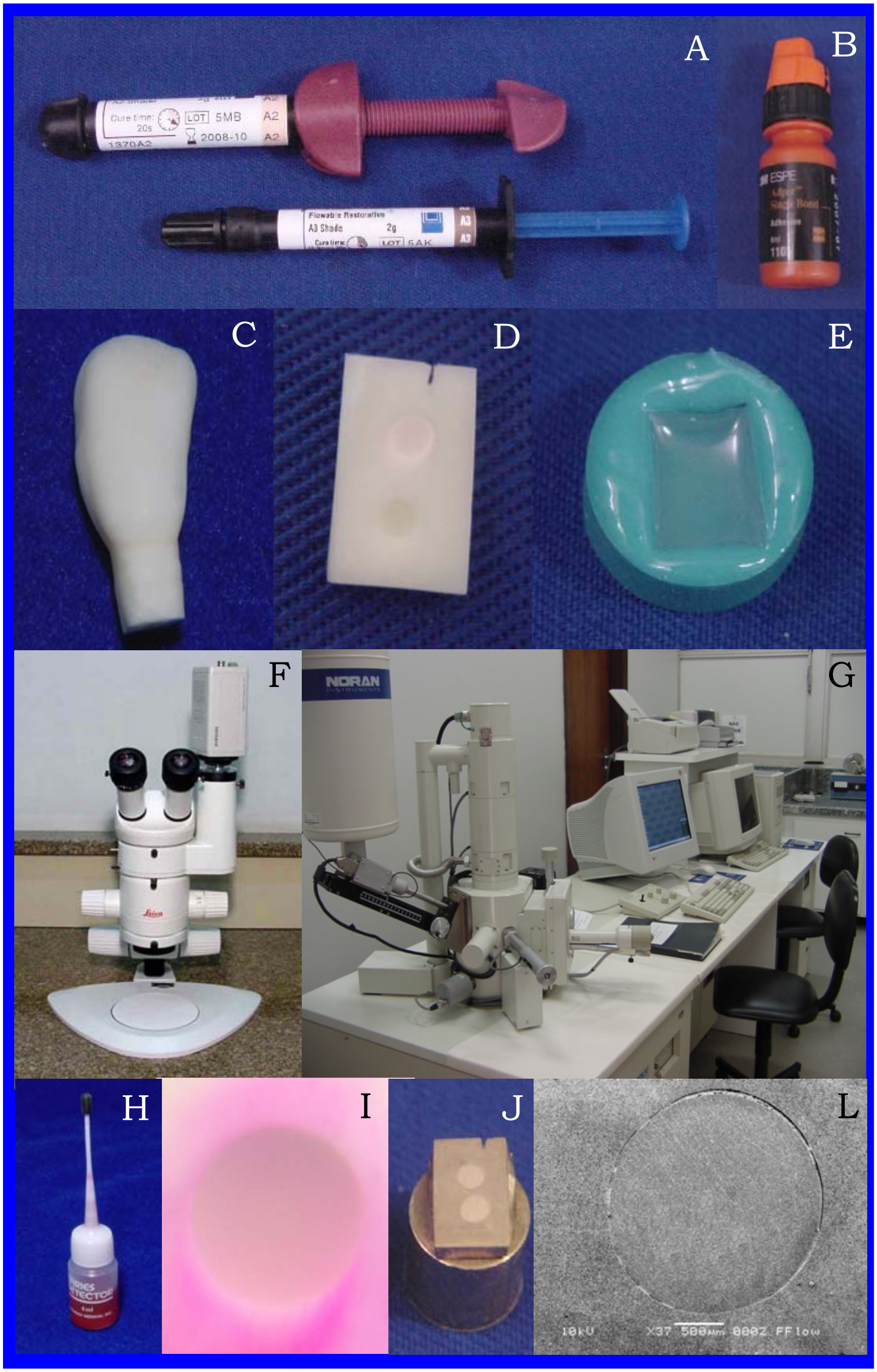
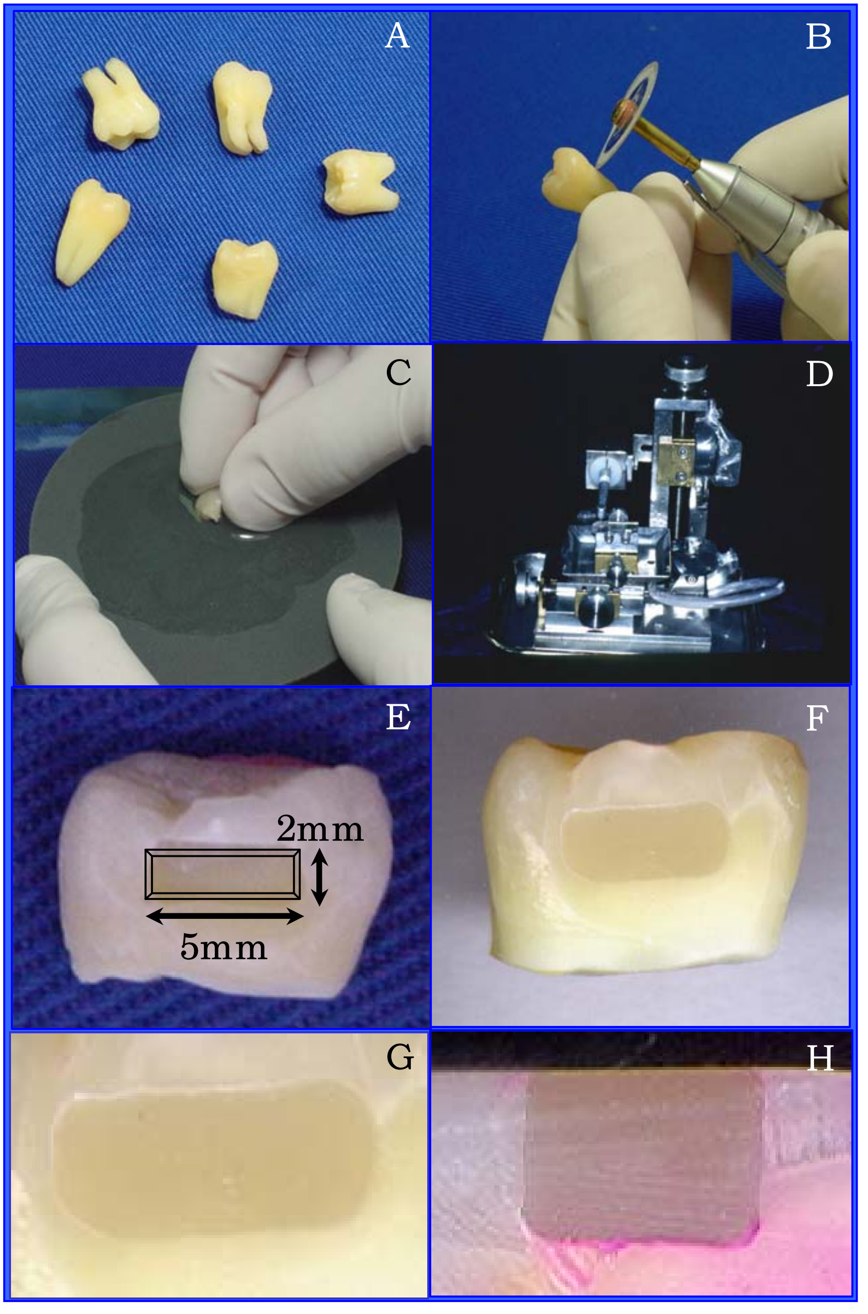
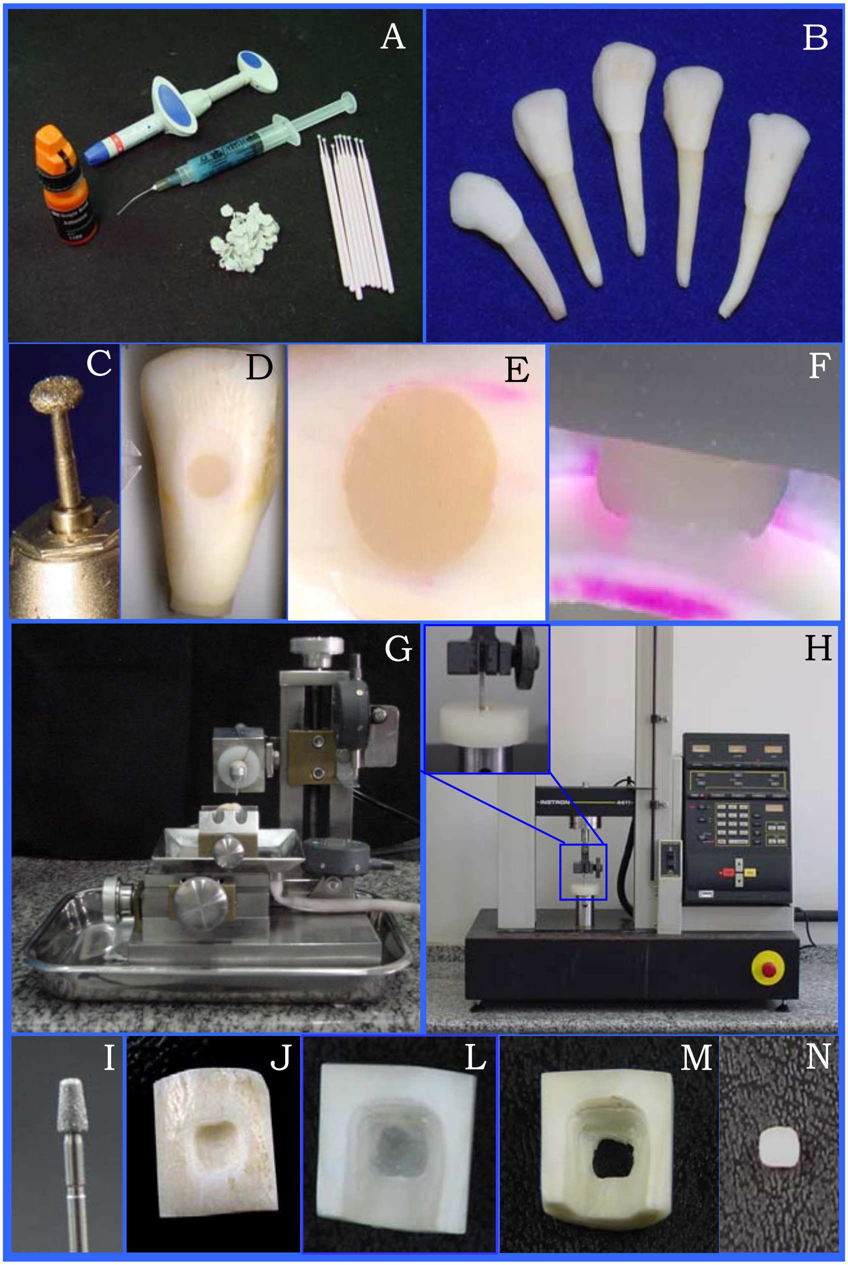


Prancha 1: (A) Compósitos restauradores Filtek Z250 e Filtek Flow; **(B)** Sistema de União Single Bond; **(C)** Dente bovino utilizado para a confecção dos espécimes; **(D)** Espécimes restaurados; **(E)** Vazamento do molde do espécime em resina epóxica; **(F)** Lupa Estereoscópica Leica MZ6 utilizada para captar as imagens na técnica do corante; **(G)** Microscópio Eletrônico de Varredura Jeol JSM-5600LV; **(H)** Corante Caries Detector – Kuraray utilizado para evidenciar as fendas na técnica do corante; **(I)** Imagem da restauração obtida através da técnica do corante; **(J)** Réplica do espécime após metalização; **(L)** Imagem da restauração obtida através de MEV;



Prancha 2: (A) Terceiros-molares humanos selecionados para o estudo; **(B)** Secciomento das raízes para obtenção do espécime; **(C)** Obtenção de uma área plana em esmalte com lixa d'água; **(D)** Máquina padronizadora de preparos; **(E)** Espécime com preparo; **(F)** Espécime após restauração; **(G)** Imagem da restauração (margens externas) obtida após aplicação do técnica do corante – Adaptação externa – não observa-se a formação de fendas; **(H)** Imagem da restauração após seccionamento do espécime e reaplicação do corante nas margens internas – Adaptação interna – observa-se que as fendas formam-se nas parede de fundo e nos ângulos internos da cavidade.



Prancha 3: (A) Sistema de união Adper Single Bond e compósito restaurador Esthet X; **(B)** Dentes bovinos utilizados para a confecção dos espécimes; **(C)** Ponta diamantada em formato de roda # 3053; **(D)** Espécime utilizado para avaliação da formação de fendas marginais e internas; **(E)** Imagem digital utilizada na avaliação da adaptação marginal; **(F)** Imagem digital utilizada na avaliação da adaptação interna; **(G)** Maquina padronizadora de preparos utilizada para a confecção das cavidades em ambos os testes; **(H)** Máquina universal de testes mecânicos Instron com espécime posicionado para avaliação da resistência de união através do teste *push out*; **(I)** Ponta diamantada cônica # 3131; **(J)** Espécime com preparo cavitário utilizado no teste de resistência de união *push out*; **(L)** Espécime após desgate seletivo (exposição da parede de fundo da restauração) para realização do teste *push out*; **(M)** Espécime após a fratura no teste *push out*; **(N)** Restauração removida do preparo.

Anexo 1

COMITÊ DE ÉTICA EM PESQUISA

UNIVERSIDADE ESTADUAL DE CAMPINAS

FACULDADE DE ODONTOLOGIA DE PIRACICABA

UNICAMP

CERTIFICADO-2ª VIA

Certificamos que o Projeto de pesquisa "Efeito de métodos de fotoativação nas características de polimerização e qualidade de união de restaurações em compósito", protocolo CEP nº ***090/2004***, dos Pesquisadores ***Roberta Caroline Bruschi Alonso*** e ***Mário Alexandre Coelho Sinhoreti***, está de acordo com a Resolução 196/96 do Conselho Nacional de Saúde - MS e foi aprovado pelo Comitê de Ética em Pesquisa da Faculdade de Odontologia – UNICAMP, em 29/09/2004.

We certify that the research project "Effect of photoactivation methods on polymerization dynamic and bonding quality of resin composite restorations", register number ***090/2004***, of ***Roberta Caroline Bruschi Alonso*** and ***Mário Alexandre Coelho Sinhoreti***, is in agreement with the recommendations of 196/96 Resolution of the National Health Committee - Brazilian Health Department and was approved by the Research Ethics Committee of the School of Dentistry of Piracicaba - State University of Campinas – UNICAMP, at 29/09/2004.

Piracicaba - SP, Brazil, November 29 2006

Profa. Dra. Cecília Gatti Guirado
Secretaria
CEP/FOP/UNICAMP

Prof. Dr. Jacks Jorge Júnior
Coordenador
CEP/FOP/UNICAMP

Nota: O título do protocolo aparece como fornecido pelos pesquisadores, sem qualquer edição.
Notice: The title of the project appears as provided by the authors, without editing.

Anexo 2

Faculdade de Odontologia de Piracicaba

Universidade Estadual de Campinas

Declaração

As cópias dos artigos de minha autoria ou co-autoria, já publicados ou submetidos para publicação em revistas científicas ou anais de congressos sujeitos a arbitragem, que constem desta tese de doutorado, entitulada FORMAÇÃO DE FENDAS EM RESTAURAÇÕES DE COMPÓSITO: TÉCNICAS DE AVALIAÇÃO, EFEITO DE MÉTODOS DE FOTOATIVAÇÃO E RELAÇÃO COM A RESISTÊNCIA DA UNIÃO, não infringem os dispositivos da Lei nº 9.610/98, nem o direito autoral de qualquer editora.

Piracicaba, 22 de fevereiro de 2007.

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